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ESSENTIAL FISH HABITAT (EFH) OMNIBUS AMENDMENT

"THE SWEPT AREA SEABED IMPACT (SASI) MODEL: A TOOL FOR ANALYZING THE EFFECTS OF FISHING ON ESSENTIAL FISH HABITAT"

Date: 21 January 2011

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1.0 Overview of the Swept Area Seabed Impact model

The Magnuson-Stevens Fishery Conservation and Management Act (MSA) requires fishery management plans to minimize, to the extent practicable, the adverse effects of fishing on fish habitats. To meet this requirement, fishery managers would ideally be able to quantify such effects and visualize their distributions across space and time. The Swept Area Seabed Impact (SASI) model provides such a framework, enabling managers to better understand: (1) the nature of fishing gear impacts on benthic habitats, (2) the spatial distribution of benthic habitat vulnerability to particular fishing gears, and (3) the spatial and temporal distribution of realized adverse effects from fishing activities on benthic habitats.

SASI increases the utility of habitat science to fishery managers via the translation of susceptibility and recovery information into quantitative modifiers of swept area. The model combines area swept fishing effort data with substrate data and benthic boundary water flow estimates in a geo-referenced, GIS-compatible environment. Contact and vulnerability-adjusted area swept, a proxy for the degree of adverse effect, is calculated by conditioning a nominal area swept value, indexed across units of fishing effort and primary gear types, by the nature of the fishing gear impact, the susceptibility of benthic habitats likely to be impacted, and the time required for those habitats to return to their pre-impact functional value. The various components of the SASI approach fit together as described in Figure 1.

The vulnerability assessment and associated literature review were developed over an approximately two year period by members of the New England Fishery Management Council's Habitat Plan Development Team. The assessment serves two related purposes: (1) a review of the habitat impacts literature relevant to Northeast US fishing gears and seabed types, and (2) a framework for organizing and generating quantitative susceptibility and recovery parameters for use in the SASI model.

The vulnerability assessment only considers adverse (vs. positive) effects and effects on habitat associated with the seabed (vs. the seabed and the water column). This bounding does not preclude the possibility of positive impacts from fishing on seabed structures or fauna, nor is it intended to indicate that the water column is not influential habitat for fish. The former is possible, and the latter is likely. However, as per the EFH Final Rule, only adverse effects are considered and, because fishing gears do not substantively alter the water column, effects from fishing on the pelagic water column are assumed to be negligible.

As a model parameterization tool, the vulnerability assessment quantifies both the <u>magnitude of the impacts</u> that result from the physical interaction of fish habitats and fishing gears, and the <u>duration of recovery</u> following those interactions. This vulnerability information is used to condition area swept (i.e. fishing effort) in the SASI model via a series of susceptibility and recovery parameters.

A critical point about the vulnerability assessment and accompanying SASI model is that they consider EFH and impacts to EFH in a holistic manner, rather than separately identifying impacts to EFH designated for individual species and lifestages. This is consistent with the EFH final rule, which indicates "adverse effects to EFH may result from actions occurring within EFH or outside of [designated] EFH and may include site-specific or habitat-wide impacts, including individual, cumulative, or synergistic consequences of actions" (§600.810). To the extent that key features of species' EFH can be related to the features in the vulnerability assessment, post-hoc analysis of SASI model outputs can be conducted to better evaluate the vulnerability of a particular species' essential habitat components to fishing gear effects.

This document contains detailed information about the various aspects of SASI, as follows:

Defining habitat (2.0), which describes the structural components and their constituent features. Fish habitat is divided into two components, geological and biological, which are further subdivided into structural features. Structural features identified include bedforms, biogenic burrows, sponges, macroalgae, etc. (see sections 2.1 and 2.2 related to geological and biological features, respectively). These features may either provide shelter for managed species directly, or provide shelter for their prey. The geological and biological features, weighted equally in the model, are distinguished as being non-living and living, respectively. While both components (geological, biological) are assumed to occur in every habitat type, the presence or absence of particular features is assumed to vary based on substrate type and natural disturbance (energy) regime. Thus, habitat types in the vulnerability assessment are distinguished by dominant substrate, level of natural disturbance, and the presence or absence of various features. The substrate and energy classifications used are described in the introduction to section 2.0.

Gear impacts literature review (3.0), which summarizes the fishing impacts literature that forms the basis of the vulnerability assessment. To facilitate use of the literature in matrix evaluations, research relevant to regional habitats and fishing gears is summarized in a database. Each study in the database is coded according to the habitat components evaluated, features evaluated, whether recovery is examined, etc. This coding is detailed in section 3.1, and the literature is summarized in section 3.2. Both the literature review database and the matrix values can be updated as new information becomes available.

Matrices (section 4.0), which describes the process used to estimate the susceptibility and recovery of features to/from fishing impacts and presents S and R scores in tabular format. The vulnerability assessment matrices organize and present estimates of susceptibility and recovery for each feature by fishing gear type. Both susceptibility and recovery are scored from 0-3. Values are assigned using knowledge of the fishing gears and habitat features combined with results from the scientific literature on gear impacts. Susceptibility is defined as the percentage of total habitat features encountered by fishing gear during a hypothetical single pass fishing event that have their functional value reduced. Recovery is defined as the time in years that would be required for the functional value of that habitat feature to be restored.

Outside of the matrix-based assessment, prey and deep-sea corals habitat components and features are described and their vulnerability to fishing impacts is evaluated. This information is presented in **section 12.0**.

Fishing gears (section 5.0), which identifies the gears evaluated by the model and describes how they are fished. SASI models the seabed impacts of bottom tending gear types, both static and mobile. The gear types include demersal otter trawls (subdivided into four types), New Bedford-style scallop dredges (subdivided into two classes), hydraulic clam dredges, demersal longlines, sink gillnets, and traps. These gears account for approximately 95% of the landings in federal waters of the Northeast region.

Estimating contact-adjusted area swept (section 6.0), which summarizes how fishing effort data is converted to area swept. The annual area of seabed swept for each gear type is used as the starting point for estimating the adverse effects from fishing. To generate these estimates, for each of the gear types, gear dimensions are estimated and a linear effective width is calculated for each gear component individually and for the gear as a whole. This linear effective width is multiplied by the length of the tow to generate a nominal area swept in km^2. Next, assumptions about the amount of contact each gear component has with the seabed during normal fishing operations are used to convert nominal area swept to contact-adjusted area swept (denoted as A). In practice, these contact adjustments are applied to trawl gears only, as all the components of all other gears are assumed to have full contact with the seabed. Area swept is calculated individually for each tow, and the resulting contact-adjusted area swept values are then summed by trip, year, gear type, etc.

Defining habitats spatially/model grid (section 7.0), which describes the substrate and energy layers used in the model. Two classes of data, substrate and energy environment, are used to define habitats. These combine to form the underlying surface onto which gear-specific habitat vulnerability information and contact-adjusted area-swept data are added. Two data sources are used to create the substrate surface: the usSEABED dataset from the U.S. Geological Survey, and the University of Massachusetts Dartmouth School for Marine Science and Technology (SMAST) video survey. Based on empirical observations from these two sources, substrates are classed by particle size using the Wentworth scale for five substrate classes: mud, sand, granule/pebble, cobble, and boulder. The raw substrate data are mapped using a Voronoi tessellation procedure which calculates an unstructured grid around each individual data point. These grid cells vary in shape and size depending on the spatial arrangement of samples. As the grid is easily updated, new substrate data can be added to the model as it becomes available. Next, each of these grid cells are classified as having a high or low natural disturbance (energy) regime using a combination of shear stress and bottom depth. Finally, a 100 km^2 grid is overlaid on the unstructured grid, and the substrate composition of each 100 km^2 grid cell is calculated based on the size of the unstructured cells contained within each of the 100 km^2 grid cells. Geological and biological seabed features are inferred within each of the

100 km^2 grid cells based on the substrate and energy mosaic. Based on a literature review, susceptibility and recovery scores for each habitat feature are coded as described in section 4.0.

Spatially estimating adverse effects from fishing on fish habitat: the SASI model (section Error! Reference source not found.), which describes how fishing effort data are integrated with susceptibility and recovery estimates in a spatial context. The SASI model combines contact-adjusted area swept estimates with the substrate and energy surfaces and the assigned susceptibility and recovery scores for each of the seabed features to calculate the vulnerability-adjusted area swept (measured in km^2), represented by the letter Z. This value is the estimate of the adverse effects from fishing on fish habitat. The model can be used to estimate adverse effects based either on a simulated hypothetical amount of fishing area swept (Z_∞ outputs), or the realized area swept estimated from fishery-dependant data ($Z_{realized}$ outputs). The former estimate is intended to represent underlying habitat vulnerability, while the latter can be used to understand change in adverse effects over time. The latter approach can also be used to forecast the impacts of future management actions, given assumptions about shifts in the location and magnitude of area swept. Sensitivity analyses are also presented in this section.

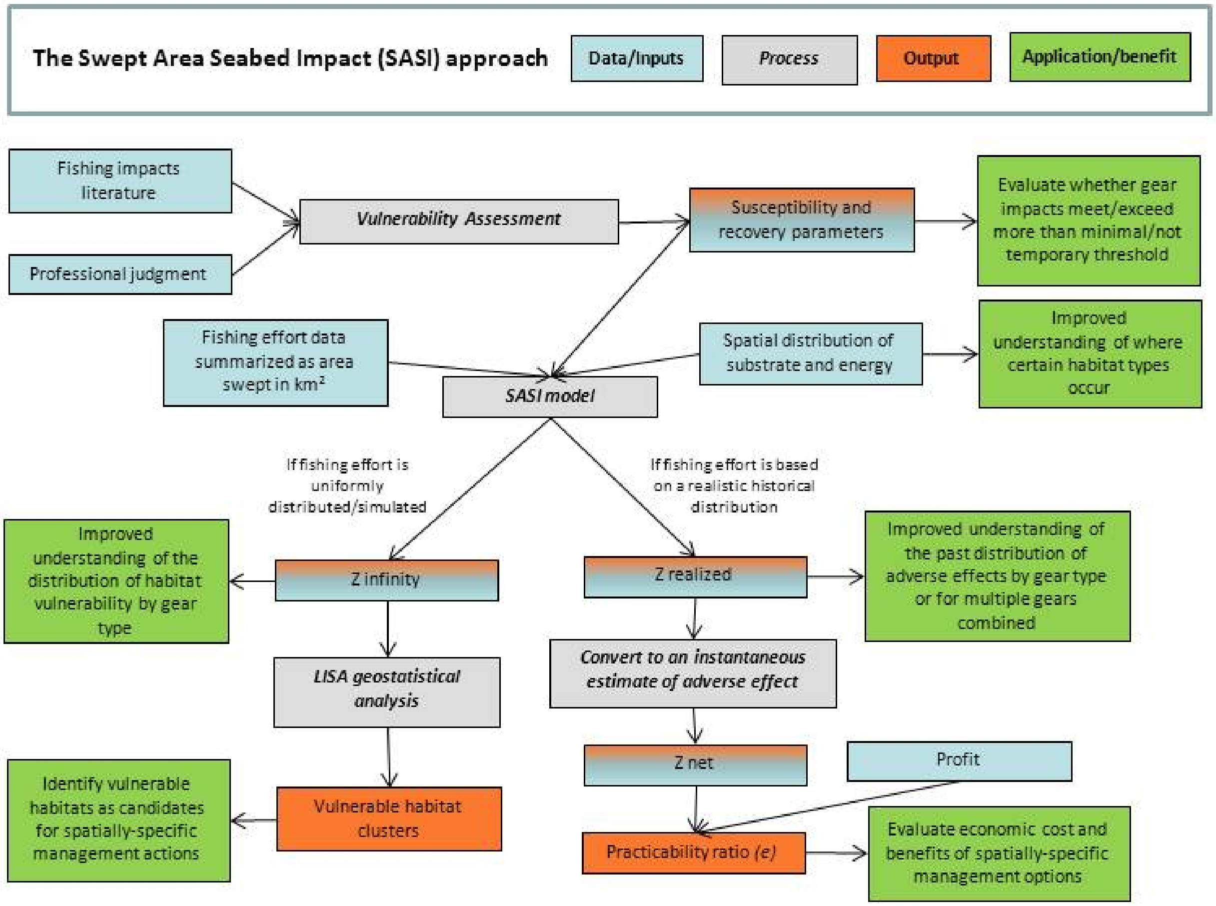
Spatial analyses (section 9.0). One way in which Z_∞ (adverse effect) estimates are evaluated is through formal spatial analysis. The objectives of the SASI spatial clustering analysis are to (explore the spatial structure of the asymptotic area swept (Z_∞), and to define clusters of high and low Z_∞ for each gear type. The analysis is intended to focus the Habitat Committee and Council's attention on areas with clusters of high vulnerability grid cells, as one starting point for developing spatially based alternatives to minimize adverse effect. Local Indicators of Spatial Association (LISA) statistics developed by Anselin (1995), which are designed to test individual sites for membership in clusters, are used.

Practicability analyses (section 10.0). Z_{net} is an instantaneous variant of $Z_{realized}$ that can be compared with trip level profit estimates to generate a practicability ratio, *e*. For gears with high habitat impact relative to profit, the *e* ratio is large, while for gears with a low habitat impact relative to revenue, the *e* ratio is small, approaching zero for some gear types. Z_{net} and *e* are developed for evaluating the relative practicabilty of various management alternatives, as the Council has expressed interest in optimizing its adverse effects minimization strategy across different gear types, fisheries, and areas.

Finally, **application of results to fishery management decision making (section 11.0)**, describes the assumptions and limitations of the model, and its potential applications to fishery management.

Section 12.0, research needs, lists habitat related research needs identified during model development. **Section 14.0, references**, includes acronyms used in the document, a glossary of key terms, and a literature cited section.

Figure 1 – SASI model flowchart



2.0 Defining habitat

Essential Fish Habitat is defined by the Magnuson Stevens Act as:

> "…those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity. For the purpose of interpreting the definition of essential fish habitat: ''Waters'' include aquatic areas and their associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate; ''substrate'' includes sediment, hard bottom, structures underlying the waters, and associated biological communities; ''necessary'' means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and ''spawning, breeding, feeding, or growth to maturity'' covers a species' full life cycle."

Fish habitat as defined above is thus an amalgamation of all the living and non-living aquatic features used by managed species throughout their lives. However, impacts to fish habitat conceptualized in this collective sense are difficult to summarize quantitatively and represent spatially. Therefore, in order to evaluate more concretely the interaction between fishing activity and fish habitat, a vulnerability assessment is developed to estimate the impacts of fishing on "substrate" as it is described above. For this assessment, "structures underlying the waters and associated biological communities" are specified as individual features that occur in areas identified as having particular "sediment" and "hard bottom" compositions. Individual features are chosen based on their known or assumed importance to managed species, and are differentiated to the extent required to capture broad differences in their susceptibility to and recovery from fishing disturbance. For a particular species of interest, the features and substrates than constitute its essential fish habitat can be inferred from both the EFH text description and also the EFH source documents, to the extent that the species dependence on such features and substrates is known.

For the purpose of this assessment, habitat features are divided into four components: geological structures, biological structures, prey, and deep-sea corals. The prey and deep-sea coral components are addressed in section 4.3, while the geological and biological structure components, which are evaluated in the matrix-based assessment and incorporated in the spatial SASI model, are discussed below.

Structural features are defined as the living and non-living seabed structures used by managed species or their prey for shelter, and are classed as either geological (non-living), or biological (living). The number of different features defined attempted to strike a balance between simplifying the analysis while allowing for expected differences in the susceptibility of features to fishing gears. For example, the biological features 'burrowing anemones' and 'actinarian anemones' are differentiated because they have different abilities to retract into the seabed and thus avoid fishing gears that skim the surface.

Features described in the following sections are exclusively benthic. While recognizing the importance of the water column as fish habitat, SASI addresses physical changes to seafloor substrates and biological communities exclusively, as it is assumed that fishing gear does not alter the water itself in any substantive way. Similarly, only bottom tending gear types are modeled.

The various geological and biological features are inferred to one or more seafloor substrate classes (mud, sand, granule-pebble, cobble, boulder - Table 1) and one or more energy environments (high or low - Table 2). The various substrate and energy combinations map directly to the model grids.

Table 1 – Substrate classes by particle size range (based on Wentworth, 1922)

Substrate	*Particle size range*	*Corresponding Wentworth class*
Mud	< 0.0039-0.0625 mm	Clay (< 0.0039 mm) and silt (0.0039 – 0.0625mm)
Sand	0.0625 – 2 mm	Sand (0.0625 – 2 mm)
Granule-pebble	2-64 mm	Granule (2-4 mm) and pebble (4-64 mm)
Cobble	64 – 256 mm	Cobble (64 – 256 mm)
Boulder	> 256 mm	Boulder (> 256 mm)

Table 2 – Critical shear stress model components

Condition	*Data source*	*Parameterization*	
		High energy	*Low energy*
Shear stress	The max shear stress magnitude on the bottom in $N{\cdot}m^{-2}$ derived from the M2 (principal lunar semidiurnal) and S2 (solar) tidal components only	High = shear stress ≥ 0.194 $N{\cdot}m^{-2}$ (critical shear stress sufficient to initiate motion in coarse sand)	Low = shear stress < 0.194 $N{\cdot}m^{-2}$
Depth	Coastal Relief Model depth data	High = depths ≤ 60m	Low = depths > 60m

The inference of features to the five substrate and two energy classes defines 10 basic physical habitat types. In reality, seabed habitats cannot be classed so simplistically, and there are certainly areas which contain a greater or lesser diversity of features than those listed below. In addition, the various features will differ in their relative abundances between areas. The possible biases that may be introduced into the spatial SASI model as a result of characterizing habitat in this way are discussed in section 4.3.

The following sections describe the structural features evaluated, highlighting: (1) characteristics of the features that would likely influence their susceptibility to fishing-induced disturbance and their recovery times following disturbance, (2) the importance of natural disturbance (i.e. high or low energy environment) in creating or maintaining geological features, and (3) the distribution of features by substrate type. In addition, for biological features, the taxonomic bounds of each feature are specified, and species commonly found in the Northeast region are noted.

2.1 Geological habitat component

Geological habitat features include non-living seafloor structures that can be used for shelter by managed species or their prey (Table 3). These eight features may be created and maintained via physical oceanographic processes or by benthic organisms.

Table 3 – Geological habitat features and their inferred distribution by substrate and energy.

Feature	***Mud high***	***Mud low***	***Sand high***	***Sand low***	***Granule pebble high***	***Granule pebble low***	***Cobble high***	***Cobble low***	***Boulder high***	***Boulder low***
Sediments, surface/subsurface	X	X	X	X						
Biogenic burrows	X	X	X	X						
Biogenic depressions	X	X	X	X						
Bedforms			X							
Gravel, scattered					X	X	X	X	X	X
Gravel pavement					X		X			
Gravel piles							X	X	X	X
Shell deposits			X	X	X	X				

2.1.1 Sediments, surface and subsurface

A surface and subsurface sediment feature is evaluated for high and low energy mud, and high and low energy sand. Gear effects on these features include resuspension, compression, geochemical effects, and sorting/mixing. Surface sediments are defined as the top few centimeters of sediment, while subsurface sediments are defined as the top few feet of soft sediments that provide habitat for various burrowing prey species.

2.1.2 Biogenic depressions and burrows

Biogenic depressions and burrows are generated by benthic species including fishes, crabs, or lobsters, and may be used by other species for shelter. Depressions are shallower, and burrows are deeper. Gear effects on these features include filling and collapsing. Impacts to these features are evaluated separately from impacts to the organisms that create them or may live on them. As they are of biological origin, recovery depends on the continued presence of the organism that created the feature, with timing dependent on the complexity of the feature: shorter for depressions, and longer for burrows. Biogenic depressions and burrows are found throughout the region in mud and sand substrates. More complex burrows are likely to be found in mud substrates, which are more cohesive than sand. One specialized type of biogenic structure is a tilefish burrow[1]. However, because of their very specific affinity for clay outcrops,

[1] Various authors, including Twichell et al. (1985), Able et al. (1982, 1993), Grimes et al. (1986, 1987), and Cooper et al. (1987), have studied the burrows and their use by the tilefish; this research is summarized in Steimle et al. 1999. Tilefish burrow may be tubular or funnel shaped.

and their limited spatial distribution, vulnerability of tilefish burrows to fishing is not carried forward into the matrices and spatial SASI model.

2.1.3 Bedforms

Sedimentary bedforms include ripples, megaripples, and waves. Twichell (1983) defines these features by size (Table 4). Bedforms are created by the action of waves and tides over the seabed. The susceptibility and recovery of bedforms to gear impacts are assumed to relate to both bedform size and energy environment. Bottom tending fishing gear can smooth bedforms of various sizes. Ripples can occur in high-energy mud or sand, although mud ripples are considered rare and therefore not carried forward into the matrices or spatial SASI model. Megaripples and waves are inferred to high-energy sand.

Table 4 – Bedform classification (after Twichell 1983)

Bedform	*Wavelength*	*Height*	*Found in*
Ripple	< 0.6 m		Mud, sand
Megaripple	1-15 m	Less than 1 m	Sand
Wave	50-1000 m	1-25 m	Sand

2.1.4 Gravel and gravel pavements

'Scattered gravel in sand' refers to areas with scattered granules/pebbles, cobbles, or boulders in a sand matrix, while 'gravel pavement' refers to areas covered or nearly covered with granules/pebbles or cobbles. Gear effects on gravel and gravel pavements include burial in underlying soft substrates, displacement, and resorting. Gravel pavements are found in high-energy environments where tidal or wave-generated disturbance removes finer grained sand and mud and leaves larger gravel particles behind. Scattered gravel surrounded by mud or sand is inferred to both high and low-energy environments.

2.1.5 Cobble and boulder piles

When glaciers extended over what is now submerged continental shelf, larger size classes of gravel (i.e. cobbles and boulders) are deposited as glacial till, sometimes occurring in piles on the seafloor. Fishing gear may smooth these piles and displace the cobbles and boulders they are made of. For boulder dominated habitats, redistribution will reduce availability of deep

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They range in size, but the largest are up to 5 meters wide and several meters deep. It is believed that either tilefish (Grimes et al. 1986, 1987) or crustaceans (Grimes et al. 1986, 1987, Cooper et al. 1987) form the burrows initially. The burrows may be created over the lifetime of the tilefish (Twichell et al. 1985); the maximum observed ages for female and male tilefish respectively are 46 and 39 years (Nitschke 2006). If completely destroyed, tilefish burrows would have a longer recovery time than other biogenic burrows.

crevices that are utilized by fish, such as Acadian redfish, for shelter. Because of the size of cobbles and boulders, these features will not reform naturally due to wave action.

2.1.6 Shell deposits

Shell deposits are the non-living remains of mollusks distributed in windrows (due to wave and current energy), along the base of steep slopes, and as continuous pavements, and may form as the result of fishing activities, predation, senescence, or all factors. These aggregations provide interstices for small organisms that serve as prey for managed species as well as directly providing cover for juvenile fishes. Such deposits are distinguished from occasional shells or shell pieces (i.e. shell debris). Gear effects on shell deposits include burial, breakage/crushing, or displacement. Recovery is possible if the organisms that generate the shells, such as scallops, razor clams, quahogs, surfclams, or mussels, remain in or recolonize the area following disturbance. Empty shells may aggregate to form deposits as a result of storm events. Shell deposits are inferred to high and low energy sand and gravel habitats.

2.2 Biological habitat component

Biological habitat features are macrofauna that attach to, emerge from, or rest on top of the substrate, and provide physical structure for managed species (Table 5). The functional roles of such habitats are to increase growth rates and survivorship, and to enhance reproduction. Generally, these biological features are broad taxonomic or functional groupings at family and higher levels, as opposed to individual species. Although differential susceptibility and recovery due to variation in life history or form is intuitive and has been demonstrated in various studies (e.g. Tillen et al. 2006), much of the fishing impacts literature considers impacts on a species- or taxon-specific basis. For example, impacts to sponges are considered, rather than impacts to erect, soft, long-lived epifauna.

Table 5 – Biological habitat features and their inferred distribution by substrate and energy.

Feature	*Mud high*	*Mud low*	*Sand high*	*Sand low*	*Granule pebble high*	*Granule pebble low*	*Cobble high*	*Cobble low*	*Boulder high*	*Boulder low*
Amphipods	X	X	X	X						
Anemones, actinarian					X	X	X	X	X	X
Anemones, cerianthid	X	X	X	X	X	X				
Ascidians			X	X	X	X	X	X	X	X
Brachiopods					X	X	X	X	X	X
Bryozoans					X	X	X	X	X	X
Corals, sea pens		X		X						
Hydroids	X	X	X	X	X	X	X	X	X	X
Macroalgae					X		X		X	
Mollusks, mussels	X	X	X	X	X	X	X	X	X	X
Mollusks,			X	X	X	X	X	X		

scallop								
Polychaetes, *F implexa*			X	X	X	X	X	X
Polychaetes, other			X	X	X	X	X	X
Sponges	X	X	X	X	X	X	X	X

2.2.1 Amphipods – tube-dwelling

A number of marine amphipod species construct temporary or permanent burrows, tunnels, or tubes. A variety of materials, including mud, clay, sand grains, and shell and plant fragments may be used to form the tubes. The material is usually bound together with a cementing secretion produced by the animal. All amphipods belonging to the family Ampeliscidae, with the exception of those living on hard substrate, are tube-dwelling. They are common in marine sediments throughout the world and certain species may occur at very high densities in coastal sediments, forming tube beds or mats (Sheader 1998). Another species – *Erichthonius* sp., belonging to the family Corophiidae – has also been reported to form tube mats on Fippennies Ledge, in the Gulf of Maine, that are susceptible to damage by fishing gear (Langton and Robinson 1990). This species has also been observed in deep water in Jordan Basin on undisturbed mud bottom (Watling 1998). Many amphipod species in the Northeast region are tube-dwelling, but do not create tubes that extend above the sediment surface (Steimle and Caracciolo 1981). (See Section 12.1.1.1 for more information on the importance of amphipods as prey).

The vulnerability assessment for structure-forming amphipods is based on the susceptibility and recovery potential of the most common east coast ampeliscid species, *Ampelisca abdita*. This species ranges from Maine to at least Florida and produces dense masses of tubes in soft sediments at depths ranging from shallow, sub-tidal waters to about 60 meters. In Raritan Bay, New Jersey, dense *A. abdita* tube mats are common in mud and fine sand, covering mud surfaces at certain times of year so completely that the mud surface is not visible (MacKenzie et al. 2006). The tubes are about 3.5 cm long and flattened laterally, and are composed of nonchitinous, pliable organic material. About two-thirds (2-2.5 cm) of the tube extends vertically into the water. In Raritan Bay, the tube mats are covered with a continuous layer of brown fecal pellets and finer particles held in place by mucous secreted by the amphipods. Tube mat formation is highly seasonal because *A. abdita* has three breeding seasons per year. In Raritan Bay, new generations settle onto the bottom and construct new tubes in May-June, September-October, and December-January. Several weeks after the new tubes are constructed, they slowly begin to disintegrate and lay flat on the bottom.

Amphipod tube mats also occur further offshore on the continental shelf. Auster et al. (1991) identified flat sand with amphipod tubes (species not identified) as one of four microhabitats utilized by fish at a low relief outer continental shelf site (55 m) in southern New England. This microhabitat type was found to support the highest density of young-of-year silver hake at various locations on the southern New England continental shelf on silt-sand bottoms at depths of 47-82 m (Auster et al. 1997). Lindholm et al. (2004) also identified a sand dominated habitat with amphipods and polychaete tubes that extended approximately 2 cm above the sediment surface on eastern Georges Bank, in depths >60 meters.

Tube-dwelling amphipods are inferred to high and low energy mud and sand-dominated habitats.

2.2.2 Anemones – actinarian and cerianthid

Anemones are members of the class Anthozoa, a very large and diverse group of Cnidarians that also includes corals. Anemones are soft-bodied and flexible, consisting of a ring or rings of tentacles atop a base or column. For the purpose of the vulnerability assessment, burrowing (order Ceriantharia) and non-burrowing anemones (order Actinaria) are differentiated. Whereas Actinarians (true) anemones are able to retract their oral disk and tentacles, cerianthids cannot. However, cerianthids can withdraw very rapidly into permanent, semi-rigid tubes buried in the substrate that are constructed of specialized cnidae and mucus, with adhering substrate debris (Shepard et al. 1986). Available information for four actinarian species and the two cerianthids known to exist in the region is summarized in Table 4. Sources used to compile this information are Shepard et al. (1986, Sebens (1998), the Marine Life Encyclopedia [on-line], Wikipedia [on-line], and the website actiniaria.com.

Actinarian anemones in the region include the northern red anemone *Urticina (Tealia) felina (=Urticina crassicornis?)*, the frilled anemone *Metridium senile*, *Bolocera tueidae*, and *Stomphia coccinea* (Table 4). Actinarians adhere to the substrate with a pedal disk, and are thus restricted to hard substrates including larger size classes of gravel and biogenic structures. In the British Isles, both *U. felina* and *M. senile* are found in areas with varying tidal flows and wave exposures (Jackson and Hiscock 2008, Hiscock and Wilson 2007). *U. felina* and *M. senile* are present on Ammen Rock, in the central Gulf of Maine, at depths of 30-65 m (Witman and Sebens 1988) and *B. tueidae* has been observed on hard substrates in the central and eastern Gulf of Maine (Langton and Uzmann 1989). *U. felina* has also been observed on settlement panels deployed on the northern edge of Georges Bank (Collie et al. 2009).

Burrowing anemones in the Northeast region include *Cerianthus borealis* and *Ceriantheopsis americanus*. *C. borealis* is found from the Arctic to Cape Hatteras at depths of 10-500 m, while *C. americanus* has a more southerly and shallow distribution, ranging from Cape Cod to Florida at depths between 0-70 m. Other unclassified cerianthids have been sampled from deeper waters of the continental slope (Shepard et al. 1986). Between Nova Scotia and Cape Hatteras, cerianthids are most common on the shelf off Nova Scotia, between 40-41° N latitude, and between 37-38° N latitude (Shepard et al. 1986). Shepard et al. found that cerianthid distribution was independent of sediment type, although they are not found in areas with 100% gravel or bedform-dominated coarse sand substrates. Langton and Uzmann (1989) reported that *C. borealis* in the central and eastern Gulf of Maine were most abundant in mixed sandy substrates and in silt, but entirely absent from 100% sand and gravel substrates. Tubes inhabited by *C. americanus* remain entirely in the substrate (Peter Auster, personal communication) whereas the tubes of *C. borealis* extend 15 cm above the sediment surface (Valentine et al. 2005). Under certain conditions, *C. borealis* are found in dense aggregations (up to 10 animals per m^2) in the Gulf of Maine (Valentine et al. 2005).

Cerianthids are important ecologically. For example, Shepard et al. (1986) found a positive relationship between the abundance of hydroids, sponges, anemones, blackbelly rosefish, and redfish and cerianthids in deeper waters (137-183 m) of Block Canyon. Acadian redfish as well as other fish species use dense patches of cerianthids for shelter (Auster et al. 2003). Pandalid shrimp are known to aggregate around the base of anemones and may serve to concentrate crustacean prey. In addition, cerianthids are known prey of cod, haddock, flounder, scup, and skates, which may consume whole juveniles or the tentacles of adults, and they serve as a substrate for epifaunal and infaunal organisms (Shepard et al. 1986). Both cerianthid and actinarian anemones are carnivorous, feeding primarily on zooplankton.

Generally, both types of anemones are long-lived and slow growing, and like other cnidarians, many species reproduce both asexually and sexually. Anemones are solitary, but show a gregarious distribution, which might be expected due to the importance of sexual reproduction. Both *U. felina* and *M. senile* are gonochoristic (separate males and females, Jackson and Hiscock 2008, Hiscock and Wilson 2007), while cerianthids are protandric hermaphrodites (sequentially male then female, Shepard et al. 1986). However, for many species, it seems that few details are known about growth rates, age at maturity, longevity, or fecundity.

Actinarian anemones are inferred to high and low energy granule-pebble, cobble, and boulder substrates, while cerianthid anemones are inferred to high and low energy mud, sand, and granule-pebble substrates.

Table 6 – Actinarian and cerianthid anemones of the Northeast Region.

Species	***Range***	***Size***	***Form***	***Habitats***
Bolocera tuediae	Arctic to North Carolina	25 cm high, base 25 cm wide	Solitary	Rock and shell substrates, 20-1000 m, rarely to 2000 m
Cerianthus borealis	Arctic to Cape Hatteras	Semi-rigid tube extends 15 cm above seabed	Solitary, burrowing	Mud, stable sand, or gravelly substrates (<50% gravel cover), 10-500 m
Ceriantheopsis americanus	Cape Cod to Florida	Animal extends above sediment, but not tube	Solitary, burrows up to 45 cm into sediment,	Muddy or sandy bottom, up to 70 m
Metridium senile	Arctic to Delaware Bay	Large, to 30 cm, base 15 cm wide	Solitary, very common	Rock outcrop, large gravel or biogenic structure, intertidal to 166 m
Stomphia coccinea	Circumarctic boreal, to Cape Cod	Moderate, height and diameter to 7	Solitary, can detach	Surfaces of stones and rocks, on shells, 5-400 m

		cm	easily from substrate	
Urticina (Tealia) felina (crassicornis)	Just below Cape Cod to Arctic	Large, base up to 70 cm diameter when expanded	Solitary	Cobble or gravel, 2 to >300 m

2.2.3 Ascidians

Ascidians are a class of tunicates, and as such are members of the phylum Chordata, along with fish, birds, and mammals. They are suspension feeders; water and food enter through an incurrent siphon, are filtered through a U-shaped gut, and exit through an excurrent siphon. The ascidian's outer covering, or tunic, may range from soft and gelatinous to thick and leathery, depending on the species. A few ascidians live interstitially or attached to soft sediments, but most require a hard surface for attachment. Ascidians reproduce both asexually and sexually; in the latter case the larval stage is typically very short, ranging from hours to days.

Ascidians may be solitary (often gregarious), social (individuals are vascularly attached at the base), or compound/colonial (many individuals live within a single gelatinous matrix). However, only the solitary species are considered in the vulnerability assessment. Compound, or colonial, ascidians (genera like *Didemnum* and *Botryllus*) are not included because they spread out over the substrate and do not create any appreciable vertical structure. All of the eight species listed in Table 7 reach maximum heights >2 cm, and four of them grow up to 5-7.5 cm tall. One species, (*Molgula arenata*) does not attach to the substrate, and one (*Boltenia ovifera*) is attached by a stalk. Only two species (*M. arenata* and *M. manhattensis*) occur in the Mid-Atlantic region. Very little is known about the deep-water species *Ascidia prunum*. *Molgula* spp. (sea grapes) live in soft bottom habitats, but the others attach to hard substrates.

Ascidians are inferred to all substrate and energy environments except for high and low energy mud.

Table 7 – Structure-forming solitary ascidians of the Northeast Region

Species	***Range***	***Height***	***Form***	***Habitats***
Ascidia callosa	Arctic south to Cape Cod	To 50 mm	Attached	Subtidal
Ascdia prunum	?	?	Attached	Deep water only
Boltenia ovifera	Arctic to Cape Cod, rarely to Rhode Island	Body to 75 mm, stalk 2-4 times longer (smaller near shore)	Attached, on stalk	generally subtidal to great depths (?), on rock outcrop, gravel, seagrasses
Boltenia	Arctic south to Cape	To 34 mm	Cactuslike cushion,	Lower intertidal to

Species	Range	Height	Form	Habitats
echinata	Cod, rarely beyond		attached, no stalk	subtidal, shallow
Ciona intestinalis	Arctic south to Cape Cod, rarely to Rhode Island	To 62 mm	Attached, tall and slender	In shallow water on pilings, etc.
Halocynthia pyriformis	Subarctic to Massachusetts Bay, uncommon south of eastern Maine	To 62 mm, often only half that size	Attached, large, barrel-shaped	Usually subtidal, Rock outcrop, gravel, seagrasses
Molgula arenata	Bay of Fundy to Cape May	To 19 mm	Unattached, globular	On sand or mud, subtidal, 5-22 m
Molgula manhattensis	Bay of Fundy to Gulf of Mexico	To 34 mm	Attached, globular	Intertidal to subtidal in shallow water

2.2.4 Brachiopods

Brachiopods – also known as lamp shells – resemble bivalve mollusks, but belong to an entirely separate phylum. The resemblance is only superficial: they do possess a calcareous shell with two valves, and are approximately the same size as many bivalve mollusks, but one valve is typically larger than the other and the larger valve is attached to the substrate directly or by means of a short, cord-like stalk. All brachiopods are marine, and most live on the continental shelf. Most species live attached to rocks or other hard substrate. They have very thin, light shells and some species are very long-lived (up to 50 years).

The common species in the Northwest Atlantic is *Terebratulina septentrionalis*. It is locally common from Labrador south at least to Cape Cod in the lower intertidal zone in the northern part of its range, but is resticted to deep water at its southern limit (Gosner 1978). It is a common epifaunal organism on rocky bottom in the Bay of Fundy, on Western Bank (Scotian shelf), and on Browns Bank and Jeffreys Ledge in the Gulf of Maine (Kenchington et al. 2006/2007, Kostylev et al. 2001, and D. Stevenson, pers. comm.). The shells of this species are small, ranging from 12-30 mm in size (Gosner 1978). Unlike other brachiopod species, it is relatively short-lived, with a lifespan ranging from 1-5 years (Witman and Cooper 1983).

Brachiopods are inferred to high and low energy granule-pebble, cobble, and boulder substrates.

2.2.5 Bryozoans

The bryozoans (Greek, meaning moss animals), are a highly diverse group of colonial animals found in both fresh and saltwater. Marine bryozoans have been found at nearly all depths and latitudes, primarily on hard substrates; they are almost always sessile. They may be calcified or soft, and encrusting or erect. Each colony is comprised of hundreds to millions of tiny individuals called zooids; individual zooids may be specialized for feeding, cleaning, providing structure to the colony, etc. The soft parts of each zooid are typically enclosed in a tiny calcified 'house', or cystid. Bryozoans suspension feed using a lophophore, which is a ring of tentacles surrounding the mouth that can be protracted and retracted through a pore in the cystid. As colonial organisms, asexual reproduction via budding is an important strategy for bryozoans. The directionality of budding (e.g. circular or chainlike) varies by species, and helps to determine the structure of the larger colony. As for sexual reproduction, most bryozoans are hermaphroditic, and the eggs may be brooded or released and externally fertilized depending on the species. The bryozoan larva, which may be mobile for several months in some species, settles, and then a new colony forms asexually by budding (Gosner 1971).

Only erect (or "bushy") bryozoans are considered structural habitat for fish or their prey and included in the vulnerability assessment. These bryozoans are anchored via a holdfast (Gosner 1971). Some are calcified, others are not. Some species that occur in the Northeast region are quite large, reaching heights of 30 cm, but the majority are <10 cm high. *Eucratea loricata* grows to a height of 25 cm and is found in shallow and deep water from the Arctic to Cape Cod. *Bugula turrita* and *Alcyonidium* spp. can reach 30 cm and are found in shallow water. Other erect species that inhabit deeper water are *Crisia eburnea, Dendrobaenia murrayana, Flustra foliacea, Idmonea atlantica, Cabrera ellisi,* and *Tricellaria ternata.* The information in Table 8 was compiled from Gosner (1978), Stokesbury and Harris (2006), Henry et al. (2006), and Witman and Sebens (1988).

F. foliacea biology was summarized by Tyler-Walters and Ballerstedt (2007). The species lives between 5-10 years, and growth rate estimates range from 1-3 cm per year. Growth has been shown to vary seasonally, annually, by colony age, and according to the degree of fouling by other bryozoans, hydroids, polychaetes, barnacles, ascidians, etc. The holdfast is thickened and strengthened as the colony ages. *F. foliacea* is able to recover from grazing damage within a few days. *F. foliacea* settles on any hard substrate and seems to prefer high-flow conditions.

Bryozoans are inferred to high and low energy granule-pebble, cobble, and boulder substrates.

Table 8 – Erect bryozoans (>1.5 cm high) of the Northeast Region.

Species	***Range***	***Height***	***Form***	***Substrate***
Aeverrillia spp.	Mostly south of Cape Cod; A. armata estuarine, reported north to Casco Bay	10 cm	Horny but not calcified	Shallow water
Alcyonidium spp.	Three species, one boreal, one south of Cape Cod, and one whole coast	To 30 cm or more	Rubbery or gelatinous, not calcified	Shallow water
Amathia convoluta and *vidovici*	*A. convoluta* south of MD, *A. vidovici* south of Cape Cod	50 and 150 mm	Not calcified	Variety of substrates in shallow water
Anguinella palmata	Cape cod to Brazil, abundant Delaware Bay and south	65 mm	Soft, grows in palmate, branching tufts	Shallow; can be found in estuaries

Species	*Range*	*Height*	*Form*	*Substrate*
Bugula turrita	Bay of Fundy to Florida	Usually <75mm but sometimes to 30 cm	Lightly calcified, bushy, thickly tufted	At shallower depths, can be found in estuaries
Bugula simplex	South shore of Cape Cod to Maine	To 25 mm	Lightly calcified, thick, fan-shaped tufts and whorls	Shallow water
Cabrera ellisi	Cape Cod north to Arctic	?	Branching	Usually offshore on pebbles and shells
Crisia eburnea and *cribaria*	*C. eburnea* Arctic to Cape Hatteras, *C. cribaria* north of Cape Cod only	To 19 mm	Calcified, in twiggy tufts	*C. eburnea* to 300+ m, can be found in estuaries
Dendrobaenia murrayana	*Dendrobaenia* sp. common colonial epifauna on Scotian shelf, on Ammen Rock (central Gulf of Maine)	To 38 mm	Leafy, in narrow to broad fans or ribbons	On pebble-cobble-boulder substrate on Scotian shelf
Eucratea loricata	Arctic to Cape Cod	To 25 cm	Calcified; some colonies short and stiff, others bushier	Subtidal, shallow to deep (in mixed sand, gravel, and boulders
Flustra foliacea	Arctic south to Georges Bank	100 mm +	Calcified, erect, leafy, broad-lobed fronds	Attached to rocks, seaweed, etc., at 52-70 m on Georges Bank
Idmonea atlantica	Arctic to Cape Cod	25 mm or more	Antler-like colonies	On rocky substrate at 30-65 m on Ammen Rock, central Gulf of Maine)
Tricellaria ternata	Present on western part of Georges Bank	To 16 mm?	Calcified	In 52-70 m on GB, mixed sand, gravel, and boulders

2.2.6 Sea pens

Sea pens are members of the phylum Cnidaria[2], a large and diverse group whose benthic, structure-forming species include the hydroids, sea anemones, and corals. They belong to the Class Anthozoa, along with corals and sea anemones, and are placed under the Subclass Octocorallia (Alcyonaria), or octocorals. Unlike most other corals, sea pens live in muddy and

[2] Cnidarians are distinguished by their cnidae, or stinging cells, for which jellies in particular are commonly known.

sandy sediments, anchored in place by a swollen, buried peduncle. Some species are capable of retracting into the sediment when disturbed.

Records of sea pens were drawn from Smithsonian Institution collections and the Wigley and Theroux benthic database (Packer et al. 2007). Nearly all materials from the former source were collected either by the U.S. Fish Commission (1881-1887) or for the Bureau of Land Management (BLM) by the Virginia Institute of Marine Sciences (1975-1977) and Battelle (1983-1986). These latter collections heavily favor the continental slope fauna. The Wigley and Theroux collections (1955-1974) were made as part of a regional survey of all benthic species (Theroux and Wigley 1998), heavily favoring the continental shelf fauna. A list of 21 sea pen species representing ten families was compiled from these sources for the northeastern U.S. The majority of these species have been reported exclusively from continental slope depths (200-4300 m), although two uncommon species have been recorded from shallow depths (e.g., < 30 m) off the North Carolina coast.

Sea pens are evaluated as structural biological features in the matrix-based vulnerability assessment because of two sea pen species which are fairly common in continental shelf waters. In contrast, other cold-water coral species are less abundant in shallower, more commonly fished waters. The species diversity, known location information, and vulnerability of these other cold water corals, e.g. the soft corals, gorgonians, stony corals, and deep-water sea pens are discussed in section 12.2. The most common and fairly widespread species found in this region in the deeper parts of the continental shelf (80-200 m) are *Pennatula aculeata* (common sea pen) and *Stylatula elegans* (white sea pen). *P. aculeata* is common in the Gulf of Maine (Langton et al. 1990), and there are numerous records of *Pennatula* sp. on the outer continental shelf as far south as the Carolinas in the Theroux and Wigley database. *S. elegans* is abundant on the Mid-Atlantic coast outer shelf (Theroux and Wigley 1998). Given the 51 m minimum depth in the region, sea pens are only inferred to low energy mud and sand environments.

Table 9 – Common sea pen species on the continental shelf of the Northeast Region

Species	***Range***	***Form***	***Habitats***
Pennatula aculeata	Newfoundland to Virginia	Solitary	Mud or sand, 119-3316 m; also in sand with scattered gravel
Stylatula elegans	New York to Florida	Solitary	Mud or sand, 20-812 m, 51 m minimum depth in NE region; also in sand with scattered gravel

2.2.7 Hydroids

Hydroids are also Cnidarians within the Class Hydrozoa. Most hydroids are colonial, branching, and live attached to the substrate directly or to another organism. Each branch of the colony terminates in an individual polyp, or zooid. Most marine hydroids are encased in an exoskeleton made of chitin or calcium carbonate; when this structure extends around the polyp in a cup-shape, the species is considered thecate, which is an important identifying characteristic. Within a colony, individual polyps are modified for different functions, which may include reproduction, feeding, and defense.

Hydroids reproduce both asexually and sexually. In the case of sexual reproduction, the reproductive, or gonozooids produce gonophores, which may either remain attached to the colony or detach as a free medusae (the upside-down bell-shaped form commonly associated with jellyfish). Some of these medusae may live for several months and feed on their own, thus allowing for wide dispersal. Eggs and sperm released by the attached or detached reproductive structures come together to produce a planula larvae. These larvae have varying degrees of dispersal, ranging from attached to the mother colony, to crawling along the seafloor, to detached but floating in the currents, to free swimming (Boero 1984). Generally, hydroid species living in estuarine environments tend to have free medusae, while hydroids living in colder, saltier waters tend to have gonophores that remain attached (Calder 1992). Some species (e.g., *Sertularella polyzonias*) reproduce asexually and can rapidly recolonize new substrates by using terminal tendrils located at the distal ends of each hydroid plume (Henry et al. 2003).

Hydroids settle precociously on hard bottoms, and then also settle on top of the algae, sponges, polychaetes, barnacles, bryozoans, mollusks, and ascidians that succeed them (Boero 1984). In fact, some hydroids have fairly exclusive preferences for settlement on other epifaunal species (Boero 1984). In soft bottom environments, they are less common in shallow waters, but increase in importance below 40-50 m depth (Boero 1984). Auster et al. (1996), for example, observed dense growth of *Corymorpha pendula* on coarse sand on Stellwagen Bank (southwest Gulf of Maine) in depths of 32-43 meters and Henry et al. (2006) identified 30 species of colonial hydroids at 70 meters on a mixed pebble, cobble, boulder, and sand bottom on Western Bank (Scotian shelf).

Generally, hydroids tend to grow quickly, and some show pronounced seasonal cycles, particularly in areas where temperatures vary at different times of year (Boero 1984). Hydroid polyps filter food from the water column, and as such are sensitive to suspended sediment. In high-flow areas, this is generally not an issue, but in low-flow areas hydroids tend to 'climb' on other organisms, presumably to increase their distance from the seabed (a phenomenon known as acrophily) (Boero 1984). Species in low-flow areas also tend to be thinner, so that less surface area is available to collect suspended sediment (Boero 1984). Hydroids tend to orient their colonies perpendicular to the dominant flow direction (Boero 1984).

Hydroid colonies are generally relatively low relief, such that they are unlikely to be used directly by fish for shelter, but they do provide complex structure that can be used by other smaller epifauna, some of which are prey for managed species. For example, at two different Irish Sea sites, samples with abundant hydroids had significantly higher abundances of some other epifaunal species (Bradshaw et al. 2003). Three types of associations were found between the hydroid colonies and other species: (1) species that settle on the hydroids directly (e.g. amphipods, *Erichthonius punctatus*, and scallops, *Pecten maximus*), (2) species that shelter amidst the upright structure of the hydroids, and (3) species that shelter at the base of the hydroids. For example, high densities of pandalid shrimp were differentially distributed within hydroid patches on Stellwagen Bank (Auster et al. 1996), influencing the distribution of an important prey resource for crustacean-eating fishes.

Many species of hydroids do not reach maximum sizes that are sufficient to (potentially) provide shelter for managed species of fish. Therefore, the habitat vulnerability assessment focused on species known to occur in the region that exceed 2 cm in height (see Table 10 for details). The identified genera and species are derived from information for the Atlantic coast from the Bay of Fundy to Cape Hatteras (Gosner 1978) and by Calder (1975), based on a survey of Cape Cod Bay. Additional information for Georges Bank and the Gulf of Maine (Stellwagen Bank) was derived from Stokesbury and Harris (2006) and Auster et al. (1996).

Calder (1992) examined the distribution of hydroids in the western North Atlantic by comparing species diversity at sites that were reasonably well-studied. He found that the hydroid assemblage changes significantly around Cape Hatteras, somewhere between Chesapeake Bay and Beaufort, NC. Hydroid assemblages from the Canadian Arctic to the Mid Atlantic Bight were distinct from those found from Beaufort, NC south to the Caribbean. In particular, the hydroid assemblage in Cape Cod Bay was more similar to the assemblages found in the Canadian Maritimes, while the assemblage from Woods Hole was more similar to the one from Chesapeake Bay.

Hydroids are inferred to all ten substrate and energy environments.

Table 10 –Hydroids (>2 cm) in the Northeast Region

Species	***Range***	***Height***	***Habitat***
Abietinaria spp.	Arctic to Cape Cod	To 30 cm	Usually subtidal, common on seaweeds, rocks, pilings
Aglantha digitale	Arctic south to Chesapeake Bay	To 28 mm	Mainly subtidal (> 15 m), year-round in Gulf of Maine, winter-spring southward
Bougainvillia carolinensis	Central Maine to Florida	To 30 cm	Lower intertidal to subtidal in shallow water
Bougainvillia superciliaris	Arctic south to Cape Cod	To 5 cm	Lower intertidal to subtidal in shallow water
Bougainvillia rugosa	Chesapeake Bay south	To 25 cm	Shallow water
Capanularia spp.	Four conspicuous species, two mainly boreal, two along entire coast	Two species 25-35 cm, two 32 mm	Rocks, shells, pilings in shallow water
Clytia edwardsi	Chesapeake Bay north	To 25 mm	Lower intertidal to subtidal in shallow water on rocks, shells, pilings
Corymorpha (Hybocodon) pendula	Gulf of St. Lawrence to Rhode Island	To 10 cm	Deep water, in sand at 32-43 m in SW Gulf of Maine

Species	***Range***	***Height***	***Habitat***
Diphasia spp.	Arctic to Rhode Island	To 10 cm	Common on seaweeds, rocks, pilings from lower intertidal to subtidal at considerable depths
Eudendrium spp.	Whole coast, 10 species, most conspicuous are *E. carneum* and *E. ramosum, E. capillare on Georges Bank*	To 15 cm	Most in shallow water on a wide variety of substrates; E. capillare on mixed sand and gravel in 52-70 m
Garveia spp.	Whole coast	To 15 cm	
Gonothyraea loveni	Chesapeake Bay north	To 32 mm	Lower intertidal to subtidal in shallow water, on rocks, shells, pilings
Halecium spp.	Numerous species, mostly boreal	To 75 mm	Lower intertidal to subtidal at depths of 12 m or more
Hybocodon (Corymorpha) pendula	Chiefly boreal	To 10 cm	Present in SW Gulf of Maine in coarse sand at 32-43 m, abundant in Cape Cod Bay in sand and mud
Lovenella spp.	Whole coast (distribution uncertain)	16-50 mm	Some species subtidal in shallow water, others only in deep
Obelia bicuspidata	Whole coast	To 25 mm	Lower intertidal to subtidal in shallow water, on rocks, shells, pilings
Obelia commissuralis	Whole coast	To 20 cm	Lower intertidal to subtidal in shallow water, on rocks, shells, pilings
Obelia longissima	N. Canada to Chesapeake Bay	15 cm	On mud and sand in Cape Cod Bay
Opercularella spp.	Whole coast (distribution uncertain)	16-50 mm	Some species subtidal in shallow water, others only in deep
Pennaria tiarella	Maine south to West Indies	To 15 cm	Common on eelgrass, pilings, and other substrates in summer-early fall
Schizotricha tenella	Casco Bay to Caribbean	To 10 cm	On pilings, seaweeds, and other substrata to shallow depths
Sertularella polyzonias	N. Canada to Georgia	20 mm	
Sertularia cupressina	Labrador to New Jersey	11.5 cm	Common on sand and mud in Cape Cod Bay
Sertularia argentea	Northern Canada to North Carolina	To 30 cm	Chiefly a winter species, common on seaweeds, rocks, pilings to considerable depths, on sand and mud in Cape Cod Bay
Sertularia latiuscula	Gulf of St. Lawrence to Virginia	8.5 cm	Common in Cape Cod on sand and mud
Sertularia pumila	Labrador to Long Island Sound	To 50 mm	Common on seaweeds, rocks, pilings to considerable depths
Tubularia	Whole coast,	15 cm	From lower intertidal to subtidal at shallow

Species	Range	Height	Habitat
spp.	several species (*T. crocera* common south of Cape Cod, *T. larynx* north of Long Island Sound)		depths

2.2.8 Macroalgae

A wide variety of macroalgae can be found in coastal areas of the Northeast region, but fewer species have been documented in deeper, offshore waters. Because macroalgae are photosynthetic, their distribution is restricted to the photic zone. They require a hard substrate for attachment. The most important species of macroalgae, in terms of providing habitat for fish, are the kelps, brown algae belonging to the order Laminariales. This order includes the largest and most structurally complex of all the algae. They are an important floristic component of the lower littoral and sublittoral zones on almost any rocky coast in temperate or polar seas (Bold and Wynne 1978). On the east coast of North America they range southward to Long Island Sound (Table 11). All the species found in the Northeast Region are perennials. The blades of these kelps slough off after reproduction and a new blade is produced at the beginning of the next growing season (Bold and Wynne 1978). Owing to their large size (up to 10 meters in length), these plants provide habitats for a variety of pelagic and benthic marine invertebrates and fish. There are also a number of larger red algal species that grow in subtidal waters in the region (Table 11). Five of the 17 red algal taxa identified as inhabiting subtidal waters in the region, and reaching sufficient sizes to provide three-dimensional structure, reach lengths of 30-60 cm. Because of differences in their photosynthetic pigments, red algae occur in deeper water than brown algae. Four of those listed range southward from Cape Cod and Long Island Sound, five northward, and eight are common to both areas. Information in Table 11 was based primarily on Gosner (1978), with some supplementary information from Sears and Cooper (1978), Schneider (1976), and Vadas and Steneck (1988).

Macroalgae are inferred to high energy granule-pebble, cobble, and boulder substrates.

Table 11 – Brown and Red Macroalgae (>5 cm high) in the Northeast Region

Species	Type	Range	Height	Habitat
Alaria (5 species?)	Brown	Arctic to Cape Cod, A. esculenta sparingly to Long Island Sound	Stalked, with lateral bladelets, main blade to 3 m	Primarily subtidal, sometimes in lower intertidal zone
Agarum cribrosum	Brown	Arctic to Cape Cod	Single broad blade, to 1.8 m, sometimes twice that	Chiefly subtidal, present at 24-40 on Ammen Rock, central Gulf of Maine
Laminaria digitata	Brown	Arctic to Long Island Sound	Wide blade split into 6-30 or more “fingers,” to 1.1 m	In extreme lower intertidal on exposed rocks, subtidal southward
Laminaria	Brown	Arctic to Cape Cod,	Long stalk, usually to	Present (with an

Species	***Type***	***Range***	***Height***	***Habitat***
longicruris		locally to Long Island Sound	4.5 m, but to 10 m or more in deep water	unidentified species of Laminaria) at 24-40 on Ammen Rock, central Gulf of Maine
Laminaria saccharina (form of *L. agardhii*?)	Brown	Northern Massachusetts to Arctic		
Laminaria agardhii	Brown	Long Island Sound and off NY Harbor to Gulf of Maine (only common long-bladed kelp south of Cape Cod)	To 3 m	
Champia parvula	Red	Cape Cod to tropics	Bushy, branched, to 75 mm	Chiefly subtidal in quiet water, often epiphytic, at 17-27 m in North Carolina
Chondria spp.	Red	Nova Scotia to tropics, four species	Bushy, branched, 10-25 cm	Lower intertidal to subtidal in summer, found at 14-60 m in NC
Cystoclonium purpureum	Red	Long Island Sound to Newfoundland	Bushy, to 60 cm	Abundant, mainly subtidal on sandy or shelly bottoms in protected and exposed locations
Dasya spp.	Red	Maine or Nova Scotia to tropics	Furry strands to 60 cm	*D. baillouviana* found at 18-40 m in NC
Gracilaria spp.	Red	Cape Cod to tropics, two species, one locally north to central Maine and one to Prince Edward Island	Coarsely bushy, to 30 cm	Common in shallow bays and sounds south of Cape Cod
Griffithsia globulifera	Red	Two species , one from Cape Cod to tropics, the other to Virginia	Bushy, with branches, fragile, to 20 cm	Subtidal in quiet water, 17-47 m in NC
Grinnellia americana	Red	Northern MA south at least to the Carolinas	Thin, undivided leaf up to 60 cm	Subtidal, appears and disappears abruptly during summer, little more than a month in north, longer in south, 15-50 m in NC
Hypnea musciformis	Red	Cape Cod to tropics	Delicate, mosslike bushy weed, to 45 cm	Subtidal, in warm coves from Cape Hatteras to Cape Cod, at 21 m in NC
Lomentaria spp.	Red	Two species, New England to tropics	Small and delicate, to 75 mm	Subtidal in shallow protected waters, 15-40 m in NC

Species	*Type*	*Range*	*Height*	*Habitat*
Membranoptera spp.	Red	Two species, one Arctic to northern MA, one to Long Island Sound	Finely divided lacy thalli, to 20 cm	Usually subtidal, *M. alata* at 24-40 m on Ammen Rock, central Gulf of Maine
Neoagardhiella baileyi	Red	Cape Cod south to tropics, locally north to central Maine	A coarsely bushy red weed, to 30 cm	In warm bays and sounds south of Cape Cod, attaches to shells and stones, found at 29-45 m in NC
Phycodrys rubens	Red	Arctic to Cape Cod, less common to NY Harbor	Leafy, deeply-lobed, to 15 cm	Subtidal in deep water southward, present 24-50 m in southwest Gulf of Maine and on Ammen Rock, central Gulf of Maine
Phyllophora spp.	Red	Delaware to subarctic, two common species	10-15 cm	Chiefly subtidal, *P. truncata* at 24-40 m in southwest Gulf of Maine and on Ammen Rock, central Gulf of Maine
Polysiphonia spp.	Red	Two species, one from New England to North Carolina, the other New England to the Caribbean	Bushy with fine filaments, up to 40 cm	Present 15-48 m in NC
Ptiloda serrata	Red	Arctic to Cape Cod, rarely and in deep water south to Long Island Sound	Bushy, main branches flat and fernlike, to 15 cm	Subtidal, on rocky substrates 24-50 m in SW Gulf of Maine and Ammen Rock
Rhodymenia palmata	Red	Long Island Sound to Arctic	Broad bladed with small stalk, to 30 cm	Lower mid-littoral to deep water
Spyridia filamentosa	Red	Cape Cod to tropics	Bushy with fine filaments, to 30 cm	20-32 m in NC, chiefly in summer

2.2.9 Mollusks, epifaunal bivalve

While many bivalve mollusks live in the sediment or bore into hard substrates, some are epifaunal, including the scallops, oysters, and mussels. In our region, three epifaunal species are commonly found offshore in deeper water, the blue mussel, *Mytilus edulis*, the horse mussel, *Modiolus modiolus*, and the Atlantic sea scallop, *Placopecten magellanicus*. Mussels and scallops are considered as two separate habitat features because of differences in attachment and factors contributing to recovery rates.

Sea scallops provide direct shelter for juvenile red hake, which can be found between the shell valves amidst the scallop's tissues. They also provide a settlement substrate for other epifauna including hydroids, bryozoans, and sponges. Mussels also provide a settlement substrate for other epifauna. All three species are solitary, but have a contagious distribution. This is particularly true of the mussels. Blue mussels occur as far south as South Carolina and are common in shallow, nearshore waters. They attach by means of byssal threads to any type of firm substrate and often form shoals or "beds," even on muddy tidal flats. They also occur on the continental shelf to depths of several hundred feet (Gosner 1978). The horse mussel is a boreal species that is reported to occur as far south as Cape Hatteras (Coen and Grizzle 2007), but may be scarce south of Cape Cod (Gosner 1978). It mainly inhabits deeper waters (to 70 meters) and most commonly occur partially buried in soft sediments, or attached by byssal threads to hard substrates where it forms clumps or extensive beds that vary in size, density, thickness, and form (ASMFC 2007). In prime habitats, blue mussels can reach full growth within a year; elsewhere 2-5 years are needed (Gosner 1978). *M. modiolus* is a long-lived species, with some individuals living for 25 years or more (ASMFC 2007). *P. magellanicus* may reach 20 years of age.

Mussels are inferred to all substrate and energy environments, while scallops are only inferred to high and low energy sand, granule-pebble, and boulder substrates.

Table 11 –Structure-forming epifaunal bivalves of the Northeast Region

Species	*Range*	*Size*	*Form*	*Habitats*
Modiolus modiolus	Circumpolar, south in NW Atlantic to New York	Largest may be >22 cm	Solitary, gregarious; attached to substrate	Muddy sand, sand, any hard substrates; adapted to live semi-infaunally; subtidal, to 70 m (280 m in Europe)
Mytilus edulis	Arctic to South Carolina	To 10 cm	Solitary, gregarious; attached to substrate	Cling to any firm substrate, form beds, even on mud; in estuaries and offshore to several hundred feet deep
Placopecten magellanicus	Labrador to Cape Hatteras	To 20 cm wide, < 2 in deep	Solitary, gregarious; adults unattached to substrate, lie "flat" on bottom, often in depressions	Generally found on firm sand, gravel, shells and cobble substrate to 180 m (deeper waters south)

2.2.10 Polychaetes – tube-dwelling

Two different tube-dwelling polychaete features are included in the assessment. *Filograna implexa* is considered as its own feature in the vulnerability assessment because of its unique clump-forming morphology. It is commonly called the lacy tube worm because it lives colonially in calicified tubes. Although many other polychaetes form calcified tubes, *F. implexa* is unusual in that it forms large clumps. These occur when individual worms divide asexually, and one worm bores out of the tube and forms a new tube adjacent to the first. *F. implexa* is found on all types of hard substrates, including shell and sand, and encrusting other organisms as well (Richards 2008). It is distributed from Newfoundland to Cape Cod at depths of 33-55 m (ten Hove et al. 2009).

A few other non-colonial tube-dwelling polychaetes also form bottom structure that could provide shelter for managed species of fish. They are known commonly as feather-duster or fanworms and are considered a separate feature from *F. implexa* in the vulnerability assessment because of differences in their morphology and life histories (see Table 12). Many common tube-dwelling polychaetes (e.g., the fanworm *Myxicola infundibulum, Sabella* spp. and *Spirorbis* spp.) either occupy tubes that do not extend above the sediment surface at all, or are found encrusting rocks and shells and, therefore, do not create shelter for juvenile fish. Two of the structure-forming species listed below (*P. reinformis* and *P. tubularia*) are found on granule-pebble pavement on the northern edge of Georges Bank, and are more abundant in deeper (90 m versus 40 meters) sites undisturbed by scallop dredging and trawling (Collie et al. 1997, 2000). Another species, *Thelepus cincinnatus*, reported to be one of three top-ranking species for biomass on Western Bank (Scotian shelf), builds tubes that can exceed 10 cm in diameter out of shell debris, granules, and bryozoans and are attached to rocks and cobbles (Kenchington et al. 2006).

Both polychaete features, *Filograna implexa* and other tube-dwelling species, were inferred to high and low energy granule-pebble, cobble, and boulder substrates.

Table 12 – Tube-dwelling polychaetes of the Northeast Region

Species	***Range***	***Size***	***Form***	***Substrate***
Filograna implexa	Newfoundland to Cape Cod	Calcified tubes several inches long	Colonial, tubes in tangled masses, twisted together	All types of hard substrates, including shell and sand
Potamilla reinformis	Eastern coast of North America from Maine to North Carolina	In leathery tubes approx 4 inches long	Solitary, attached to substrate	Rocks and shells, common fouling animals on pilings, buoys, etc.
Potamilla neglecta	Penobscot Bay south to at least Chesapeake Bay	Same as P. reinformis ?	Solitary, attached to substrate	Rocks and shells, common fouling animals on pilings, buoys, etc.
Protula tubularia	In UK, on lower shore and sublittoral zones to depths of 100 m Northwest Atlantic?	Forms a white, calcareous tube	Solitary, attached to substrate	Hard substrates such as stones and rocks
Thelepus cincinnatus	Arctic Ocean, warmer and colder parts of the Atlantic	Tough tubes made out of shell debris,	Solitary, attached to substrate	Rocks and cobbles

Species	*Range*	*Size*	*Form*	*Substrate*
		granules, etc		

2.2.11 Sponges

Sponges (phylum Porifera) are sessile animals that come in a variety of forms, colors, and sizes. Forms vary from encrusting to ball-shaped, vase-shaped, and fan-shaped. Some forms branch or even anastomose[3], others are stalked. Some sponges have calcareous skeletons (composed of spicules), but most have siliceous skeletons. The siliceous spicules of some sponges in the group Hexactinellida (glass sponges) have fused spicules providing a rigid structure. Sponges range in size from minute to in excess of one meter. They can be found on both hard and soft substrates, but hard substrates appear to be favored by a majority of species. Sponges suspension feed by pulling water through pores on their surface, and are thus very sensitive to suspended sediment.

It is thought that all sponges are likely capable of regeneration from fragments. Sexual reproduction often involves sequential hermaphroditism, although other strategies are used as well. Fertilization is typically external, although internal fertilization occurs in some species, and the larval period is short. Sponges are typically long-lived. Growth rates vary widely from fast for the annual sponges (larvae to adult in months), to much slower for the perennial sponges. There are numerous examples of symbioses between sponges and other species.

There are numerous species of sponges in the Northeast region. For the purposes of this assessment, the species of primary importance are those that are large enough that they could provide shelter for managed species of fish, especially juveniles that seek refuge from predators. Information on the geographic range (or locations where present), size, morphological form, and habitats (depth and substrates) is compiled for 12 potential structure-forming species that are found in the region (Table 13). Encrusting species or species that do not extend very far above the seafloor are not included. Information sources included Gosner (1978), the Marine Life Information Network, the Stellwagen Bank National Marine Sanctuary [on-line], the European Marine Life Network, the Marine Life Encyclopedia website, Georgia Southern University [on-line], the Chesapeake Bay Program website, Fuller et al. (1998), Stokesbury and Harris (2006), Steimle and Zetlin (2000), and Witman and Sebens (1988).

Examples of species found on Georges Bank include *Suberites ficus* (Johnston, 1842) (fig sponge), *Haliclona oculata* (Pallas, 1759) (finger sponge), *Halichondria panicea* (Pallas, 1766) (breadcrumb sponge), *Isodictya palmata* (Lamarck, 1814) (palmate sponge), *Microciona prolifera* (Ellis & Solander, 1786) (red beard sponge), and *Polymastia robusta* (Bowerbank, 1860) (encrusting sponge) (Almeida et al. 2000; Stokesbury and Harris 2006).

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[3] Anastomose – when branches reconnect to form a web or network

The larger species that inhabit deeper water are probably the most susceptible to the adverse effects of fishing. These include the large form of the boring sponge *Cliona celata*, the "bread-crumb" sponge *Halichondria panicea*, the finger sponge *Haliclona oculata*, the palmate sponge *Isodictya palmata*, *Mycale lingua*, and the fig sponge *Suberites ficus*. All of these species attach to some form of hard substrate or shell. *Suberites ficus* is very common on sandy bottom habitats on Georges Bank where it attaches to small shell fragments and provides cover for fish and crustaceans (Lindholm et al. 2004). As it grows, the substrate on which it originally attached can no longer be seen and the sponge often is rolled along the bottom by currents and wave action. The other species are more common in hard bottom habitats. Based on the available information, only two of the species – *Cliona celata* and *Haliclona oculata* – listed in Table 13 are known to occur south of southern New England (also see Van Dolah et al. 1987). This may reflect the fact that natural rocky bottom habitats are rare south of New York Harbor (Steimle and Zetlin 2000). Other structure-forming species of sponge are undoubtedly present in the Mid-Atlantic region, but are either found on the continental slope (e.g., in canyons) or on the shelf attached to gravel, scallop shells, and shell fragments in predominantly sandy habitats.

Sponges are inferred to all substrate and energy environments except high and low energy mud.

Table 13 –Structure-forming sponges of the Northeast Region

Species	*Range*	*Height*	*Form*	*Habitats*
Cliona celata	Gulf of Mexico to Long Island Sound, locally to Gulf of St. Lawrence	Up to 1 m, 60 cm diameter	Two growth forms, boring into shells and large "barrel" shape, firm with tough outer layer, embeds rocks and sediments into tissue	On rock to 200 m; begins life by boring into limestone, shells, or calcareous red algae
Halichondria panicea	Arctic south to Cape Cod, rarely beyond	Up to 30 cm	Encrusting, globular, or branched	Cobbles, boulders, bedrock, shells, algae down to 60 m (570 m in Europe), esp abundant in strong tidal flows
Halichondria parma	Range unknown, found in SW Gulf of Maine	Up to several ft in diameter	Encrusting, in many shapes with cone-shaped bulges	On rocks, pilings
Haliclona oculata	Labrador to Long Island, rarely to North Carolina, but present in Georgia	Up to 45 cm	Short stalk with flat to rounded finger-like branches, very flexible, not fragile	Sandy, rocky substrates, often attached to stones, to 150 m
Haliclona ureolus	Range unknown, found in Bay of	To 15 cm, stalk typically <half	Tubular, even bell shaped, with thin,	On rock, shell fragments, etc.

Species	*Range*	*Height*	*Form*	*Habitats*
	Fundy	body length	hard, flexible stalk	
Isodctya deichmannae	Newfoundland to Rhode Island			
Isodictya palmata	Nova Scotia to Gulf of Maine, Georges Bank	Up to 35 cm	Large, palmate with finger-like branches	Deep water on rocks, 52-70 m in sand and gravel on Georges Bank
Microciona prolifera	Nova Scotia to Florida and Texas	Up to 20 cm	At first encrusting, then forms small clumps with fingerlike branches	Shells, pilings, hard surfaces, in shallow to moderate depths (52-70 m on Georges Bank)
Mycale lingua	Range unknown, found in the Gulf of Maine	Up to 30 cm high with variable width and depth	In mounds, sometimes in erect, flattened form with base narrower than apex	Between 30-2460 m on rocky bottom
Myxilla fimbriata	Range unknown, found in GOM		mounds	
Polymastia robusta	Range unknown, found on Georges Bank, in the Gulf of Maine and southern New England	Volume of 40 cm^3	Globular with thick base, body is soft	Most common on upward facing rock or boulder tops, as deep as 2300 m (in Europe)
Suberites ficus	Arctic south to Rhode Island, possibly to Virginia	10-40 cm diameter	Variable, lobed or globular cushion, rolls over bottom if it outgrows its substrate	Attaches to rocks and to small stones, empty shells, in sandy or muddy bottom, from 15 to 200 m

3.0 Gear impacts literature review

A goal of the vulnerability assessment is to base estimates of susceptibility and recovery of features to gear impacts on the scientific literature to the extent possible. Thus, after identifying fishing gears (section 0), and key habitat features (section 2.0), the next step is to summarize the scientific literature that examines interactions between the two[4]. Studies were selected for evaluation based on their broad relevance to Northeast Region habitats and fishing gears. Synthesis papers and modeling studies are excluded from the review, but the research underlying these publications is included when relevant. Most of the studies reviewed are published as peer-reviewed journal articles, but conference proceedings, reports, and theses are considered as well. Studies that examined gear types very different from those used in the Northeast Region are not evaluated. Also, studies conducted in habitats very different from those found in the Northeast Region are not evaluated.

3.1 Methods: database and coding

A Microsoft Access database, described in detail below, was developed to organize the review and to identify in detail the gear types and habitat features evaluated by each study. In addition to identifying gear types and features, the database included fields to code for basic information about study location and related research; study design, relevance and appropriateness to the vulnerability assessment; depth and energy environment; whether recovery of features is addressed; and substrate types found in the study area. Analysts interacted with the database via a form (Figure 2). Table 14 summarizes each of the fields.

Most studies were read and coded by a single team member initially, and then the coding was reviewed by one or more additional team members at a later time. The process of coding the database was somewhat iterative, as the matrix-based approach, SASI model implementation, and literature review were developed contemporaneously. For example, each study's high/low energy coding was reviewed and updated as necessary when the depth threshold for the unstructured model grid was adjusted.

The database is intended to serve as a legacy product, so some features are coded but not used in the current analysis. For example, if prey feature susceptibility and recovery matrices are developed in the future, the database could be queried to determine the studies relevant to each S/R evaluation. The long-term intention is to create new records in the database as additional gear impacts studies are published.

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[4] For readers familiar with NOAA Technical Memorandum NMFS-NE-181, this review builds on but is distinct from that report and subsequent updates, and includes many of the same studies.

For easy reference, a list of citations by study number is provided on the last page of this document (Table 94). Nearly 100 studies are evaluated, although additional literature referenced in the previous section on feature descriptions was used in some cases to inform recovery scores, and not all of the studies are used equally to inform the matrix-based vulnerability assessment.

Figure 2 – Literature review database form. Data field descriptions provided in Table 14.

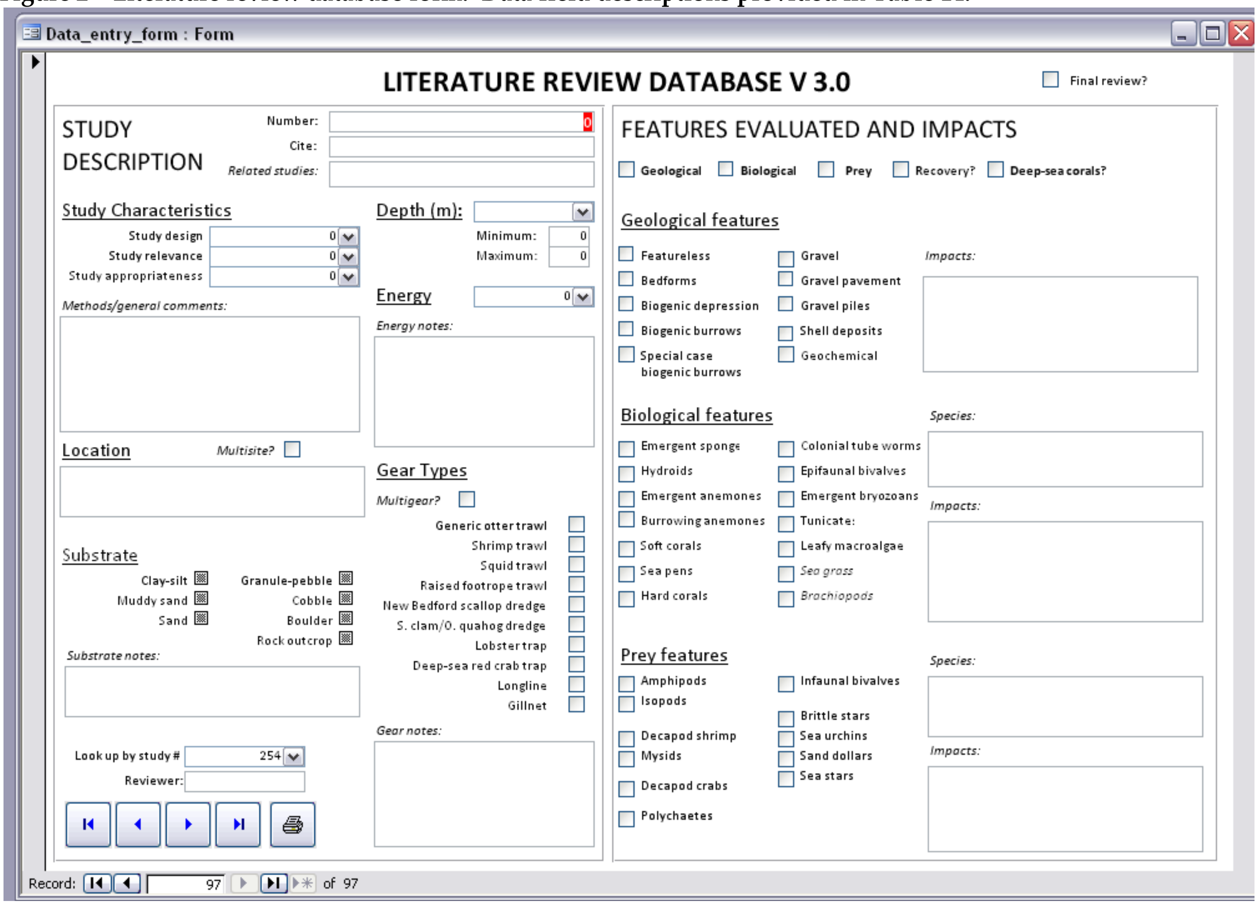

Table 14 – Literature review database fields

Database field	*Coding options*	*Purpose of coding*	*Coding guidelines*
Study design	Choice of: observational, comparative, or experimental	The design of a particular study influences the way in which analysts might interpret the results.	**Observational** refers to studies where fished sites were characterized in terms of the distribution and status of habitat features, without an unfished reference site for comparison. **Comparative** refers to studies that assessed impacts to otherwise similar fished and unfished areas. **Experimental** refers to studies that either: evaluated the experimental use of fishing gear in comparison with an unfished control, or used a before-after control-impact design to study the effects of either experimental use of fishing gear or actual fishing effort.
Study relevance	Choice of: (1) Similar gears or habitats but geographically remote study area (2) Geographically similar (though non-NE) study area, similar gears/habitats (3) Study area overlaps with NE area (incl. CA side of Georges) and uses similar gears (4) Study performed in NE area with NE gears	This field was intended to provide some indication of the types of studies considered; although the results of those receiving a higher score were weighted explicitly during evaluation of susceptibility and recovery.	All studies used or observed the effects of gears similar to those used in the Northeast U.S. in similar habitats. A score of (1) would indicate that the study met these basic criteria. A score of (4) would indicate that they study was conducted in Northeast U.S. waters and evaluated the impacts of Northeast U.S. gear types. Values of (2) and (3) fall between these two extremes.
Study appropriateness (to Vulnerability Assessment)	Choice of: study (1) tangentially supports, (2) supports, or (3) is perfectly aligned with the vulnerability assessment	This field was intended to provide some indication of how well the study fit the gear impacts/feature/substrate assessment approach. Studies with higher appropriateness values were more straightforward to incorporate into the matrix-based assessment.	Regardless of relevance, studies that specifically examine the effects of particular gear types on particular habitat components should receive the highest appropriateness values. Studies that are more general, perhaps aggregating multiple gear types or impacts, or that do not provide clear information on the substrate, depth, or energy, would receive lower values.
Gear type, multiple gear types checkbox	One or more of the following: generic otter trawl, shrimp trawl, squid trawl, raised footrope trawl, New Bedford scallop dredge, surfclam/ocean quahog dredge, lobster trap, deep-sea red crab trap, demersal longline, sink gill net	The susceptibility and recovery of features estimated in the matrix assessment was disaggregated by gear type. Therefore, an understanding of which gear types were used to create the impacts studied was key to the assessment.	Multiple gear types could be checked as applicable, with details summarized in the comments section. If the study area was subject to the impact of two or more gear types and these could not be fully distinguished, the multiple gear types checkbox was selected.

Database field	*Coding options*	*Purpose of coding*	*Coding guidelines*
Energy	Choice of: (1) high author stated, (2) high inferred, (3) low author stated, (4) low inferred, or (5) not specified	Feature recovery was assumed to vary by environmental energy, so it was important to know what type of environment a particular study occurred in.	Energy environment was determined based on the shear stress and depth criteria for high and low energy used in the SASI model
Depth	Choice of four ranges: (1) 0-50m, (2) 51-100m, (3) 101-200 m, (4) deeper than 200m	Depth information helped to determine energy environment and also relates to feature distributions.	Additional space was provided to input minimum and maximum study depths.
Location	Text box	Gives a better sense for the study environment than the relevance column alone	Space to indicate where the study was conducted.
Related studies	Text box	Allows analyst to compare results easily between studies at the same or similar sites, or to review studies done by the same or similar authors	Space to indicate if the study was directly related to other studies reviewed (i.e. a follow up study, or a similar study in the same area conducted by the same group of authors).
Recovery addressed	True/false	Estimates of recovery times were based on study results whenever possible, and absent results to draw from, on descriptions of the features themselves	'True' indicates that the study addressed the recovery of habitat components from disturbance.
Deep-sea corals	True/false	The MSRA allows for explicit protection of deep-sea corals independent of Essential Fish Habitat impacts. While some cold-water coral species are found in shallower areas and are included in the matrix-based assessment as a biological habitat component, other studies were specific to deep-sea species; this code allowed those deep-sea coral studies to be easily distinguished.	'True' indicates that the study referred to any deep-sea coral species, whether impacts to corals are evaluated separately or if they are simply mentioned as a biological habitat component in the study area. In the Northeast, deep-sea corals include five Anthozoan orders: Scleratinia (stony corals), Alcyonacea (soft corals), Antipatharia (black corals), Gorgonacea (sea fans), and Pennatulacea (sea pens).
Substrate	Choice of: clay-silt, muddy-sand, sand, granule-pebble, cobble, boulder, rock outcrop,	The spatial grid on which habitat sensitivity and fishing effort are overlaid is based on dominant (modal) substrate data, so the substrate present in a particular study area was key to determining to which grid cells the study results applied.	This section indicates when a particular substrate type was present in the study area.
Geological habitat components	True/false for overall evaluation and for each feature, 256 character text boxes for impacts	Geological habitat components indicates that fishing gear effects on non-living seafloor structures were evaluated as part of the study	'Geological' was checked when the study assessed impacts to substrate subclasses or features. Checkboxes in this section indicated when impacts to and/or recovery of specific geological habitat features were evaluated. There was an additional checkbox for geochemical effects. A text box was used to summarize gear impacts.

Database field	*Coding options*	*Purpose of coding*	*Coding guidelines*
Biological habitat components	True/false for overall evaluation and for each feature, 256 character text boxes for species and impacts	Biological habitat components indicates that fishing gear effects on living seafloor structures were evaluated as part of the study	'Biological' was checked if fishing impacts to the various biological features were studied. Checkboxes in this section indicated when impacts to and/or recovery of specific biological habitat features were evaluated. A text box was used to summarize gear impacts and another text box was used to list particular species.
Prey habitat components	True/false for overall evaluation and for each feature, 256 character text boxes for species and impacts	Prey habitat components indicates that fishing gear effects on prey were evaluated as part of the study	'Prey' was checked if prey features were mentioned in the study. Checkboxes in this section were used to indicate when impacts to and/or recovery specific prey features was evaluated. A text box was used to summarize gear impacts and another text box was used to list particular species.
General comments	256 character text box	Provide additional information to help analysts understand study design.	This section was used to note any details about gear used, provide additional information about the study methods, or to state caveats as to the usefulness of the study for the Vulnerability Assessment.

3.2 Tabular summary of literature

The tables that follow reproduce the contents of the literature review database in a format amenable to a written document. They list, by study, attributes (Table 15), gears evaluated (Table 16), physical environment (Table 17), geological features evaluated (Table 18), and biological features evaluated (Table 19). The database file itself is available upon request.

Table 15 – Study attributes. Columns shown below are described in Table 14. MS column indicates a multi-site study; MG column indicates a multi-gear study. Relevance values are coded as follows: 1 – similar gears, different habitats; 2 – similar gears, similar habitats; 3 – similar gears, overlapping habitats; 4 – Northeast gears, Northeast habitats. Appropriateness values are coded as follows: 1 – Study tangentially supports VA evaluation; 2 – Study supports VA evaluation; 3 – Study perfectly aligned with VA evaluation.

Citation	*Related studies*	*MS*	*MG*	*D*	*R*	*A*	*Summary/notes*
Asch and Collie 2007 (404)	69, 70, 71, 158	-	X	Comp	4	3	386 photos (rep 100 m^2 total) analyzed for percent cover of colonial epifauna and abundance of non-colonial organisms at shallow & deep disturbed/undisturbed sites. Good data/discussion on recovery rates of different epifaunal taxa (also see #71).
Auster et al 1996 (11)	-	X	X	Comp	4	3	Video transects in/outside SI closed area (10 yr); sonar and video observations of trawl/scallop dredge impacts (individual tows) on SB in 1993; JB site surveyed before (1987) and after (1993) trawling
Ball et al 2000 (17)	-	-	-	Comp	2	2	Exp fish at 35 m (light fishing=LF) and 70 m (heavy fishing=HF) sites, with shipwrecks used as controls; sampled 24 hr after. Both areas in prawn trawl fishing ground. Effects of exp trawling could not be evaluated.
Bergman and VanSantbrink 2000 (21)	-	-	-	Exp	2	3	Estimated mortality of large, sedentary megafauna due to damage/predation within 24-48 hrs after single trawl tows in fishing grounds, (beam trawl data not included in this summary), mortality of animals caught in net was minor
Blanchard et al 2004 (24)	-	-	-	Comp	2	2	Sampled invert megafauna and demersal fishes with a beam trawl in areas w/ 3 levels of fishing by var otter trawl types. Tested hypotheses about community-level indicators under different effort regimes. Effort data at ICES stat rectangle resolution.
Boat Mirarchi and CR Environmental 2003 (408)	409	-	-	Exp	4	2	Evaluated immediate effects of 6 replicate tows in 2 lanes at 2 locations, one heavily and one lightly trawled (HT/LT) locations, with controls, using SS sonar, grab samples, benthic dredge, and video cameras.
Boat Mirarchi and CR Environmental 2005 (409)	408	-	-	Exp	4	2	Follow up (2nd yr) to Mirarchi and CR Env 2003 (#408); additional tows (aver 1.3x per wk for 4 mos) in same lanes at two locations to evaluate temporal changes and cumulative effects, SPI camera added to sampling array
Brown et al 2005a (34)	35	-	-	Exp	2	3	Compared macrofauna in area closed for 10 yrs with an area recently reopened using divers (core samples) and video transects, also examined immediate effects of exp trawling (10 parallel tows in 4km2) at 11 stations (2 controls) in closed area
Brown et al 2005b (35)	34	-	-	Exp	2	3	Same study design (compared chronically trawled and untrawled area/exp fishing in closed area) as in #34, focus on grain size and labile carbon dist in sediments; compared trawling effects to wave disturbance.
Burridge et al 2003 (38)	Poiner et al 1998, 285	-	-	Exp	1	3	Depletion experiment, n=6 sites, 3 deep-35m, 3 shallow-20 m. Goal: achieve 90% depletion at conclusion of trials. Lack of perfect coincidence in trawls may have incr var in depletion rate - used simulations to test magnitude of this effect (see p 249 results).
Caddy 1968 (42)	-	-	-	Obs	2	2	Direct observations of gear impacts by divers attached to dredge during two 5-min tows made at 2 knots.

Citation	*Related studies*	*MS*	*MG*	*D*	*R*	*A*	*Summary/notes*
Caddy 1973 (43)	-			Obs	2	2	Submersible observations inside/outside of tow tracks 1 hr after single dredge tows
Clark and O'Driscoll 2003 (64)	541, 209	-	-	Comp	1	1	Comparison of seamounts at similar depths that are fished and unfished; developed fishing importance index to rate sites as to use by fishermen
Coggan et al 2001 (414)	--	X	-	Exp	1	2	Good discussion of trawl effects, with interesting pictures. Distinctions btwn high, med and low fishing intensity are unclear. Good info on classification of functional groups and sediments.
Collie et al 1997 (69)	70, 71, 158, 404	-	X	Comp	4	3	Benthic macrofaunal collected and counted in video transects at 4 deep and 2 shallow sites classified as disturbed (D) or undisturbed (U) by trawls and scallop dredges; data collected during two 1994 cruises using 1 m Naturalists dredge
Collie et al 2000 (70)	69, 71, 158, 404	-	X	Comp	4	3	Follow-up publication to #69 based on analysis of video images and still photos at 3 deep (80-90m) and 2 shallow (42-37m) sites, some disturbed (D) and some undisturbed by trawls and dredges
Collie et al 2005 (71)	69, 70, 158, 404	-	-	Comp	4	3	Data collected during 1994-2000 at 2 deeper sites in Canada (heavily and lightly fished, HF and LF); recovery monitored at shallower, previously disturbed US site after CAII was closed to trawling and dredging in 1995, rel to 2 sites outside CAII.
De Biasi 2004 (88)	-	-	-	Exp	1	2	14 1 hr tows in 24 hrs at each of 5 stations in an unfished area, effects evaluated rel to landward and seaward control sites after, 24/48 hrs and 1 mo after trawling with side scan sonar and box core samples
de Juan et al 2007a (89)	90	-	-	Comp	2	2	Changes in functional components of benthos analyzed rel to seasonal variability and variations in fishing intensity during 1 yr study comparing a chronically trawled location and an area closed to fishing for 20 yrs
de Juan et al 2007b (90)	89	-	-	Comp	2	1	compared diets of starfish and flatfish from fished and unfished locations to relative abundance of their prey, some study areas as de Juan et al 2007a (study #89)
DeAlteris et al 1999 (92)	-	-	-	Obs	4	2	Diver obs of persistence of hand-dug trenches and modeling of bottom hydrodynamic and sediment transport processes
Dellapenna et al 2006 (406)	-	-	-	Exp	1	2	Pre- and post-trawl sediment and water column profiling in small, heavily-fished area, 3 exp tows on 2 occasions
Drabsch et al 2001 (97)	360	-	-	Exp	2	2	Effects of 2 passes of trawl evaluated at 3 sites (2 in sand, 1 mud) in area with no trawling for 15 yrs, compared to control areas, effects on infauna assessed after 1 week (at one sand and mud site) and 3 mos (other sand site), core sampling
Engel and Kvitek 1998 (101)	-	-	-	Comp	2	2	Multi-year study comparing adjacent lightly trawled (LT) and heavily trawled (HT) areas using a submersible (video transects/still photos) and bottom grabs.
Eno et al 2001 (102)	-	X	-	Exp	2	3	Short term study. - sea pen recovery assessed. Some depths not well specified.
Fossa et al 2002 (108)	-	-	X	Obs	1	1	Two goals: estimate extent of L. pertusa reefs in Norweigen waters, and examine fishing-related impacts at some of the sites; one method found very valuable was to ask fishermen to document coral locations on charts
Freese 2001 (110)	111	-	-	Exp	2	3	Follow up to 111, examining recovery of seafloor ans sponges a year after experimental trawling
Freese et al 1999 (111)	110	-	-	Exp	2	3	Submersible obs (with control transects) 2 hr-5 days after single trawl passes, in area with little or no commerial trawling for 20 yrs - 8 trawl and 8 reference video transects
Frid et al 1999 (113)	-	-	-	Comp	2	2	Related changes in benthic fauna in a lightly trawled (LT) and heavily trawled (HT) location to low, mod, and high fishing activity and primary production over 27 yrs; organisms grouped according to predicted responses to fishing
Gibbs et al 1980 (119)	-	-	-	Exp	2	2	Grab sampling in 3 treatment sites and 1 control site prior to and imm after 1 wk of repeated exp tows before

Citation	*Related studies*	*MS*	*MG*	*D*	*R*	*A*	*Summary/notes*
							opening of fishing season, more sampling at end of season, control area not fished
Gilkinson et al 1998 (120)	120	-	-	Obs	2	3	This study was conducted in a flume tank; habitat is meant to simulate northeastern edge of Grand Banks, which would be high energy; Characterizes shell damages in 4 categories: No damage, minor damage, moderate, and major; animals were already dead
Gilkinson et al 2003 (121)	122, 123	-	-	Exp	2	3	BACI study, recovery of physical habitat features monitored 1,2 and 3 yrs after initial disturbance in previously un-dredged area on Scotian Shelf; good description of how gear fishes, rel betwn fishing and natural disturbance discussed
Gilkinson et al 2005a (122)	121, 123	-	-	Exp	2	2	BACI study, recovery of macrobenthic community monitored immediately aftrer and 1 and 2 yrs after initial disturbance in previously un-dredged area on Scotian Shelf
Gilkinson et al 2005b (123)	121, 122	-	-	Exp	2	3	Efffects of dredging on abundance of soft coral Gersemia rubiformis evaluated on Scotian shelf (see Gilkinson et al. 2003 and 2005a - based on same study).
Gordon et al 2005 (128)	192, 291, 325	-	-	Exp	2	3	Summary of research in studies 192, 291, and 325 (see them for details)
Grehan et al 2005 (136)	108, 146, 393 (NE Atlantic coral studies)	X	X	Obs	1	1	Part of Atlantic Coral Ecosystem Study. Video and sonar mapping. Magnitude of fishing effort not really quantified; evidenced from ghost gear and physical marks on seabed.
Hall et al 1990 (140)	-	-	-	Exp	2	1	Escalator dredge using water pressure to harvest razor clams in highly dynamic, shallow-water environment in Scotland.
Hall et al 1993 (141)	-	-	-	Comp	2	2	Sampled benthic infauna from a fishing ground in the North Sea using distance from a shipwreck as a proxy for changes in trawling intensity.
Hall-Spencer et al 2002 (146)	Norway sites similar to #108	X	-	Obs	2	1	Analyzed coral bycatches from two French trawlers over a two year period in W. Ireland; examined two Norweigan sites (fished/unfished) using video for coral damage
Hansson et al 2000 (149)	407, 313, 575	-	-	Exp	2	2	Exp trawling for 1 yr (2 tows/wk, 24 tows per unit area) in area closed to fishing for 6 yrs, effects evaluated during last 5 mos of experiment, 3 control and 3 treatment sites
Henry et al 2006 (157)	193, 194	-	-	Exp	2	3	12-14 tows (all in 1 day) along same trawl line in 3 consecutive yrs in closed area (10 yrs), videograb sampling of colonial epifauna before and 1-5 days after trawling each year along trawled and multiple (3) control lines.
Hermsen et al 2003 (158)	69, 70, 71, 404	-	X	Comp	4	3	Compared secondary production rates at heavily fished and lightly fished (HF/LF) sites and changes in production over time after CAII was closed to mobile, bottom-tending gear - see #71 for more details.
Hinz et al 2009 (658)	292	-	-	Exp	2	2	Quantified response of macrofaunal community along a gradient of otter trawling effort, epifauna sampled with beam trawl at 20 sites (15 sites analyzed), infauna with grab samplers
Hixon and Tissot 2007 (164)	-	-	-	Comp	2	1	Submersible obs on edges of rocky, offshore bank, 2 transects in untrawled (UT) area (183-215m) and 4 in heavily trawled (HT) area (274-361m), as evidenced by trawl tracks; densities of fish and benthic inverts
Kaiser et al 2000 (184)	-	-	X	Comp	2	1	Compared benthic communities in areas of low, medium and high fishing effort, three habitat types (depth/sediments) at each site, sampling with grab, beam trawl, and anchor dredge
Kenchington et al 2001 (192)	same site as 128, 291, 325	-	-	Exp	2	3	See #325 for description of exp design - this 3 yr study evaluated grab samples for short-term (imm after trawling) and long-term (1-2 yrs later) effects of trawling on benthic community, trawling effects dwarfed by natural decline
Kenchington et al 2005 (193)	157, 194	-	-	Exp	2	3	12-14 tows along same trawl line in one day of experimental fishing in 3 consecutive yrs in closed area (10 yrs) - compared stomach contents of 22 fish species between first 2 tows (time 1) and subsequent tows (time 2)
Kenchington et al 2006 (194)	157, 193	-	-	Exp	2	3	Same experimental design and sampling gear as Henry et al (2006) - study #157. Analysis of impacts to much broader range of epifaunal and infaunal taxa.

Citation	*Related studies*	*MS*	*MG*	*D*	*R*	*A*	*Summary/notes*
Knight 2005 (203)	-	-	-	Comp	4	2	Extent of shrimp trawling in WGOM closure prior to 2004?
Koslow et al 2001 (209)	541, 64	-	-	Comp	1	1	Good basic description of why seamounts have high biodiversity, study examined effects of trawling on benthic macrofauna, but depth and fishing effects confounded; trawl logbook data assumed accurate because vessels have VMS (?)
Koulouri et al 2005 (211)	-	-	-	Comp	1	1	Study used 3-level experimental sledge to collect hyperbenthos (small 0.5-20 mm inverts living very close to or on seabed); sledge used with and w/o groundrope (disturbed/undist) before and during trawling season in an actively fished area
Kutti et al 2005 (214)	-	-	-	Exp	2	3	Short-term effects (but recovery addressed as part of larger study); study area not fished since 1978 but adj. to fishing grounds; one transect trawled 10 times along same center line, epibenthic sled used for sampling.
Langton and Robinson 1990 (217)	-	-	-	Comp	4	2	Two sites - Jeffreys (one set of dives) and Fippennies (fishing at latter which was undist prior to study for 5-7 yr, dives before and after fishing); spp associations and densities varied at Jeff, Fipp before, Fipp after
Lindegarth et al 2000 (575)	313 ,407, 149	-	-	Exp	2	1	BACI design with multiple before and after samples (see Hansson et al 2000, study #149), area closed to shrimp trawling for 5 years
Lindholm et al 2004 (225)	228	-	X	Comp	4	2	Compared relative abundance of 7 microhabitats at 32 stations inside/outside area closed to mobile, bottom-tending gear for 4.5 yrs, video and still photos taken along transects
Link et al 2005 (228)	225	-	X	Comp	4	3	Evaluation of effects of area closures on nekton (fish) and benthic community composition in a variety of habitat types, benthos sampled with grab, still photos to quantify microhabitat dists and dist of sand ripples/dunes
MacKenzie 1982 (232)	-	-	-	Comp	4	2	Compararive study of an actively fished, recently fished, and never fished area off NJ.
Mayer et al 1991 (236)	-	-	X	Exp	4	3	Single tow of scallop dredge at 8m site/trawl at 20 m site, sediment core samples to 18 cm inside and outside drag lines the day after dragging
McConnaughey et al 2000 (238)	239	-	-	Comp	2	2	Compared abundance of epifauna caught in small-mesh trawl inside and outside area closed to trawling for ca 40 yrs
McConnaughey et al 2005 (239)	238	-	-	Comp	2	1	Analyzed mean size (wt) of 16 invert taxa in 42 paired trawl samples from inside and outside closed area
Medcof and Caddy 1971 (244)	-	-	-	Obs	3	3	SCUBA and submersible obs during and after two tows with a cage dredge in a shallow (7-12 m) coastal inlet in southern Nova Scotia
Meyer et al 1981 (245)	-	-	-	Exp	4	3	South shore of Long Island, direct obs (divers) of physical impacts during and after a single tow with a cage dredge, samples inside and outside of dredge track compared, recovery noted after 2 and 24 hrs.
Morais et al 2007 (247)	-	-	-	Obs	1	1	Submarine obs along 5 transects near head and on flanks of a canyon; occurence of large epifauna and epi-benthic organisms quantified using video
Moran and Stephenson 2000 (248)	-	-	-	Exp	2	3	Compared demersal and semi pelagic trawl effects on macrobenthos. Video surveys of benthos before/during/after 4 exp trawling events (one tow per unit area) at 2-day intervals in unexploited area
Morello et al 2005 (249)	-	-	-	Exp	2	1	
Mortensen et al 2005 (254)	-	-	X	Obs	3	2	Video survey to det dist of deepwater corals and extent of damage. 52 transects, totalling 32 km - divided into 1751 video sequences. Corals classed as intact, broken, tilted, or dead. To rep fishing effort, 5 yrs logbook data agg into 1 min sq.
Murawski and Serchuk 1989 (256)	-	-	-	Obs	4	2	Submersible obs following dredge tows at various locations on continental shelf in Mid-Atlantic Bight.

Citation	*Related studies*	*MS*	*MG*	*D*	*R*	*A*	*Summary/notes*
Nilsson and Rosenberg 2003 (407)	575, 149	-	-	Exp	2	1	Sediment Profile Images (SPI's) used to describe seabed before and after trawling in area closed to shrimp trawling for 6 yrs, using a benthic habitat quality (BHQ) index . BHQ = f(surface structures, structures in sediment, and redox potential)
Palanques et al 2001 (277)	-	-	-	Exp	1	1	7 repeated sets at 30m and 14 at 40m in unfished area, before and after changes in bottom morphology monitored with side scan sonar, also eval turbidity, sediment comp in trawl lines before and at various times after trawling
Pilskaln et al 1998 (283)	-	-	-	Obs	4	1	Focus on sediment resusp as evid by infaunal worms in sediment traps 25-35 m off bottom; ; good disc of pros and cons of fishing on bottom geochemistry, but prelim study with few specifics
Pranovi and Giovanardi 1994 (287)	-	-	-	Exp	2	1	Study conducted in a coastal lagoon (Adriatic Sea) in dredged and undredged areas where variety of clams are harvested (not surfclams), recovery monitored after 20, 40, and 60 days
Prena et al 1999 (291)	same site as 128, 192, 325	-	-	Exp	2	3	See #325 for description of exp design - this study focused on trawl bycatch and effects on epifauna (and some infauna), used epibenthic sled for sampling
Probert et al 1997 (541)	64, 209	X	-	Comp	1	1	Evaluated bycatch in hill sites and flat sites during a survey for orange roughy.
Queiros et al 2006 (292)	658,368	-	-	Exp	2	2	Evaluated effects of diff levels of chronic trawling dist on community biomass and production and comm bio size spectra at two sites (North Sea, Irish Sea); only Irish Sea results should be used due to gear types
Rosenburg et al 2003 (313)	407	X	-	Comp	2	2	Sediment Profile images to evaluate macrofaunal biomass and abundance, sediment relief, redox profile discontinuity (variation in oxidation) in 2 locations.
Sanchez et al 2000 (320)	-	-	-	Exp	2	3	Exp study in trawled area at 2 sites swept once and twice in one day, effects on infauna evaluated after 24, 72, 102, and 150 hrs
Schwinghamer et al 1998 (325)	same site as 128, 192, 291	-	-	Exp	2	3	Experimental trawling (12 tows in 3 corridors, 3-6 tows per unit area, in 5 days) in area closed to trawling 1 yr previous to study and lightly fished for ca 10 yrs, repeated for 3 yrs; this study assessed physical impacts only
Sheridan and Doerr 2005 (330)	-	-	-	Comp	2	1	Compared sediments and benthos in 2 adjacent areas, one closed to shrimp trawling for 7 mos, core samples collected by divers
Simboura et al 1998 (599)	-	-	-	Comp	2	1	Assessed the structure of the benthic communities in relation to natural and anthropogenic factors; two sites compared, one w/o fishing and one fished, results componded by differences in sediment composition
Simpson and Watling 2006 (333)	-	-	-	Comp	4	2	Block exp design comparing habitat/macrofaunal community structure in trawled and untrawled areas at 2 sites before, during, and after shrimp trawling season using video and box core samples; trawling only occurred at inshore (84m) site during study.
Smith et al 1985 (334)		-	-	Comp	4	1	Used diver obs to estimate effect of trawling on lobsters and lobster habitat (summary on page v).
Smith et al 2000 (335)	336	-	X	Comp	1	2	Compared 2 stations inside a commercial trawling lane with 2 outside, video and grab sampling for 11 mos starting before 8 mo trawling season and ending well after
Smith et al 2003 (336)	335	X	X	Exp	1	1	Sediment profile imagery used to analyze sed penetration and roughness, plus a number of sediment attributes in trawled and untrawled areas at 2 sites; exp trawling in shallow-water site (13 tows during 2days)
Sparks-McConkey and Watling 2001 (338)	-	-	-	Exp	4	3	4 tows along one line (?) in one day at 2 stations, Pen Bay closed to trawling for 20 yrs, pre-trawl sampling of sediments/infauna for 1.5 yrs before trawling at exp stations and 7 reference stations, and 5d, 3.5mo and 5 mo after trawling
Stokesbury and Harris 2006 (352)	-	-	-	Exp	4	3	BACI study (video survey) in open and closed areas on GB: exp 1 compared CAII (closed) with NLCA (open) and exp 2 compared open and closed portions of CAI
Stone et al 2005 (355)	-	-	-	Comp	2	2	Examination of 'chronic' effects of trawling on epifauna inside and outside 2 areas closed to fishing for 11-12

Citation	Related studies	MS	MG	D	R	A	Summary/notes
							years, data collected along video transects by a submersible; analysis of key taxa and functional groups (prey, sedentary, low/high mobility)
Sullivan et al 2003 (359)	-	-	-	Exp	3	2	Submersible used to conduct pre-dredge and post-dredge surveys (2d, 3mo, 1 yr after dredging) and sample infaunal prey of YT flounder at 3 sites (2 deeper sites in Hudson Canyon closed area), multiple control and dredge treatments at each site
Tanner 2003 (360)	97	-	-	Exp	2	2	Anaysis of video images of sessile epifauna in treatment and control quadrats before and 1 wk/3 mos after trawling (2 tows) in 1 mud site and 2 sand sites in unfished area (15-20 yrs). Recruitment of major taxa also monitored - very good paper!
Tillin et al 2006 (368)	292	X	X	Comp	2	2	Large scale/long term impact of varying trawling intensity on functional composition of benthic invertebrate communities. Life-history based, multivariate assessment; large spatial scale study that fits well with feature-based approach
Tuck et al 1998 (372)	-	-	-	Exp	2	2	Repeated tows (10 tows, aver 1.5/unit area) 1d/mo for 16 mos in area closed to fishing for >25 yrs, infaunal surveys in trawled and ref site prior to, and after 5,10,16 mos of trawling, and 6,12,18 mos after trawling ended
Tuck et al 2000 (373)	-	-	-	Exp	2	1	Samples collected inside and outside of dredge tracks, recovery evaluated after 1 day, 5 days, and 11 wks, cage dredge designed to harvest razor clams, study site in Outer Hebrides (Scotland)
Van Dolah et al 1987 (382)	-	-	-	Exp	1	2	Diver counts of large sponges and corals (>10 cm high) in trawled and untrawled transects before, imm after, and 12 mos after a single tow in an unexploited area
Wassenberg et all 2002 (387)	-	-	-	Exp	2	1	Survey to determine depth/spatial dist of sponges, also quantified catch and damage of sponges and soft corals using a video camera in the net (McKenna demersal wing trawl) during 6 indiv trawl tows - net not used in NE region.
Watling et al 2001 (391)	-	-	-	Exp	1	2	Very shallow river-estuary. Maybe best example of gear impacts on completely undistrurbed muddy river bed. Divers collected bottom samples in control and exp plots before, imm after, and 4/6 mo after dredging (23 tows in 1 day)
Wheeler et al 2005 (393)	108, 136, 146	-	-	Comp	0	0	Seabed mapping with side scan sonar. Still, video imagery of trawled and untrawled mounds to id benthic organisms, estimate % coral cover.

Table 16 – Gears evaluated, by study. Note that all trawl types and both trap types were grouped for the matrix-based assessment.

Citation	***Generic otter trawl***	***Shrimp trawl***	***Squid trawl***	***Raised footrope trawl***	***Scallop dredge***	***Hydraulic dredge***	***Lobster trap***	***Deep-sea red crab trap***	***Longline***	***Gillnet***	***Gear notes***
Asch and Collie 2007 (404)	X	-	-	-	X	-	-	-	-	-	Scallop and otter trawl effort overlapping in study area.
Auster et al 1996 (11)	X	-	X	-	X	-	-	-	-	-	Impacts of single dredge and trawl tows observed on SB and at SI
Ball et al 2000 (17)	-	-	X	-	-	-	-	-	-	-	Exp Nephrops trawl with a light tickler chain.
Bergman and VanSantbrink 2000 (21)	X	-	-	-	-	-	-	-	-	-	Comm flatfish trawl, 20 cm rollers
Blanchard et al 2004 (24)	X	-	-	-	-	-	-	-	-	-	-
Boat Mirarchi and CR Environmental 2003 (408)	X	-	-	-	-	-	-	-	-	-	Smooth bottom (flatfish) trawl: 350 kg doors, 2.5 in rubber cookies on ground cables/bridles, sweep 0.5 in chain with continuous string of 6 in cookies
Boat Mirarchi and CR Environmental 2005 (409)	X	-	-	-	-	-	-	-	-	-	Two vessels used for exp trawling using flatfish trawls (see #408),area trawled/dredged between yr 1 and yr 2 of study
Brown et al 2005a (34)	X	-	-	-	-	-	-	-	-	-	Victory trawl, footrope rigged w 36 cm rubber diks, 13 cm rubber disks on bottom bridle and sweep lines, high lift doors 5.5 m2 weighing 1250 kg in water.
Brown et al 2005b (35)	X	-	-	-	-	-	-	-	-	-	Same gear as study 34.
Burridge et al 2003 (38)	-	-	X	-	-	-	-	-	-	-	Gear: a single 12-fathom (21.9 m) “Florida Flyer” prawn (=shrimp) trawl with a ground chain. Possible illegal fishing in closed area, but authors deemed unlikely based on distance offshore/uncharted waters (conf by Gribble and Robertson 1998).
Caddy 1968 (42)	-	-	-	-	X	-	-	-	-	-	2.4 meter wide chain-sweep dredge modified to reduce weight (forward drag bars replaced with chains)
Caddy 1973 (43)	-	-	-	-	X	-	-	-	-		2.4 m wide chain-sweep dredge
Clark and O'Driscoll 2003 (64)	X	-	-	-	-	-	-	-	-	-	-
Coggan et al 2001 (414)	X	X	X	X	-	-	-	-	-	-	-
Collie et al 1997 (69)	X	-	-	-	X	-	-	-	-	-	Authors note there was a gradient in dredging disturbance from least dist to most dist sites; degree of dist based on SS sonar evidence of gear tracks, video obs of epifauna, and VTR data of scallop dredging by TNMS in US waters
Collie et al 2000 (70)	X	-	-	-	X	-	-	-	-	-	See #69
Collie et al 2005 (71)	X	-	-	-	X	-	-	-	-	-	Fishing patterns (trawl and dredge) at study sites based on US and Canadian logbook data, VMS data for US scallop vessels
De Biasi 2004 (88)	X	-	-	-	-	-	-	-	-	-	Trawl gear - footrope with 1 kg lead weights (no chains), 2 oval, iron doors weighing 250 kg each; parallel tows spaced 160 m apart
de Juan et al 2007a (89)	X	-	-	-	-	-	-	-	-	-	-
de Juan et al 2007b (90)	X	-	-	-	-	-	-	-	-	-	-
DeAlteris et al 1999 (92)	X	-	-	-	-	-	-	-	-	-	combined gear used in area 95% trawl, 5% mussel dredge

Citation	Generic otter trawl	Shrimp trawl	Squid trawl	Raised footrope trawl	Scallop dredge	Hydraulic dredge	Lobster trap	Deep-sea red crab trap	Longline	Gillnet	Gear notes
Dellapenna et al 2006 (406)	-	X	-	-	-	-	-	-	-	-	1.5 x 2.5 m >50kg doors, tickler chain on footrope
Drabsch et al 2001 (97)	-	-	X	-	-	-	-	-	-	-	Triple prawn (shrimp) trawl with chain sweeps, each door 1x2 m/200 kg - more approp for squid trawl evaluation?
Engel and Kvitek 1998 (101)	X	-	-	-	-	-	-	-	-	-	HT area fished commercially for >100 yrs and exposed to 12 x more trawling than LT area which is inside 3 mi no trawling zone, but was open in one yr as a "refuge site" in bad weather
Eno et al 2001 (102)	-	-	-	-	-	-	X	-	-	-	Gear: pots (H. gammarus, C. pagurus, B. undatum); creels (N. norvegicus).
Fossa et al 2002 (108)	X	-	-	-	-	-	-	-	X	X	-
Freese 2001 (110)	X	-	-	-	-	-	-	-	-	-	-
Freese et al 1999 (111)	X	-	-	-	-	-	-	-	-	-	60 cm rubber tires at center of footrope, 45 cm rockhopper/steel bobbins on wings, trawl similar to those used in rockfish fishery
Frid et al 1999 (113)	-	-	X	-	-	-	-	-	-	-	Deep water site located in prawn trawl fishing ground
Gibbs et al 1980 (119)	-	-	X		-	-	-	-	-	-	Prawn trawl with 1 x 0.5 m flat doors
Gilkinson et al 1998 (120)	X	-	-	-	-	-	-	-	-	-	-
Gilkinson et al 2003 (121)	-	-	-	-	-	X	-	-	-	-	-
Gilkinson et al 2005a (122)	-	-	-	-	-	X	-	-	-	-	-
Gilkinson et al 2005b (123)	-	-	-	-	-	X	-	-	-	-	-
Gordon et al 2005 (128)	X	-	-	-	-	-	-	-	-	-	Otter trawl with rock hopper gear.
Grehan et al 2005 (136)	X	-	-	-	-	-	-	X	X	X	Typical gears described on p 820.
Hall et al 1990 (140)	-	-	-	-	-	X	-	-	-	-	-
Hall et al 1993 (141)	X	-	-	-	-	-	-	-	-	-	-
Hall-Spencer et al 2002 (146)	X	-	-	-	-	-	-	-	-	-	-
Hansson et al 2000 (149)	-	X	-	-	-	-	-	-	-	-	Commercial shrimp trawl with leaded ground rope and 125 kg doors
Henry et al 2006 (157)	X	-	-	-	-	-	-	-	-	-	Rockhoppers on footrope
Hermsen et al 2003 (158)	X	-	-	-	X	-	-	-	-	-	-
Hinz et al 2009 (658)	X	-	X	-	-	-	-	-	-	-	Nephrops and gadid trawl fisheries, trawling intensity ranged from 1.3 to 18.2 times trawled/yr, area fished for >100 yrs
Hixon and Tissot 2007 (164)	X	-	-	-	-	-	-	-	-	-	-
Kaiser et al 2000 (184)	X	-	-	-	-	-	X	-	-	-	Fishing effort defined as low=pots only, medium=seasonal trawl use, high=trawling year-round
Kenchington et al 2001 (192)	X	-	-	-	-	-	-	-	-	-	See #325
Kenchington et al 2005 (193)	X	-	-	-	-	-	-	-	-	-	Rockhopper gear.

Citation	*Generic otter trawl*	*Shrimp trawl*	*Squid trawl*	*Raised footrope trawl*	*Scallop dredge*	*Hydraulic dredge*	*Lobster trap*	*Deep-sea red crab trap*	*Longline*	*Gillnet*	*Gear notes*
Kenchington et al 2006 (194)	X	-	-	-	-	-	-	-	-	-	See p. 252 for info re how often grab-sampled locations were swept by trawl (average 4-8 times yrs 1-2 by some part of trawl, 1-4 x just rock hoppers and net)
Knight 2005 (203)	X	-	-	-	X	-	-	-	-	-	-
Koslow et al 2001 (209)	X	-	-	-	-	-	-	-	-	-	-
Koulouri et al 2005 (211)	X	-	-	-	-	-	-	-	-	-	-
Kutti et al 2005 (214)	X	-	-	-	-	-	-	-	-	-	Gear: commercial trawl equipped with 2300 kg otter boards and 21 in rockhoppers.
Langton and Robinson 1990 (217)	-	-	-	-	X	-	-	-	-	-	-
Lindegarth et al 2000 (575)	-	X	-	-	-	-	-	-	-	-	Detailed description of gear in Hansson et al (2000)
Lindholm et al 2004 (225)	X	-	-	-	X	-	-	-	-	-	Open area impacted by bottom trawls and scallop dredges
Link et al 2005 (228)	X	-	-	-	X	-	-	-	-	-	-
MacKenzie 1982 (232)	-	-	-	-	-	X	-	-	-	-	-
Mayer et al 1991 (236)	X	-	-	-	X	-	-	-	-	-	Trawl footrope with tickler chain and 90 kg doors
McConnaughey et al 2000 (238)	X	-	-	-	-	-	-	-	-	-	Flatfish Trawl used for Yellowfin sole.
McConnaughey et al 2005 (239)	X	-	-	-	-	-	-	-	-	-	-
Medcof and Caddy 1971 (244)	-	-	-	-	-	X	-	-	-	-	-
Meyer et al 1981 (245)	-	-	-	-	-	X	-	-	-	-	-
Morais et al 2007 (247)	-	X	X	-	-	-	-	-	-	-	Area heavily fished by crustacean trawlers (shrimp, prawns), but mostly outside canyon (<200m?)
Moran and Stephenson 2000 (248)	X	-	-	X	-	-	-	-	-	-	"Light" bottom trawl, 20 cm diameter disks separated by 30-60 cm long spacers of 9 cm diameter on footrope (may have lifted over some benthic organisms w/o removing them)
Morello et al 2005 (249)	-	-	-	-	-	X	-	-	-	-	-
Mortensen et al 2005 (254)	X	-	-	-	-	-	-	-	X		-
Murawski and Serchuk 1989 (256)	-	-	-	-	-	X	-	-	-	-	-
Nilsson and Rosenberg 2003 (407)	-	X	-	-	-	-	-	-	-	-	-
Palanques et al 2001 (277)	X	-	-	-	-	-	-	-	-	-	Fishing done by two commercial trawlers - lead weights in footropes

Citation	*Generic otter trawl*	*Shrimp trawl*	*Squid trawl*	*Raised footrope trawl*	*Scallop dredge*	*Hydraulic dredge*	*Lobster trap*	*Deep-sea red crab trap*	*Longline*	*Gillnet*	*Gear notes*
Pilskaln et al 1998 (283)	X	-	-	-	-	-	-	-	-		-
Pranovi and Giovanardi 1994 (287)	-	-	-	-	-	X	-	-	-		-
Prena et al 1999 (291)	X	-	-	-	-	-	-	-	-		See #325
Probert et al 1997 (541)	X	-	-	-	-	-	-	-	-		O. roughy trawl has 600 mm steel bobbins.
Queiros et al 2006 (292)	X	-	X	-	-	-	-	-	-		Beam trawls used on Dogger Bank, otter trawls in Irish Sea (Nephrops fishery).
Rosenburg et al 2003 (313)	X	-	-	-	-	-	-	-	-		Exp fishing in fjord (site a) - see #407- data collected at 4 locations at site b exposed to unknown levels of fishing, no controls
Sanchez et al 2000 (320)	X	-	-	-	-	-	-	-	-		No info
Schwinghamer et al 1998 (325)	X	-	-	-	-	-	-	-	-		Engel 145 bottom trawl with 1250 kg doors and 46 cm rockhopper gear
Sheridan and Doerr 2005 (330)	-	X	-	-	-	-	-	-	-		-
Simboura et al 1998 (599)	X	-	-	-	-	-	-	-	-		Gear types fishing in Petalioi not well specified (=bottom trawlers).
Simpson and Watling 2006 (333)	-	X	-	-	-	-	-	-	-		
Smith et al 1985 (334)	X	-	-	-	-	-	-	-	-		Gear: otter trawl with 1.8 m door and 1 cm footrope chain.
Smith et al 2000 (335)	X	X	-	-	-	-	-	-	-		Commercial fishing for hake and shrimp (no description of gear)
Smith et al 2003 (336)	X	X	-	-	-	-	-	-	-		Commercial fishing for hake and shrimp at 200 m, no description of trawl used for exp fishing at shallow-water site
Sparks-McConkey and Watling 2001 (338)	-	X	-	-	-	-	-	-	-		Modified commercial silver hake net (increased mesh size and decreased diameter of float rollers) to reduce impacts to seafloor (to mimic impacts of shrimp trawl)
Stokesbury and Harris 2006 (352)	-	-	-	-	X	-	-	-	-		-
Stone et al 2005 (355)	X	-	-	-	-	-	-	-	-		Site 1 open area for trawling and scallop dredging, site 2 just for trawls (?)
Sullivan et al 2003 (359)	-	-	-	-	X	-	-	-	-		Impact "boxes" thoroughly dredged with paired NB-style dredges (4.6 m wide, 89mm ring size)
Tanner 2003 (360)	-	X	X	-	-	-	-	-	-		Triple prawn (shrimp) trawl with chain sweeps, each door 1x2 m/200 kg - more approp for squid trawl evaluation?
Tillin et al 2006 (368)	X	-	X	-	-	-	-	-	-		Beam trawls used in southern North Sea, OT in north (FG and LF fishing grounds) for Nephrops and gadoids, low energy for prawn trawls (mud), high for OT (sand, gr-p)
Tuck et al 1998 (372)	X	-	-	-	-	-	-	-	-		No net (??), modified rockhopper ground gear
Tuck et al 2000 (373)	-	-	-	-	-	X	-	-	-		-

Citation	*Generic otter trawl*	*Shrimp trawl*	*Squid trawl*	*Raised footrope trawl*	*Scallop dredge*	*Hydraulic dredge*	*Lobster trap*	*Deep-sea red crab trap*	*Longline*	*Gillnet*	*Gear notes*
Van Dolah et al 1987 (382)	X	-	-	-	-	-	-	-	-	-	"Roller" trawl with 30 cm rubber rollers on footrope separated by 15 cm rubber discs
Wassenberg et all 2002 (387)	X	-	-	-	-	-	-	-	-	-	Groud gear with 60/80 mm diameter bobbins or rubber discs and lead weights, suspended by drop chains from footrope, allowing leading part of net to clear bottom
Watling et al 2001 (391)	-	-	-	-	X	-	-	-	-	-	2 meter wide chain-sweep dredge towed at 2 knots
Wheeler et al 2005 (393)	X	-	-	-	-	-	-	-	-	-	-

Table 17 – Study environment. For the matrices, the following categories were combined to designate studies belonging in particular cells: If energy was listed as high, high-inferred, both, or unknown, the study was added to the high energy column; similarly, low, low-inferred, both, or unknown was added to the low energy column. For substrate, clay-silt and muddy sand were assigned to mud; muddy sand and sand were assigned to sand. Rock outcrop was assigned to boulder.

Citation	*Location*	*Energy*	*Energy notes*	*Depth range*	*Clay-silt*	*Muddy sand*	*Sand*	*Granule-pebble*	*Cobble*	*Boulder*	*Rock outcrop*	*Substrate notes*
Asch and Collie 2007 (404)	Northern Edge (in and around Closed Area II), Eastern Georges Bank, US/CAN	High	All sites high energy, author's notes confirmed by output of critical shear stress model	42-90				X	X			Only examined sites dominated by gravel substrate (as identified by Valentine et al 1993)
Auster et al 1996 (11)	Gulf of Maine: Swans Island (SI), Jeffreys Bank (JB), Stellwagen Bank (SB)	High	SI - 30-40m; JB - 94; SB - 20-55m; high energy at SB and SI, low at JB	20-94	X		X	X	X	X		SI - sand, cobble, shell; JB - mud draped gravel and large boulders; SB - gravel, sand, shell
Ball et al 2000 (17)	Irish Sea	Both	Deeper site low energy, shallow site high energy (?)	35-75	X	X						Sandy silt at deeper site (44% fine sand, 55% silt-clay), muddy sand at shallow site (55/40%).
Bergman and VanSantbrink 2000 (21)	Southern North Sea, Dutch Coast	High, inf	inferred from depth and location	20-45		X	X					Silty sand (offshore, <30-40m) and sand (inshore, 40-50m), silty sand 3-10% silt
Blanchard et al 2004 (24)	Bay of Biscay, France	Low, inf	Low, based on depth - samples collected around 100 m to "avoid strong natural disturbances"	106-129	X	X	X					Mud (muddy sand and sandy mud (10-35% silt)) sampled with Reineck corer
Boat Mirarchi and CR Environmental 2003 (408)	Gulf of Maine, MA coast	High, inf	inferred based on shallow depth	36-48		X	X					HF - muddy sand; LF - sand
Boat Mirarchi and CR Environmental 2005 (409)	Gulf of Maine, MA coast	High	inferred based on shallow depth; description of site as high natural disturbance, storm prior to last sampling date (Nov) eroded finer sediments and created sand waves	36-48		X	X					See #408: shallow (36m) site sand, deeper site (48m) muddy sand
Brown et al 2005a (34)	Bristol Bay, eastern Bering Sea	High	Persistent wave disturbance to study area (see Brown et al 2005b, which modeled energy)	20-30		X	X					Fine sand
Brown et al 2005b (35)	Bering Sea	High	modeled wave energy of seabed	20-30		X	X					

Citation	*Location*	*Energy*	*Energy notes*	*Depth range*	*Clay-silt*	*Muddy sand*	*Sand*	*Granule-pebble*	*Cobble*	*Boulder*	*Rock outcrop*	*Substrate notes*
Burridge et al 2003 (38)	A large closed area in the Far Northern Great Barrier Reef off Queensland, Australia. Towed in lagoon/shoal area between mainland and reef. Used prev BACI study to choose tow sites w/ typical sponge, gorgonian, coral fauna, but avoid reefs.	High, inf	Inferred based on depth.	20-35			X	X				Assumed. However, Poiner et al show substantial variation in sed comp and biol comm in same area.
Caddy 1968 (42)	Northumberland Strait, Gulf of St. Lawrence, CAN	High, inf	Tidal currents up to 0.7 knots	20-20	X	X	X					substrate patchy with mud and sand areas
Caddy 1973 (43)	Chaleur Bay, Gulf of St. Lawrence, CAN	High, inf	Energy inferred from depth	40-50			X	X	X	X		Gravel over sand, with occ boulders
Clark and O'Driscoll 2003 (64)	New Zealand seamounts - N Chatham Rise, Graveyard Hills (one heavily fished one lightly fished per seamount)	Low, inf	low based on depth	748-1100								
Coggan et al 2001 (414)	Clyde Sea and Aegean Sea	Low, inf	Clyde Sea site depths ranged 30-100 m, water column remains stratified much of year; Aegean Sea sites 70-250 m	30-250	X	X	X					Clyde Sea -mud, muddy-sand, or sandy-mud at all depths; Aegean Sea - sand/maerl at shallower depths, mud at deeper depths
Collie et al 1997 (69)	Eastern Georges Bank (US and Canada)	High	All sites high energy, author's notes confirmed by output of critical shear stress model	42-90			X	X	X	X		pebble-cobble pavement with some overlying sand, <5% scattered boulders create obstacles to fishing
Collie et al 2000 (70)	Eastern Georges Bank (US and Canada)	High	All sites high energy, author's notes (in #69) confirmed by output of critical shear stress model	42-90			X	X	X	X		pebble-cobble pavement with some overlying sand and scattered boulders (see #69)
Collie et al 2005 (71)	Eastern Georges Bank (US and Canada)	High	All sites high energy, author's notes (in #69) confirmed by output of critical shear stress model	47-84			X	X	X	X		pebble-cobble pavement with some overlying sand and boulders (see #69,70)
De Biasi 2004 (88)	Tyrrhenian Sea, Mediterannean	Unk	energy regime not described - discussion alludes to expectation of quick recovery in shallow-water disturbed environments	32-34	X							
de Juan et al 2007a (89)	Coast of Spain, Mediterranean Sea	Low, inf	study done in same area as Palanques et al (2001) and near Gulf of Lions, where mud sediment at this depth was in low energy portion of shelf	30-80	X							95% muddy sediment

Citation	*Location*	*Energy*	*Energy notes*	*Depth range*	*Clay-silt*	*Muddy sand*	*Sand*	*Granule-pebble*	*Cobble*	*Boulder*	*Rock outcrop*	*Substrate notes*
de Juan et al 2007b (90)	Coast of Spain, Mediterranean Sea	Low, inf	study done in same area as Palanques et al (2001) and near Gulf of Lions, where mud sediment at this depth was in low energy portion of shelf	30-80	X							-
DeAlteris et al 1999 (92)	Naraganett Bay, Rhode Island, USA	High, inf	Inferred based on depth	7-14	X		X					Sand at 14 m, mud at 7 m
Dellapenna et al 2006 (406)	Galveston Bay, Texas, USA	High, inf	Inferred based on depth: episodic high energy, re wind/weather; very shallow 2-3 m	2-3	X							-
Drabsch et al 2001 (97)	Gulf of St Vincent, S. Australia	Low, inf	Depths >20m in central gulf, GSV protected from high wave activity by large,offshore island, depositional environment (see Tanner et al 2003, study #360)	20-20	X		X					Medium-coarse sand and shell fragments at sites 1 and 3, fine silt at site 2, all sites at same depth
Engel and Kvitek 1998 (101)	Monterey Bay Natl Marine Sanctuary, central California, USA	Low, inf	Inferred based on depth	180-180	X		X	X	X	X		No signif difference in pct comp of any grain size category between areas
Eno et al 2001 (102)	Great Britain: (a) off Scotland (B) Lyme Bay (c) Greenala Point	Unk	Depths (A) - uncertain, but divable (B,C) - no deeper than 23 m. Energy - examining norway lobster fishery; spp lives in soft mud - but depths are rel. shallow, so coded as unknown.	-	X				X	X	X	Clay-silt substrate described as "soft mud".
Fossa et al 2002 (108)	Off west Norway	Low, inf	Most corals dist between 200-400 m	200-400						X	X	Corals most common on 'substrate of morainic origin' - not sure if this indicates rock outcrops or gravel piles
Freese 2001 (110)	Gulf of Alaska	Low, inf	Inferred based on depth	206-274				X	X	X		93% pebble, 5% cobble, 2% boulder
Freese et al 1999 (111)	Gulf of Alaska	Low, inf	Inferred based on depth	206-274				X	X	X		93% pebble, 5% cobble, 2% boulder - occ in large piles
Frid et al 1999 (113)	North Sea (NE England)	Both	Shallow site high, deep site low??? No info in paper	55-80	X		X					55 m site (Station M1) has 20% silt clay; 80 m site has > 50% silt clay, of which 20% is faecal pellets - both sites have brittle-star dominated community
Gibbs et al 1980 (119)	Botany Bay, New South Wales, Australia	High, inf	Inferred based on location (a shallow estuary) although no specific depth given	-		X						Sand with 0-30% silt-clay

Citation	*Location*	*Energy*	*Energy notes*	*Depth range*	*Clay-silt*	*Muddy sand*	*Sand*	*Granule-pebble*	*Cobble*	*Boulder*	*Rock outcrop*	*Substrate notes*
Gilkinson et al 1998 (120)	flume tank to sim Grand Banks off Newfoundland	High	Simulated habitat in a flume tank	-			X					-
Gilkinson et al 2003 (121)	Scotian Shelf	Low	low energy zone (defined by Amos and Fader 1988); adjacent Eastern Shoal is high energy	70-80			X					Sand with shell deposits
Gilkinson et al 2005a (122)	Scotian Shelf	Low	same site as study 121	70-80			X					Sand with shell deposits
Gilkinson et al 2005b (123)	Scotian Shelf	Low	same site as study 121	70-80			X					-
Gordon et al 2005 (128)	Grand Banks off Newfoundland	Low	sediment thought to be below depth of wave induced sediment transport (Amos and Judge 1991 cited by authors))	120-146			X					-
Grehan et al 2005 (136)	NE Atlantic - carbonate mounds in Irish Porcupine Seabight and Rockall Trough	Low, inf	current speeds > 40 cm/s close to mounds	500-1200								-
Hall et al 1990 (140)	Loch Garloch, Scotland	High		7-7			X					Fine sand
Hall et al 1993 (141)	North Sea	Unk		80-80			X					-
Hall-Spencer et al 2002 (146)	off West Ireland and off West Norway	Low, inf	Also shallower sites (200 m) W. Norway	840-1300								-
Hansson et al 2000 (149)	Fjord off W. Sweden	Low, inf	bottom water described as stagnant; turns over in spring; assumed low energy from setting, depth, and substrate	75-90	X							substrate features not described
Henry et al 2006 (157)	Western Bank (Scotian Shelf)	High		70-70			X	X	X	X		Pebbles/cobbles overlaying medium to gravelly sand with some sand and boulders
Hermsen et al 2003 (158)	N. Edge Georges Bank, US/CAN sides	High	All sites high energy, author's notes (in #69) confirmed by output of critical shear stress model	47-90			X	X	X	X		pebble-cobble pavement with some overlying sand and boulders
Hinz et al 2009 (658)	Northeastern Irish Sea off the Cumbrian coast (same area as #292)	High, inf	shear stress at 15 sites that were analyzed averaged 0.21 N/m2 (based on 2D hydrographic model): 0.21 N/m2 is moderate energy	31-31	X	X						mostly fine sand and muddy sediment deposits, average 67% (+-14%) silt and clay at 15 analyzed sites
Hixon and Tissot 2007 (164)	Oregon Coast, USA (Coquille Bank)	Low, inf	inferred by depth - authors describe "minimal water motion" in study area	183-361	X							-

Citation	*Location*	*Energy*	*Energy notes*	*Depth range*	*Clay-silt*	*Muddy sand*	*Sand*	*Granule-pebble*	*Cobble*	*Boulder*	*Rock outcrop*	*Substrate notes*
Kaiser et al 2000 (184)	South Devon Coast, England	High, inf	one inshore site (15-18 m), two offshore (53-70 m), deeper sites "less likely" to be affected by wave action, but assumed high energy given depth and exposure	15-70			X					discriminated between fine, medium/fine, coarse/medium sand; also stone (size not specified) at deeper sties and shell debris at all sites
Kenchington et al 2001 (192)	Grand Banks, Newfoundland, CAN	Low	See #325	120-146			X					See #325
Kenchington et al 2005 (193)	Western Bank (Scotian Shelf)	High	See 194	70-70			X	X	X			Pebbles/cobbles overlaying medium to gravelly sand
Kenchington et al 2006 (194)	Western Bank, Scotian Shelf	High	"Moderate levels of natural dist with major perturbations induced by storms, esp in winter"	70-70			X	X	X	X		Pebbles/cobbles overlaying medium to gravelly sand with some sand and boulders
Knight 2005 (203)	Gulf of Maine	Low, inf	defined based on depth and shear stress model	100-130	X	X	X	X				-
Koslow et al 2001 (209)	South of Tasmania	Low, inf	deep water	714-1580								-
Koulouri et al 2005 (211)	Crete, Mediterannean Sea	Unk		50-50	X							-
Kutti et al 2005 (214)	Barents Sea, Norway; 9 nm west of Bear Island	Low, inf	Inferred based on depth	85-101			X		X	X		bottom substrate at site is dom by shell debris mixed to varying degrees with finer sed, agg of boulders at several locations
Langton and Robinson 1990 (217)	Jeffreys and Fippennies Ledges, Gulf of Maine, USA	Low, inf	defined by depth and shear stress estimates	80-100		X	X	X	X	X		Grain size analysis on Fipp showed that 84% of sediment to 5 cm was sand, with some gravel; shell hash, small rocks also present
Lindegarth et al 2000 (575)	Gullmarsfjorden, Sweden-	Low, inf	inferred from depth and sediment type	75-90	X							study area is described in Hansson et al (2000)
Lindholm et al 2004 (225)	Eastern Georges Bank - southern part of Closed Area II	High, inf	coded as high energy, but lower influence of tidal and storm driven currents at deeper stations as compared to shallower stations	40-95			X					Microhabitats all sandy, gravelly sand, or shell fragments with and w/o emergent epifauna
Link et al 2005 (228)	Closed Area I and southern part of Closed Area II, Georges Bank, USA	High	CAI (55-110m) exposed to strong storm/tidal currents, CAII (35-90m) higher energy in shallower, NW portion of study area, but all impacted by intermittent storm currents	35-90		X	X	X	X			CAI divided into 3 zones based on energy and substrates, CA II into 2 zones; substrate highly variable in CAI, sand in CAII

Citation	*Location*	*Energy*	*Energy notes*	*Depth range*	*Clay-silt*	*Muddy sand*	*Sand*	*Granule-pebble*	*Cobble*	*Boulder*	*Rock outcrop*	*Substrate notes*
MacKenzie 1982 (232)	East of Cape May, NJ, USA	High, inf	No indication of energy regime, only depth -	37-37			X					Very fine to medium sand
Mayer et al 1991 (236)	Gulf of Maine, Coastal ME, USA	High, inf	8 m site in a channel among coastal islands, well flushed by tidal currents. 20 m site protected from open ocean waves by rock ledge	8-20	X							8m site poorly sorted mud with abundant shell hash, 20m site fine-grained mud. Sand and mud below sediment surface at 8m.
McConnaughey et al 2000 (238)	Eastern Bering Sea, AK, USA	High	Site in similar location as compared to studies 34, 35; author describes site as 'high tidal currents'	44-52			X					Sand with ripples
McConnaughey et al 2005 (239)	Bristol Bay, Eastern Bering Sea, AK, USA	High	Site in similar location as compared to studies 34, 35; author describes site as 'high tidal currents', Flow >1m/s	44-52			X					Same study area as #238
Medcof and Caddy 1971 (244)	Southern Nova Scotia, CAN	High, inf	inferred based on shallow depth	7-12		X	X					-
Meyer et al 1981 (245)	Long Island, NY, USA	High, inf	inferred based on depth	11-11		X	X					Fine to medium sand covered by silt layer
Morais et al 2007 (247)	Canyon south of Portugal	Low		120-286	X	X	X	X		X	X	Multiple substrates
Moran and Stephenson 2000 (248)	Northwest Australia	High, inf	high energy inferred from depth (see study #387	50-55			X	X				Sand and gravel INFERRED, but not stated explicitly
Morello et al 2005 (249)	Coastal Adriatic Sea, heavily dredged for bivalve Chamelea gallina	High, inf	inferred based on depth	6-6			X					-
Mortensen et al 2005 (254)	Northeast Channel, Nova Scotia, Between Georges Bank and Browns Bank	High, inf	Strong currents, 40-50 cm/s 16 m off bottom	190-500		X	X	X				Thick till - unstrat glacial dep with mix of gravel, sand, silt, clay; % cover of subst types est for each video sequence
Murawski and Serchuk 1989 (256)	Mid-Atlantic Bight, USA	High, inf	No info re depths or energy levels. High inferred - most shellfish resources shallower than depth threshold in spatial model?	-	X	X	X	X				-
Nilsson and Rosenberg 2003 (407)	Fjord, W coast Sweden	Low, inf	fairly deep, muddy sediments; low energy inferred from depth and sed type	75-90	X							See Hansson et al (2000) for description of study area

Citation	*Location*	*Energy*	*Energy notes*	*Depth range*	*Clay-silt*	*Muddy sand*	*Sand*	*Granule-pebble*	*Cobble*	*Boulder*	*Rock outcrop*	*Substrate notes*
Palanques et al 2001 (277)	NW Mediterranean Sea	Low	study done in summer when shear stress from bottom currents and wave action was not energetic enough to suspend muddy sediments	30-40	X							> 80% clay and silt
Pilskaln et al 1998 (283)	Jordan and Wilkinson Basins, Gulf of Maine, USA	Low, inf	250 meters	-	X							Mud bottom inferred from depth and observed turbidity
Pranovi and Giovanardi 1994 (287)	Venice Lagoon (coastal), Adriatic Sea, Italy	Low	Environment described as med/low energy, but subject to strong env and anthropogenic stresses (eg temp changes, O2 depletion)	1-2			X					-
Prena et al 1999 (291)	Grand Banks, Newfoundland, CAN	Low	See #325	120-146			X					See #325
Probert et al 1997 (541)	New Zealand seamounts on Chatham Rise: Graveyard, Spawning Box, NE Area	Low, inf		662-1524							X	Hills and flats examined; substrate not well specified
Queiros et al 2006 (292)	Irish Sea	High	Irish Sea - large tidal ranges that allow accum of mud-sand belts	27-40	X	X						muddy sand (16-75% silt-clay at 7 study areas)
Rosenburg et al 2003 (313)	(a) fjord on W coast Sweden (b) Gulf of Lions, NW Mediterranean	Low, inf	(a) Gullmarsfjord - 73-96 m deep; (b) GOL - 35-88 m deep - low energy mud (see Dufois et al 2007)	73-93	X	X	X					Mud and some sand at site a - for site a, see related studies
Sanchez et al 2000 (320)	Coastal Spain, Mediterreanean Sea	Low, inf	Same study area as Palanques et al (2001) and De Juan et al (2007), low energy inferred from substrate and proximity to Gulf of Lions, where shelf at this depth is low energy	30-40	X							"muddy seabed"
Schwinghamer et al 1998 (325)	Grand Banks, Newfoundland, CAN	Low	no wave induced ripples (authors cited Barrie et al 1984); below depth of storm induced sed trans (cited Amos and Judge 1991)	120-146			X					Moderately to well-sorted medium to fine grained sand
Sheridan and Doerr 2005 (330)	Gulf of Mexico, TX coast, USA	High, inf	High energy area implied (shallow, open coast)	5-20	X	X	X					-
Simboura et al 1998 (599)	Two adjacent gulfs in the Aegean Sea.	High, inf	Most sites 60-70 m, some shallower.	31-70	X	X	X					ca 100% finer sed at S. Evvoikos and sand (70-83%) at Petalioi
Simpson and Watling 2006 (333)	Maine coast, Gulf of Maine, USA	Low, inf	Inferred based on depth and shear stress	84-102	X							-
Smith et al 1985 (334)	Long Island Sound, NY, USA	High, inf	Inferred based on depth	-	X	X	X					-

Citation	*Location*	*Energy*	*Energy notes*	*Depth range*	*Clay-silt*	*Muddy sand*	*Sand*	*Granule-pebble*	*Cobble*	*Boulder*	*Rock outcrop*	*Substrate notes*
Smith et al 2000 (335)	N. coast Crete, Mediterreanean Sea	Low, inf	inferred from sed type and depth	-200	X							80% silt-clay
Smith et al 2003 (336)	Aegean Sea, north coast of Crete	Low, inf	Low energy inferred at deep site (see #335); unknown at shallow site	80-200	X	X	X					mud at 200 m (same site as #335), coarse sand (68%), with some localized mud and maerl fragments at 80-90 m site
Sparks-McConkey and Watling 2001 (338)	Gulf of Maine, Penobscot Bay, ME, USA	Low, inf	Not 100% sure about this one; Paper hints that it's a low energy environment (P. 74, 2nd paragraph) because of presence of clay-silt sediments.	60-60	X							-
Stokesbury and Harris 2006 (352)	Georges Bank, USA	High, inf	Both sites in each exp with similar tidal current velocities	52-70			X	X	X	X		Depth range is means at 4 sites; impact areas in boith exps deeper with more sand than control areas
Stone et al 2005 (355)	Central Gulf of Alaska near Kodiak Island	Both	Bottom currents strong (28 cm/s at neap tide) at site 1, moderate to light (<0.28 m/s) at site 2; depths in transect areas 105-151m site 1, 125-157m site 2	105-157			X					Two sites, one with medium/fine sand (site 1), the other with very fine sand (site 2)
Sullivan et al 2003 (359)	New York Bight, USA	High	Sediment transport model based on wave oscillatory currents predicted bottom disturbance 100% of time at all seasons at 10m, 17% at 50m, and 3% at 100m, with almost all transport >50m storm-driven.	45-88		X	X					Medium-coarse sand at 10 and 50m, fine sand-silt at 100m
Tanner 2003 (360)	Gulf of St. Vincent, Australia	Low, inf	Depths >20m in central gulf, GSV protected from high wave activity by large, offshore island, depositional environment	20-20	X		X					Medium-coarse sand and shell fragments at site 1 and 3, fine silt at site 2
Tillin et al 2006 (368)	North Sea - 4 sites - focus on northern sites here	Both	FG - shear stress 0.08-0.11 N/m2 (low), depth 142-153 m; LF - shear stress 0.30-0.36 (high), depth 74-83 m	74-153	X		X	X				Fladen Ground (FG) - mud; Long Forties (LF) - gravelly sand
Tuck et al 1998 (372)	West coast of Scotland	Low	Sheltered loch; tidal currents of up to 5 knots occur over the shallow (12 m) sandy sill at the narrow (350 m) entrance to the loch, but in the deeper water of the main loch currents are greatly reduced and the seabed is muddy	30-35	X							Approx 95% silt and clay

Citation	*Location*	*Energy*	*Energy notes*	*Depth range*	*Clay-silt*	*Muddy sand*	*Sand*	*Granule-pebble*	*Cobble*	*Boulder*	*Rock outcrop*	*Substrate notes*
Tuck et al 2000 (373)	Sound of Ronay, Outer Hebrides, Scotland	High, inf	These areas provide extreme shelter from wave action, and a wide range of tidal stream strengths through the many narrow channels and rapids (Boyd, 1979)	2-5			X					-
Van Dolah et al 1987 (382)	Georgia, USA	High, inf	Inferred based on depth	20-20			X					Smooth rock (no outcrops) with thin layer of sand, described as "low relief, hard-bottom habitat"
Wassenberg et all 2002 (387)	NW Australia	High, inf	Average depth 78.3 m, most sponges caught <100m, none >156m; high energy inferred based on depth and sediment type plus open exposed nature of coastline	25-358			X	X				coarse sand with 10-30% gravel
Watling et al 2001 (391)	Damariscotta River, ME, USA	High, inf		15-15	X	X						-
Wheeler et al 2005 (393)	Darwin Mounds, small (up to 5 m high, 75 m across) coral-topped mounds about 1000 m deep in N Rockall Trough off UK	Low, inf		900-1060								-

Table 18 – Geological features evaluated by various studies.

Citation	*Surfacne and subsurface sediments*	*Biogenic depressions*	*Biogenic burrows*	*Bedforms*	*Scattered gravel*	*Gravel pavement*	*Piled gravel*	*Shell deposits*	*Geo-chemical*	*Geological impacts description*
Auster et al 1996 (11)		X		X	X	X		X		SI: signif fewer bio dep outside conservation area - assumed related to reduction in spp that create dep.; JB: much of mud veneer removed by fishing, boulders moved; SB: sand ripples smoothed by fishing, shells dispersed
Brown et al 2005b (35)	X	X		X					X	Sediments better sorted in fished area vs closed. No S differnce in grainsize. No diff in mean C content between areas. Sed Chl A was higher in fished area. Sand wave formation was seasonal and therefore differed from fishing effects.
Caddy 1968 (42)	X									Dredge produced a 'bulldozing' effect on substrate at low speeds when bag was not open, but not at higher speeds; lateral skids produced parallel furrows ca 2 cm deep with series of smooth ridges between them caused by rings in chain belly of dredge
Caddy 1973 (43)					X	X				Dredge resuspended sand, burried gravel, overturned gravel fragments, dislodged cobble, plowed boulders; marks left by belly rings in sand/fine gravel, narrow depression made by tow bar, skid marks, thin layer of silt on gravel in vicinity of tows
De Biasi 2004 (88)	X									Trawling re-suspended and re-distributed finer sediments, door tracks less distinct after 48 hr, almost invisible after 1 month, no marks left by net
DeAlteris et al 1999 (92)	X									Door tracks 5-10 cm deep, berm 10-20 cm high. Scarred area 0.9%; sand eroded 100% of time daily, mud eroded <5% of time (mode analysis); 2 month study: mud scars lasted >60 d, sand scars 1-3d.
Drabsch et al 2001 (97)	X		X							Tracks left by otter boards and skids evident within all trawl corridors, removal of topographic features such as mounds
Engel and Kvitek 1998 (101)		X	X				X	X		Signif fewer rocks and biogenic mounds, S less flocculent material, and S more exposed sediment and shell fragments in HT area. Impacts on particular geological subtrates not well defined.
Freese 2001 (110)	X				X					Furrows still prominent after 1 year
Freese et al 1999 (111)	X				X		X			10-27% boulders displaced in 8 tows (mean 19%), tires left furrows 1-8 cm deep in less compact sediment; layer of silt removed in more compact sediment (more cobble); boulder piles mentioned but not evaluated
Gilkinson et al 1998 (120)	X									Trawl doors created berm 5.5 cm high next two furrow 2 cm deep
Gilkinson et al 2003 (121)	X		X					X		Furrows observed in seabed immed after dredging; appeared visually to recover by 1 yr but visible in sonar at 3 yr. Shell dep inc over time, as did polychaete tubes. Burrows and shells from C. siliqua - burrows did not recover due to high F on this spp
Koulouri et al 2005 (211)	X			X						Towed video showed evidence of recent trawling as fresh marks on seabed, uncovered lighter-grey sediments, and flat areas with no sedimentary features
Kutti et al 2005 (214)	X									resuspension of surface sediment
Langton and Robinson 1990 (217)	X									Change from organic silty sand to gravelly sand
Lindholm et al 2004 (225)	X	X	X	X	X			X		Biogenic depressions more abun in immobile sand habitats (>60m) inside closed area, more shell fragments in closed area
MacKenzie 1982 (232)	X									
Mayer et al 1991 (236)	X			X					X	Door tracks several cm deep. Trawl dispersed fine surface sediment, planed surface features, but did not plow bottom.

Citation	*Surfacne and subsurface sediments*	*Biogenic depressions*	*Biogenic burrows*	*Bedforms*	*Scattered gravel*	*Gravel pavement*	*Piled gravel*	*Shell deposits*	*Geo-chemical*	*Geological impacts description*
										Dredging lowered sed surface 2cm, injected finer sed into lower 5-9cm, increased mean grain size upper 5 cm, disrupted surface diatom mat
Medcof and Caddy 1971 (244)	X									-
Meyer et al 1981 (245)	X									-
Morais et al 2007 (247)	X	X		X	X		X			Trawl doors, groundrope, tickler chains caused marks on seabed. Door marks were 40 cm wide and 20 cm deep. Cleaning and flattening seafloor by nets and chains noted. Even in low-energy environments, persistency of trawl marks noted as "low."
Murawski and Serchuk 1989 (256)	X									Trenches in gravelly areas collapsed quickly, in hard packed sand trenches still visible after a few days
Palanques et al 2001 (277)	X									Footrope removed 2-3 cm fine sediment, silt settled w/in 1 hour, turbidity still 3 times above ambient 4 days later, representing 10% resuspended sediment, rest accumulated on bottom; door tracks still visible 1 yr after trawling, surface seds mixed in 1d
Pilskaln et al 1998 (283)	X									More infaunal worms suspended in water column in more heavily trawled area (W Basin), more abundant during periods of greater trawling activity
Pranovi and Giovanardi 1994 (287)	X									-
Rosenburg et al 2003 (313)	X		X							Gulf of Lions - sig trawl impacts in mud, i.e. lower number of polychaete tubes, greater sediment relief (door tracks), mud clasts ripped up
Sanchez et al 2000 (320)	X									Door tracks remained visible throughout experiment
Schwinghamer et al 1998 (325)	X	X	X					X	X	Door tracks increased relief/roughness, still visible in SS sonar after 2 mos, but not 1 yr later. Trawling susp/disp sed, removed hummocks and organic matter, topography recovered in 1 yr, no effect on sed texture, shells/organisms in linear features
Sheridan and Doerr 2005 (330)	X									No increase of fine sediment in untrawled area
Simpson and Watling 2006 (333)	X		X						X	At inshore site, signif more 3-4 cm d burrows in untrawled area, NS differences for smaller and larger sizes; NS changes in sed porosity on fishing grounds, no net loss of fine sediments, but trawling may alter sed mixing regimes.
Smith et al 1985 (334)	X		X							Door tracks, 5-15 cm in mud, <5 cm in sand, "naturalized" by tidal currents
Smith et al 2000 (335)	X								X	No effect of trawling on organic C surface sediment values
Smith et al 2003 (336)	X	X	X							NS differences in sediment compaction or roughness or in substrate attributes in trawled and untrawled areas (door tracks cancel out smoothing and scraping action of groundrope and net)

Citation	*Surfacne and subsurface sediments*	*Biogenic depressions*	*Biogenic burrows*	*Bedforms*	*Scattered gravel*	*Gravel pavement*	*Piled gravel*	*Shell deposits*	*Geo-chemical*	*Geological impacts description*
Sparks-McConkey and Watling 2001 (338)									X	Signif decline in porosity, increased food value/chlorophyll production of surface sediments; all geochemical sediment properties recovered within 3.5 months
Stokesbury and Harris 2006 (352)	X				X			X		-
Stone et al 2005 (355)		X	X							Biogenic structures signif less abundant in open area at site 2 (not assssed at site 1)
Sullivan et al 2003 (359)		X		X						Frequency of sand waves, tube mats, and biogenic depressions decreased rel to control plots, vigorous reworking of surface sediments to 2-6 cm
Tuck et al 1998 (372)	X								X	Door tracks, bottom roughness increased during dist period/declined during recovery, no effect on sediment grain size, organic C higher in treatment area
Tuck et al 2000 (373)	X									-
Watling et al 2001 (391)	X								X	Imm loss of fine sediments from top few cm, reduction in food value (S reductions in amino acids and microbial biomass); no recovery of fine seds 6 mos after dredging, but food value completely restored
Dellapenna et al 2006 (406)	X								X	sed props analyzed for physical and geochem properties; susp. Sed settled in hours, turbidity returned to pre-trawl levels in 14 mins; doors, net, and chains excavate to max 1.5 cm (much less in most areas)
Nilsson and Rosenberg 2003 (407)	X		X						X	BHQ values lower/more variable in trawled transects, a severe mechanical disturbance observed in 43% of images increased spatial var of indices in trawled areas
Boat Mirarchi and CR Environmental 2003 (408)	X	X	X	X						Doors created furrows/ridges in seabed (6" in mud, 2-3" in sand), smoothed seafloor, exposed worm tubes, reduced grain size in trawl and control lanes (resuspension by trawl); physical impacts of trawling less visible at shallower/sandy site
Boat Mirarchi and CR Environmental 2005 (409)	X	X	X	X						no signif trawling-induced changes in either physical or biological conditions at the sediment- water interface (analysis of SP images)
Coggan et al 2001 (414)	X			X						-
Simboura et al 1998 (599)	X									Sediments better sorted, higher proportion of fines at S. Evvoikos than Petalioi. Not clear if these differences were related to fishing directly or to degree of enclosure of area.

Table 19 – Biological features evaluated by various studies. Seagrass was not carried forward into the matrices.

Citation	***Sponge***	***Bryozoan***	***Hydroid***	***Anemone***	***Burrowing anemone***	***Soft corals***	***Hard corals***	***Sea pens***	***Tube worms***	***Bivalves***	***Brachiopods***	***Tunicates***	***Macroalgae***	***Sea grass***	***Impacts description***
Asch and Collie 2007 (404)	X	X	X		X				X	X					In shallow water, structurally complex colonial taxa more abundant at UD sites, encrusting taxa at D sites; rel abundance of some taxa at D and UD sites different in deep water ; sponges and bushy bryos recovered inside CAII within 2 yrs of closure
Auster et al 1996 (11)	X	X	X	X					X	X		X			SI: signif lower epifaunal cover outside closed area (sea cuc esp vulnerable); JB: reduced abundance of erect sponges and associated epifauna (Fig 3); SB: removal of epibenthic organisms (ascidians, hydrozoans) that anchor in coarse sand
Ball et al 2000 (17)															Reduced epifaunal/infaunal richness, diversity, and number of species in commercially fished areas compared with control areas, with bigger difference at HF site.
Bergman and VanSantbrink 2000 (21)										X					Percent reductions <0.5-52% for 9 bivalves, 16-26% for a sea urchin, 3-30% for a crustacean, and 2-33% for other species; some reductions significant (see paper); fragile species more vulnerable
Boat Mirarchi and CR Environmental 2003 (408)	X		X	X						X					Fish and inverts (eg Cancer crabs) less numerous imm after trawling, differences not obvious 4-18 hrs later
Boat Mirarchi and CR Environmental 2005 (409)	X		X	X						X					No consistent differences were found between the trawled and control areas, trawling did not appear to alter the overall faunal composition.
Brown et al 2005a (34)	X	X	X	X						X		X			Reduced macrofaunal density, biomass, and richness in chronically fished area, mobile scavengers (eg amphipods) more common in fished area, polychaetes common in closed area (also see prey impacts); no detectable effects of exp trawling experiment
Burridge et al 2003 (38)	X	X	X	X		X				X		X	X		Diff catch biomass shallow vs. deep (> or < dep on taxa). Depletion rate estimates (Fig 4, Tab 2) generally 5-20%. Comparison of vulnerability betw taxa on p 247. Hyp that attachment of soft flexible organisms to large vs small rocks influ catchability.
Collie et al 1997 (69)		X	X						X	X					S effects of fishing AND DEPTH on density, biomass, and diversity, higher in deep U sites; six species abundant at U sites, rare or absent at D sites, and NOT AFFECTED by depth-two (horse mussels, starfish) might provide shelter
Collie et al 2000 (70)	X	X	X	X	X				X	X					Percent cover of all emergent epifauna S higher in deep water, but no S disturbance effect; emergent anemones, sponges, horse mussels, and some tube-worms less frequent at D sites; burrowing anemones much more prevalent at D sites
Collie et al 2005 (71)	X	X	X	X	X				X	X					S higher numercial abundance/biomass of benthic megafauna in LF site, low percent cover of hydroids, bryozoans, and worm tubes at HF site; S increases in abundance, biomass, and epifaunal cover inside CAII after 6 years (see paper for details)
Engel and Kvitek 1998 (101)	X			X				X							Lower densities of large epibenthic taxa in HT area (S for sea pens, starfish, anemones, and sea slugs), higher densities of opportunistic species (infauna and epifauna) in HT area, no differences for crustaceans/mollusks
Eno et al 2001 (102)	X	X				X		X	X			X			

Citation	*Sponge*	*Bryozoan*	*Hydroid*	*Anemone*	*Burrowing anemone*	*Soft corals*	*Hard corals*	*Sea pens*	*Tube worms*	*Bivalves*	*Brachiopods*	*Tunicates*	*Macroalgae*	*Sea grass*	*Impacts description*
Freese 2001 (110)	X		X												No recruitment of new sponges, no repair or re-growth of damaged sponges, but sponges that were knocked over or pieces of sponge lying on bottom were still viable
Freese et al 1999 (111)	X			X				X		X					30% reduction in density of sponges, 50% for anemones, 23% for motile epifauna (not structure-forming); heavy damage to some types of sponges (67% vase sponges), brittle stars (23%), and sea pens (55%)
Gilkinson et al 2005b (123)						X									No sig impacts to soft corals detected, but low power ANOVA and low rate of coral bycatch. Also, suspected corals attached to shells were displaced from dredge path. Spec that there would be greater impact if dredging in larger patches of coral.
Hall et al 1990 (140)															-
Henry et al 2006 (157)	X	X	X			X						X			Short term effects were decreased number of taxa per sample, total biomass, and hydroid biomass, but trends were NS; no cumulative effects and and no long term (3 yrs) effects.
Hermsen et al 2003 (158)									X	X					Signif lower production (P) at HF Canadian site than at LF site, increase in production inside CAII within 6 years to levels similar to LF site; scallops and sea urchins dominated P at recovering site; tube worm dominated P at LF site
Hixon and Tissot 2007 (164)								X							Marked reduction in sea pen density in fished area.
Kaiser et al 2000 (184)			X			X									S habitat effects on # species/indivs, and on spp diversity, but no S fishing effects; in general, as fishing dist increased, more mobile, robust spp, fewer immobile, large, fragile spp
Kenchington et al 2006 (194)				X	X				X	X	X	X			Few detectable imm effects on abundance or biomass of indiv taxa, none on community composition; epifaunal biomass reduced from 90% to 77% after 3 yrs (esp horse mussels); damage to mussels, tube-building polychaete and a brachiopod.
Knight 2005 (203)	X			X						X		X			-
Kutti et al 2005 (214)										X					See below
Langton and Robinson 1990 (217)					X				X	X					Densities of 3 dominant species (see below) declined signif between surveys, apparently due to dredging
Lindholm et al 2004 (225)	X	X	X	X											S higher incidence of rare sponge and shell fragment habitats inside closed area, no signif differences for 6 more common habitat types; sponges more abun in immobile sand habitats (>60m) inside closed area
Link et al 2005 (228)	X	X	X	X	X			X							See below
MacKenzie 1982 (232)					X										Ceriantheopus americanus listed but no statistical test on that spp alone; spp was found more frequently at dredged sites vs. never fished sites
McConnaughey et al 2000 (238)	X	X		X		X				X		X			Sedentary taxa (anemones, soft corals, stalked tunicates, bryozoans, sponges) more abundant inside closed area, diffs signif for sponges/anemones; more patchy dist outside closed area
McConnaughey et al 2005 (239)				X						X		X			On average, 15 of 16 taxa smaller inside closed area but individually, only a whelk and anemones were signif smaller

Citation	***Sponge***	***Bryozoan***	***Hydroid***	***Anemone***	***Burrowing anemone***	***Soft corals***	***Hard corals***	***Sea pens***	***Tube worms***	***Bivalves***	***Brachiopods***	***Tunicates***	***Macroalgae***	***Sea grass***	***Impacts description***
Moran and Stephenson 2000 (248)	X					X		X							Single tow of demersal net reduced benthos (>20 cm high) by 15.5%, 4 tows 50%
Pranovi and Giovanardi 1994 (287)				X						X				X	-
Prena et al 1999 (291)						X									Overall 24% average decrease in epibenthic biomass with S trawling and year effects on total B, smaller organisms, more damage, in trawled areas; B of 5/9 dominant spp S lower in trawled corridors, no effect on molluscs
Smith et al 2003 (336)	X								X				X		Attributes identified on SPI images included a number of biological features (see paper), no analysis of fished and unfished areas
Stokesbury and Harris 2006 (352)	X	X	X	X	X				X	X		X			Changes in density before and after limited fishing in impact areas similar to changes in control areas; fishing affected epibenthic community less than natural disturbance
Stone et al 2005 (355)				X				X		X					Species richness S less in open areas at both sites, site 2 had signif fewer epifauna in open area, S reduced abundance of low-mobility taxa and prey taxa in open areas at both sites; 13/76% fewer anemones sites 1/2 open areas, more sea pens (see Table 1)
Tanner 2003 (360)	X	X								X		X		X	Overall decrease in epifauna (28%) within 1 week of trawling and by another 8% 1 wk to 3 mo after trawling; In 9 of 12 cases, (4 major taxa/3 locations) trawling S reduced abundance by >25%. Taxa=sponges, an erect bivalve, ascidians, and bryozoans.
Tillin et al 2006 (368)	X	X	X	X		X				X		X			Lower trawling intensity = greater prop B of att epifauna/filter feeders, smaller, shorter-lived spp with pelagic larvae; Higher trawl int= greater prop B of infauna, burrowers, and scavengers/predators
Tuck et al 2000 (373)									X						-
Van Dolah et al 1987 (382)	X					X	X								35% fewer barrel sponges (Cliona spp) in high-density transects, 77% fewer in low-density transects, reduced impacts on other sponges, 30% fewer stony corals, 32% sponges still on bottom were damaged; full recovery in density and damaged sponges in 12 mo
Wassenberg et all 2002 (387)	X					X									Trawl impact a function of sponge shape and size. Most sponges <500mm passed under trawl, > 500 mm impacted more (30-60% passed under net). Large branched sponges mostly removed by footrope or crushed; 90% of gorgonians passed under net.

4.0 Estimating susceptibility and recovery for biological and geological features

This section describes the matrix-based approach used to estimate vulnerability (i.e. susceptibility and recovery) of geological and biological habitat features to fishing gear impacts.

4.1 Methods: S-R matrices

As previously described, the SASI approach disaggregates fishing effort by gear type, and classifies habitat into ten types based on two energy levels and five substrate types, with a suite of geological and biological structural features inferred to each habitat type. **With respect to a feature-gear-substrate-energy combination, 'vulnerability' represents the extent to which the effects of fishing gear on a feature are adverse.** 'Vulnerability' is defined as the combination of how susceptible the feature is to a gear effect and how quickly it can recover following the fishing impact. **Specifically, susceptibility is defined as the percentage of total habitat features encountered by fishing gear during a hypothetical single pass fishing event that have their functional value reduced, and recovery is defined as the time in years that would be required for the functional value of that unit of habitat to be restored.** Functional value is intended to indicate the usefulness of that feature in its intact form to a fish species requiring shelter. This relative usefulness as shelter can be extended to the prey of managed species as well, which provides indirect benefits to the managed species. **However, because functional value is difficult to assess directly, and will vary for each managed species using the feature for shelter, feature removal or damage is used as a proxy for reduction in functional value.** Results such as percent reduction of a geological or biological feature are common in the gear impacts literature.

In order to make the susceptibility and recovery information work as a set of model parameters, the susceptibility and recovery of each feature-gear-substrate-energy combination is scored on a 0-3 scale as described in Table 20. The scaling process eliminated any differentiation in units (i.e. percent change for susceptibility vs. time for recovery). The scale is also intended to compare the magnitidue of susceptibility and recovery values, since susceptibility and recovery are closely related. Quantitative susceptibility percentages in Table 20 indicate the proportion of features in the path of the gear likely to be modified to the point that they no longer provide the same functional value. Recovery does not necessarily mean a restoration of the exact same features, but that after recovery the habitat would have the same functional value.

Table 20 – Susceptibility and recovery values

Code	*Quantitative definition of susceptibility*	*Quantitative definition of recovery*
0	0 – 10%	< 1 year
1	>10%-25%	1 – 2 years

2	25 - 50%	2 – 5 years
3	> 50%	> 5 years

Each matrix shown in the following sections includes the features present in that particular substrate and energy environment, gear effects related to that gear type and feature combination, susceptibility and recovery for each feature, and the literature deemed relevant to assigning S and R for a particular feature and gear combination.

Susceptibility and recovery are scored based on information found in the scientific literature, to the extent possible, combined with professional judgment where research results are lacking or inconsistent. To direct PDT members to the appropriate research during the evaluation process, studies are assigned to matrix cells using the literature review database. For this purpose, the set of studies used to inform a particular susceptibility or recovery value is defined fairly narrowly. In some cases, studies from the literature review beyond those listed in a given matrix cell are used as well. For example, otter trawl studies are used to inform some of the scallop dredge scores. Also, for a given scored interaction in the matrix, some studies listed may have informed the score more than other studies. Details regarding the justification for each S or R score, with numbered references, are condensed into separate tables.

In some cases, the fields from the database do not align perfectly with cells in the matrices. This is because the database fields were developed and coded somewhat earlier in the process, while the matrices were still being refined. In particular, mud, sand, and muddy sand were coded during the literature review, but only mud and sand are used to define the model grid and thus only mud and sand matrices are developed. When studies were assigned to matrix cells, those coded as muddy sand went into both the mud and sand matrices, leaving the analyst to determine whether the study was most appropriately applied to one, the other, or both.

In cases where no studies are available to inform a particular S or R value, the analyst relied on the gear and feature descriptions combined with their professional judgment. In some cases, studies that considered another gear type, or were conducted in a different habitat type (either a different substrate, energy regime, or both) are considered.

All feature-substrate-gear-energy combinations are evaluated with the exception of hydraulic dredges, which are scored for sand and granule-pebble substrates only as they are unable to fish in other substrates (Table 21).

Table 21 – Matrices evaluated. Each substrate-type matrix included both energy environments and all associated features.

Gear type	*Mud*	*Sand*	*Granule-pebble*	*Cobble*	*Boulder*
All trawl gears	X	X	x	X	X
Scallop dredge	X	X	X	X	X
Hydraulic dredge	-	X	X	-	-
Longline	X	X	X	X	X
Gillnet	X	X	X	X	X
Trap	X	X	X	X	X

Susceptibility and recovery scoring was discussed at five Plan Development Team (PDT) meetings between January and August 2009. These group discussions ensured that each team member had the same understanding of what was meant by susceptibility and recovery, and understood the assumptions underlying the assessment. During this period, matrices were evaluated in three iterations. Before the March 2009 Science and Statistical Committee (SSC) review, geological features were scored for the otter trawl and scallop dredge matrices by all team members. Before the May PDT meeting, geological and biological features were scored for all mobile gears by all team members. Before the August PDT meeting, geological, biological, and some prey features were scored for all gears, with a subset of team members scoring each matrix. At the August meeting and in subsequent weeks, the PDT divided into small groups of 3-4 members each to evaluate each gear type in detail. Individual members submitted matrices to the group, including justification for each score, and the sub-teams developed consensus scores for each feature. Once consensus was reached for each gear type, the matrices were considered more holistically and scores were compared across gear types to ensure consistency. This final consideration of values continued through March 2010. During this period, the following "rules" for matrix evaluation were developed.

1. Susceptibility was evaluated for the entire swath of seabed affected by the gear during one tow.

In most cases, a feature is small in comparison with the path of the gear. In the case of larger features, (e.g. sand waves), or gears with narrower footprints (e.g. fixed gears), impacts to the portion of the feature in the path of the gear are evaluated.

2. Susceptibility was generally assumed to be similar for both high and low energy areas and therefore a single score was given for both, but recovery was assumed to vary such that separate high and low energy scores could be assigned as appropriate.

Note that in the matrices below, separate high and low energy susceptibility scores are shown to indicate more clearly which features are inferred to which substrate-energy combinations.

3. Susceptibility to and recovery from all trawl gear impacts were considered in one matrix, even though the gears were separated for the purposes of realized area swept and adverse impact modeling.

SASI identifies four trawl gear subtypes (generic, shrimp, squid, raised footrope), but matrices for each type are not completed, for the following reasons. First, literature support for disaggregated shrimp, squid, and raised footrope matrices is limited, as indicated in Table 16. Second, because the contact indices and gear component dimensions vary by gear type, the gears can be distinguished in the model outputs even if susceptibility and recovery scores are the same.

4. The intention of the susceptibility scoring was to consider loss or damage of features in the path of the gear for the portion of the gear that was actually in contact with the seabed, allowing the contact index to account for any reduction in area swept.

However, given that the matrices are based on the results of research that uses actual fishing gears, with varying levels of contact with the seabed, it is difficult to avoid double counting seabed contact in the model, in that the level of gear contact affects the S scores and then may be further accounted for in the area swept models described in section 6.0.

5. Although gear components were modeled separately to estimate area swept, for each gear type, all components were considered together when evaluating susceptibility.

A primary reason for this is that the literature generally does not disaggregate gear effects by component. However, analysts considered the relative contribution of each gear component to area swept when evaluating the matrices.

6. The matrix evaluations consider a hypothetical single pass, with no baseline state of the seabed or features assumed.

Generally, areas within the SASI model domain as well as study sites in the fishing impacts literature have been subject to repeated fishing disturbance for many years. The single pass approach makes the results of some studies more difficult to apply to the scoring of susceptibility and recovery. While there are a number of studies among the 97 evaluated that examine habitat impacts at this level, many do not. It can be argued that such experimental impact studies are simply not practicable at 'relevant' temporal and spatial scales (Tillin et al. 2006, Hinz et al. 2009), but comparative studies also have drawbacks. Comparative studies can be somewhat difficult to evaluate and extrapolate because the scale of fishing disturbance may vary widely between studies, and is often vaguely quantified as high or low (Hinz et al 2009). More generally, a challenge inherent to evaluating the result of the fishing impacts literature is the lack of true control sites and the confounding of natural variations that predispose an area to trawling in comparison with a nearby area with the actual effects of trawling on seabed features (Tillin et al. 2006, Hinz et al. 2009).

7. Recovery rates of features assume the absence of additional fishing pressure.

As a final note regarding the methods used in the matrix-based assessment, it is possible that given the same methods, feature definitions, gear type definitions, and literature to draw from that a different group of experts might score susceptibility and recovery differently. As noted above, an iterative, team-based approach to scoring is used. The matrix evaluations are inherently qualitative, so there is no 'right' answer. The goal is to have internal consistency between team members in their approaches, and to ensure consistency across substrates and gear types in the final values. The scores are being used to estimate the relative impacts of various fishing gears on different types of seafloor features, so in this sense, internal consistency in scoring is more important than the actual scores.

4.2 Results: S-R matrices

The following sections present the S-R matrices by gear type (otter trawl, scallop dredge, hydraulic dredge, longline, gillnet, and trap). To save space, justifications for the scores are presented separately. Following the matrices, there are summary plots of the S and R values comparing scores between gears, substrates, and energies.

4.2.1 Demersal otter trawls

As indicated in the literature review section of the document, there is more research to base assessment of feature vulnerability to otter trawls as compared to other types of gear. Within this, there is more information in the literature to support S scores than R scores. Therefore, for biological features, R scores are heavily informed by life history information. Evaluations for otter trawls also relied on professional judgment gained from individual field research experience. Geological evaluations are more straightforward than biological evaluations, probably because there is less variation within a feature that might influence S and/or R. Many geological recovery scores are estimated to be very low (i.e. rapid), with the exception of features like boulder and cobble piles.

S evaluations require the assumption that disturbance of, damage to, or loss of a feature indicates a change in functional value (i.e. value as shelter). Different types of studies varied in terms of their usefulness. For example, video/photographic studies are found particularly useful for biological susceptibility evaluation. Studies that compared feature abundance before and after fishing in the same exact transect are found to be more useful than studies that compared impact vs. reference transects.

The team discussed that in piled boulders, the boulders themselves might offer some protection to the epifauna living between the boulders. However, this would only hold for boulder piles/reefs, and susceptibility of epifauna in and around smaller boulders would be similar to that in cobble habitats, because the boulders can be moved by the gear. The scores given assume a scattered boulder habitat made up of smaller boulders.

Below, Table 22 shows trawl gear S/R values, grouped by substrate and then by feature. In general, features are inferred to both high and low energy environments for a given substrate, and S and R are scored the same; with exceptions as noted. Table 23 summarizes the justification for the susceptibility scores for trawl gear. Justifications for recovery scores for all gear types are combined into two tables at the conclusion of the matrix results section (Table 31 – geological, Table 32 - biological).

Table 22 – Trawl gear matrices. Susceptibility (S) values are coded as follows: 0: 0-10%; 1: >10-25%; 2: >25-50%; 3: >50%. Recovery (R) values are coded as follows: 0: <1 year; 1: 1-2 years; 2: 2-5 years; 3: >5 years. The literature column indicates those studies identified during the literature review as corresponding to that combination of gear, feature, energy, and substrate. The studies referenced here were intended to be inclusive, so any particular study may or may not have directly informed the S or R score. Any literature used to estimate scores is referenced in Table 23 (Trawl S), Table 31 (Geo R), and Table 32 (Bio R).

Gear: Trawl					
Substrate: Mud					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Biogenic burrows (G)	filling, crushing	334, 408, 409	97, 101, 313, 333, 336, 407	2	0
Biogenic depressions (G)	filling	236, 408, 409	101, 247, 336	2	0
Sediments, surface/subsurface (G)	re-suspension of fine sediments, compression, geochemical, mixing	88, 92, 211, 236, 330, 334, 406, 408, 409, 599	88, 97, 211, 247, 277, 283, 313, 320, 333, 335, 336, 338, 372, 407, 414	2	0
Amphipods, tube-dwelling (B) – see note	crushing	34, 113, 119, 211, 228, 292, 334, 408, 409, 599, 658	89, 80, 97, 113, 149, 320, 575	1	0
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	none	none	2	2
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	none	101, 164	2 (low energy only)	2 (low energy only)
Hydroids (B)	breaking, crushing, dislodging, displacing	408, 409	368	1	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	21, 34, 368, 408, 409	89, 203, 360, 368	1	3
Substrate: Sand					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Bedforms (G)	smoothing	11, 35, 225, 408, 409	n/a	2 (high energy only)	0 (high energy only)
Biogenic burrows (G)	filling, crushing	225, 334, 355, 408, 409	97, 101, 128, 313, 325, 336, 355	2	0
Biogenic depressions (G)	filling	11, 35, 225, 355, 408, 409	97, 101, 247, 325, 336, 355	2	0

Sediments, surface/subsurface (G)	resuspension, geochemical, mixing and resorting	35, 92, 120, 225, 236, 334, 408, 409, 599, 330	97, 128, 214, 247, 313, 325, 336, 414	2	0
Shell deposits (G)	displacing, burying, crushing	11, 225	101, 325	1	1 (high), 2 (low)
Amphipods, tube-dwelling (B) – see note	crushing	113, 225	34, 97, 113, 119, 141, 194, 228, 292, 334, 408, 409, 599, 658	1	0
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	228	none	2	2
Ascidians (B)	breaking, crushing, dislodging, displacing	11, 34, 38, 157, 238, 368	203, 360, 368	2	1
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	228, 248	101, 247	2 (low energy only)	2 (low energy only)
Hydroids (B)	breaking, crushing, dislodging, displacing	11, 34, 38, 69, 70, 71, 157, 184, 225, 228, 285, 368, 408, 409	360	1	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	38, 69, 70, 71, 158, 194, 285, 355, 368, 408, 409	203, 214, 355, 360	1	3
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B) – see note	breaking, crushing	69, 70, 71, 158, 194, 355, 368, 408, 409	203, 214, 355	1	2
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 158	11, 336	2	2
Sponges (B)	breaking, crushing, dislodging, displacing	11, 34, 38, 70, 71, 157, 225, 228, 238, 248, 285, 368, 382, 387, 408, 409	336, 203, 360, 101, 247, 368	2	2
Substrate: Granule-pebble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Granule-pebble, pavement (G)	burial, mixing, homogenization	none	n/a	1 (high energy only)	0 (high energy only)
Granule-pebble, scattered, in sand (G)	burial, mixing	11	11, 110, 111, 247	1	0 (high), 2 (low)
Shell deposits (G)	burying, crushing, displacing	11, 225	11, 101	1	1 (high), 2 (low)
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	11, 38, 70, 71, 194, 225, 228, 368	11, 101, 111	2	2
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	70, 71, 194, 228, 404	none	2	2
Ascidians (B)	breaking, crushing, dislodging, displacing	11, 157, 194, 368	11	2	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	194	247	2	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	11, 38, 69, 70, 71, 157, 225, 228, 368, 404	11	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	11, 38, 69, 70, 71, 157, 225, 228, 368, 404	11, 111	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	69, 70, 71, 158, 194, 368, 404	11	2	3
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B) – see	breaking, crushing	69, 70, 71, 158, 194, 368, 404	11	1	2

note					
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 158, 404	11	2	2
Polychaetes, other tube-dwelling (B) – see note	crushing, dislodging	11, 69, 70, 71, 158, 404	11	2	1
Sponges (B)	breaking, dislodging, displacing	11, 38, 70, 71 ,157, 225, 228, 248, 368, 387, 404	11	2	2
Substrate: Cobble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Cobble, pavement (G)	burial, mixing, homogenization	11	n/a	1 (high energy only)	0 (high energy only)
Cobble, piled (G)	smoothing, displacement	none	101	3	3
Cobble, scattered in sand (G)	burial, mixing, displacement	none	11, 110, 111	1	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	11, 70, 71, 194	11, 101, 111	2	2
Ascidians (B)	breaking, crushing, dislodging, displacing	11, 157, 194	11	2	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	194	247	2	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 157, 228, 404	11	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 157, 158, 228, 404	11, 110	1	1
Macroalgae (B)	breaking, dislodging	none		1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 158, 194, 404	111, 214	2	3
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B) – see note	breaking, crushing	11, 69, 70, 71, 158, 194, 404	111, 214	1	2
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	69, 70, 71, 158, 194, 404	none	2	2
Polychaetes, other tube-dwelling (B) – see note	crushing, dislodging	69, 70, 71, 158, 194, 404	none	2	1
Sponges (B)	breaking, dislodging, displacing	11, 70, 71, 157, 158, 228, 404	11, 101, 110, 111	2	2
Substrate: Boulder					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Boulder, piled (G)	displacement	none	101, 111	2	3
Boulder, scattered, in sand (G)	displacement	none	110, 111	0	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	none	11, 111	2	2
Ascidians (B)	breaking, crushing, dislodging, displacing	none	11	2	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	194	247	2	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	none	11	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	none	11, 110	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy	1 (high energy

				only)	only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	11, 111, 214	2	3
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	none	none	2	2
Polychaetes, other tube-dwelling (B) – see note	crushing, dislodging	none	none	2	1
Sponges (B)	breaking, dislodging, displacing	none	11, 110, 111	2	2

Note: Only reference 225 is specific to tube-dwelling amphipods, the rest are derived from entries in database coded as prey/amphipods. Similarly, references for epifaunal bivalves/ scallops and other tube-dwelling polychaetes are based on database entries for epifaunal bivalves/mussels and polychaetes/F. implexa.

Table 23 – Trawl gear susceptibility summary for structural features.

Feature	***Substrates evaluated***	***Score***	***Notes***
Amphipods, tube-dwelling	Mud, sand	1	Tubes are pliable and only extend 2-2.5 cm above bottom, therefore susceptibility to single tows was assumed to be low. "Disruption" of amphipod tube mats on Fippennies Ledge (GOM) after commercial scallop dredging (217).
Anemones, actinarian	Granule-pebble, cobble, boulder	2	Anemones are able to retract tentacles, which may offer some protection. 50% reduction after single tows in a low energy area, but anemones remaining on seabed were undamaged (111). *Urticina* sp. on west coast ca 75% less abundant in heavily trawled area than in adjacent lightly trawled area at same depth (101)
Anemones, cerianthid burrowing	Mud, sand, granule-pebble	2	Anemones can retract into semi-rigid tubes. Tubes of largest species (Cerianthus borealis) extend 15 cm above sediment surface and are susceptible to trawls. E.g., the only large organism in study 194 that showed significant decline (> 50%) after trawling (12-14 tows) was *Cerianthus* sp. However, Shepard et al. (1986) surmised that because the tubes of larger cerianthids are deeply buried, shallow grab samples extending only 3-5 cm into the seabed would be unlikely to dislodge these specimens. A similar resistance to fishing gear that skims the sediment surface seems likely. However, this does not mean that the gear does not damage the tube, perhaps making the anemone more vulnerable to predation. It is important to note that tubes of another species (*Ceriantheopsis americanus*) do not extend above the sediment and the tentacle whorl is nearly flush with the sediment surface. William High, in a NMFS Northwest Center report, describes direct observations of trawl groundlines pinching cerianthids between rollers or bobbins or cookies and pulling them out of the bottom. Hence, they are not fully immune due to a retraction response. Andy Shepard also collected cerianthids using the grab sampler on the Johnson-Sea-Link submersible. He was able to collect specimens with a fast "grab", also indicating they are not all that quick.
Ascidians	Sand, granule-pebble, cobble, boulder	2	>25% reductions 1 wk and 3 mo after 2 tows with prawn trawl (chain sweeps) in sand (360)
Bedforms	Sand	2	Smoothing of seafloor (see 97, 247, 325,336), assume that smaller ripples in mud and sand would be fully susceptible, larger sand waves in sand would be less susceptible, no data indicating degree of disturbance from a single tow, probably highly variable, assume 25-50% loss.
Biogenic burrows	Mud, sand	2	Major issue is smoothing of 'surface features' (97, 236, 247, 387, 408), also removal of 'mounds, tubes, and burrows' following trawling (325); no data

Feature	Substrates evaluated	Score	Notes
			indicating degree of disturbance from a single tow, assume 25-50% loss.
Biogenic depressions	Mud, sand	2	See above for biogenic burrows.
Boulder, piled	Boulder	2	Assume that displacement of piled boulders would be more likely than displacement of scattered boulders. Loss of deep crevice habitats, potentially greater effect than on piled cobbles, but boulders are more resistant to disturbance because of their size.
Boulder, scattered in sand	Boulder	0	Average 19% displacement of boulders by single tows in a deep, undisturbed environment (111), similar results in Gulf of Maine observational study (11), but no burial, so there is no loss of physical habitat. S scores are based on probability that cobble or boulder would be buried, or partially buried, by gear (higher S for cobble reflects a higher assumed likelihood of burial for smaller sediment sizes). It was assumed that if a cobble or boulder has a depression under it/beside it and it is rolled over or moved, that it is likely to have a new depression in its new location. Thus, its functional value as a habitat is the same. If the depressions under cobble/boulders are biogenic, it was assumed that the biogenic depression under the cobble or boulder is susceptible if the cobble or boulder is susceptible, thus scores of S=1 cobble, S=0 boulder.
Brachiopods	Granule-pebble, cobble, boulder	2	62% reduction in biomass after two years of experimental trawling on Scotian shelf (est 1-4 passes each year, see 194); thus a lower percentage reduction expected after single pass.
Bryozoans	Granule-pebble, cobble, boulder	1	Bushy bryozoans significantly more abundant at shallow and deep sites undisturbed by fishing on Georges Bank, emergent growth form makes them vulnerable to fishing gear, but not as much as sponges, which generally are taller (404), one of erect but flexible taxa attached to cobbles that likely passed under trawl and rockhoppers with only limited harm on Scotian shelf (157). S=1 based on best professional judgment.
Cobble, pavement	Cobble	1	Assume that largest impact would be from doors but that overall only 10-25% of feature would be lost (buried) due to size of cobbles
Cobble, piled	Cobble	3	Assume that displacement of piled cobbles would be more likely than displacement of scattered cobbles and would have greater impact because of reduced three-dimensional structure and fewer shelter-providing crevices
Cobble, scattered in sand	Cobble	1	S scores are based on probability that cobble or boulder would be buried, or partially buried, by gear (higher S for cobble reflects a higher assumed likelihood of burial for smaller sediment sizes). It was assumed that if a cobble or boulder has a depression under it/beside it and it is rolled over or moved, that it is likely to have a new depression in its new location. Thus, its functional value as a habitat is the same. If the depressions under cobble/boulders are biogenic, it was assumed that the biogenic depression under the cobble or boulder is susceptible if the cobble or boulder is susceptible, thus scores of S=1 cobble, S=0 boulder.
Corals, sea pens	Mud, sand	2	Significantly lower densities of sea pens (>100% *Ptilosarcus* sp., 80% *Stylatula* sp.) in heavily trawled area than in adjacent lightly trawled with same depth on west coast (101), no experimental before/after impact studies, S=2 based on their size (10 cm for *Pennatula aculeata*) and fact that they don't retract into bottom when disturbed (102)
Granule-pebble, pavement	Granule-pebble	1	Assume pavement broken up mostly by trawl doors and partially buried by sand stirred up by ground cables, sweep, and net, with "loss" of 10-25% of this feature after a single tow.

Feature	*Substrates evaluated*	*Score*	*Notes*
Granule-pebble, scattered in sand	Granule-pebble	1	Rock-hoppers left 1-8 cm deep furrows in low energy pebble bottom (111) - effects of smaller ground gear (e.g., rollers, chain sweeps) probably less severe; granules and pebbles are small and are susceptible to burial in sand, reducing amount of hard substrate available for growth of emergent epifauna,
Hydroids	Mud, sand, granule-pebble, cobble, boulder	1	Significant decrease in hydroid biomass after trawling (12-14 tows) on Scotian shelf, erect but flexible morphology, low relief, reduces vulnerability to trawls and dredges (see bryozoans) (157); significantly more abundant at deep sites on George Bank undisturbed by trawls and scallop dredges, no difference at shallow sites where densities were lower (404); aggregations of *Corymorpha pendula* "absent" in trawl and scallop dredge paths in coarse sand on Stellwagen Bank (11).
Macroalgae	Granule-pebble, cobble, boulder	1	Flexible body morphology, relatively short height of many species (e.g., red algae in deeper water), assumed to limit removal/structural loss to 10-25% per tow. Although the larger kelps (*Laminaria* spp.) would likely be more susceptible, kelps are relatively rare in their distribution offshore, so the score is intended reflect the susceptibility of smaller algae.
Mollusks, epifaunal bivalve, *Modiolus modiolus*	Mud, sand	1	80% reductions in abundance of epifaunal bivalve *Hiatella* sp. Barents Sea after 10 tows (214); >60% reduction in biomass of horse mussels in cobble on Scotian shelf after 2 years of repeated tows (1-4 each year), 8% mussels remaining on bottom were damaged after 1st year (194). *Pinna* sp. reduced >25% 1 wk and 3 mos after 2 tows in mud (360). Horse mussels sensitive to bottom fishing (long-lived, thin-shelled - see 404), partially buried in mud and sand, therefore assumed to be less vulnerable than in gravel substrates.
	Granule-pebble, cobble, boulder	2	
Mollusks, epifaunal bivalve, *Placopecten magellanicus*	Sand, granule-pebble, boulder	1	Trawls not as efficient as scallop dredges at removing scallops from bottom (S=2 for scallop dredges)
Polychaetes, *Filograna implexa*	Sand, granule-pebble, cobble, boulder	2	Significantly more at shallow sites disturbed by trawling and dredging on Georges Bank, fewer at deep disturbed sites, tubes heavily affected by bottom fishing because they can be easily crushed and require stable substrate (404), susceptibility based on data for *T. cincinnatus* (see below).
Polychaetes, other tube-dwelling	Granule-pebble, cobble, boulder	2	37% reduction in biomass of *Thelepus cincinnatus* on Scotian shelf after two years of experimental trawling (1-4 tows/yr), 9% on bottom damaged (194)
Sediments, surface/subsurface	Mud, sand	2	Doors create furrows up to 20 cm deep, 40 cm wide, with berms 10-20 cm high in mud (92, 97, 236, 320, 372, 88, 247, 164, 277, 406, 336, 313, 408), shallower furrows in sand (97, 120, 325), but effect is limited to doors. Ground rope and tickler chains also leave marks, mostly in fine sediment (247, 406). Major issue is re-suspension: trawling causes loss of fine surficial sediment (88, 236, 277, 325, 406); also removal of flocculent organic material (325). Little or no evidence that remaining sediments (mud or sand) are re-sorted (35, 325, 372, 408), some evidence that sand is compacted (336), but mud bottom is not "plowed" (236). Assume all fine surficial sediment in path of trawl is subject to re-suspension during a tow, but mud is more susceptible than sand because of its biogenic structure and because it is more easily re-suspended by turbulence. Scores based on professional judgment and comparison with hydraulic dredges which have much greater effects in sand, esp sub-surface sediments. Aside from door tracks, trawls primarily affect top few cm of sediment, reducing functional

Feature	*Substrates evaluated*	*Score*	*Notes*
			value of habitat for prey organisms. (Also see scallop dredges).
Shell deposits	Sand, granule-pebble	1	Assume that displacement is more likely than burying or crushing, and that the effects of a single tow are minor (mostly trawl doors) because shells are large and aggregated in a mud or sand matrix.
Sponges	Sand, granule-pebble, cobble, boulder	2	Variations in morphology likely to influence susceptibility; values given in literature are highly variable. In 382, 30-50% reduction in density after one tow (mostly barrel sponge, other spp not signif affected), with 32% damage to sponges remaining on bottom. In 111, 30% reduction in density, heavy damage to some types (67% for vase sponges), very little damage to others (14% "finger" sponges knocked over). In 387, net removed average 14% per tow (all sizes), but removed 40-70% sponges >50 cm - all large branched sponges that did not pass into net were either removed by footrope or crushed under it. In 248, all epifauna >20cm high reduced (average per tow) by 15% - 50% in 4 tows - but sponges are more susceptible. 10% video frames on Jeffreys Bank (GOM) before trawling with >25% cover (max 35%), no frame with >7% 6 yrs later, after area was trawled.

4.2.2 New Bedford-style scallop dredge

In nearly all cases, both S and R scores are assumed to be the same for bottom trawls and scallop dredges.[5] This assumption seems reasonable since the disturbance caused by both gears is similar: aside from the trawl doors, both gears cause a scraping and smoothing of bottom features and a re-suspension of fine sediments. These effects are primarily limited to the sediment surface. While it is acknowledged that scallop gear may skim over the seabed somewhat, the features assessed, particularly the biological features, have a higher relief off the seafloor and thus are expected to be contacted by the gear. Furthermore, the scallop dredge impacts literature does not provide much support for a difference in S/R coding between gear types. In particular, for trawl gear matrix evaluations, the most useful types of studies were those that estimated reductions in features following a single or multiple passes of experimentally fished gear. However, fewer scallop dredge impact studies were designed in this way, and those that did consider single pass impacts did so for geological features only. The studies that considered scallop dredge impacts to biological features were often comparative examinations of unfished areas vs. areas fished by both dredges and trawls. In these instances, it is difficult to make inferences about the impacts of scallop dredges alone.

Table 24 shows scallop dredge gear S/R values, grouped by substrate and then by feature. Scores are the same for high and low energy unless otherwise noted. Table 25 summarizes the justifications for susceptibility scores for scallop dredge gear. Recovery

[5] Despite the close similarities in the matrices, in terms of model outputs, the resulting adverse effects estimated for the two gear types will vary based on differences in gear dimensions, number of tows, and fishing locations.

scores for all gear types are combined into two tables at the conclusion of the matrix results section (Table 31 – geological, Table 32 - biological).

Table 24 – Scallop dredge matrices. Susceptibility (S) values are coded as follows: 0: 0-10%; 1: >10-25%; 2: >25-50%; 3: >50%. Recovery (R) values are coded as follows: 0: <1 year; 1: 1-2 years; 2: 2-5 years; 3: >5 years. The literature column indicates those studies identified during the literature review as corresponding to that combination of gear, feature, energy, and substrate. The studies referenced here were intended to be inclusive, so any particular study may or may not have directly informed the S or R score. Any literature used to estimate scores is referenced in Table 25 (Scallop dredge S), Table 31 (Geo R), and Table 32 (Bio R).

Gear: Scallop					
Substrate: Mud					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Biogenic burrows (G)	filling, crushing	none	none	2	0
Biogenic depressions (G)	filling	11	11	2	0
Sediments, surface/subsurface (G)	resuspension, compression, geochem, sorting, mixing	42, 236, 256, 391	none	2	0
Amphipods, tube-dwelling (B) – see note	crushing	228, 359	217	1	0
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	228	217	2	2
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	228	none	2 (low energy only)	2 (low energy only)
Hydroids (B)	breaking, crushing, dislodging, displacing	11, 228	11	1	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	42, 43, 256	203, 217	1	3
Substrate: Sand					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Bedforms (G)	smoothing	11, 225, 236, 359	n/a	2 (high energy only)	0 (high energy only)
Biogenic burrows (G)	filling, crushing	225	none	2	0
Biogenic depressions (G)	filling	11, 225 ,359	11, 359	2	0
Sediments, surface/subsurface (G)	resuspension, compression, geochem, sorting/mixing	42, 119, 225, 236, 256, 352, 359, 391	none	2	0
Shell deposits (G)	displacing, burying, crushing	11, 225, 352	11	1	1 (high), 2 (low)
Amphipods, tube-dwelling (B) – see note	crushing	225, 228, 359	217	1	0
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	70, 71, 228, 352	217	2	2
Ascidians (B)	breaking, crushing, dislodging, displacing	11, 352	203	2	1
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	228	none	2 (low energy only)	2 (low energy only)
Hydroids (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 225, 228, 352	11	1	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	42, 43, 69, 70, 71, 158, 352	203, 217	1	3

Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B) – see note	breaking, crushing	42, 43, 69, 70, 71, 158, 352	203, 217	2	2
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 158, 352	11, 217	2	2
Sponges (B)	breaking, crushing, dislodging, displacing	11, 70, 71, 225, 228, 352	203	2	2
Substrate: Granule-pebble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Granule-pebble, pavement (G)	burial, mixing, homogenization	none		1 (high energy only)	0 (high energy only)
Granule-pebble, scattered, in sand (G)	burial, mixing	11, 43, 225, 352	11	1	0 (high), 2 (low)
Shell deposits (G)	burying, crushing, displacing	11, 225, 352	11	1	1 (high), 2 (low)
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	11, 70, 71, 203, 225, 228, 352	none	2	2
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	70, 71, 228, 352, 404	217	2	2
Ascidians (B)	breaking, crushing, dislodging, displacing	352	203	2	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	none	none	2	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 225, 228, 352, 404	11	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 225, 228, 352, 404	11	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	43, 69, 70, 71, 158, 352, 404	203, 217	2	3
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B) – see note	breaking, crushing	43, 69, 70, 71, 158, 352, 404	203, 217	2	2
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 158, 352, 404	11, 217	2	2
Polychaetes, other tube-dwelling (B) – see note	crushing, dislodging	11, 69, 70, 71, 158, 352, 404	11, 217	2	1
Sponges (B)	breaking, dislodging, displacing	11, 70, 71, 225, 228, 352, 404	11, 203	2	2
Substrate: Cobble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Cobble, pavement (G)	burial, mixing, homogenization	none	n/a	1 (high energy only)	0 (high energy only)
Cobble, piled (G)	smoothing, displacement	none	none	3	3
Cobble, scattered in sand (G)	burial, mixing, displacement	11, 43, 352	11	1	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	11, 70, 71, 228, 352	none	2	2
Ascidians (B)	breaking, crushing, dislodging, displacing	11, 352	11	2	1

Brachiopods (B)	breaking, crushing, dislodging, displacing	none	none	2	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 228, 352, 404	11	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 228, 352, 404	11	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	43, 69, 70, 71, 158, 352, 404	217	2	3
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B) – see note	breaking, crushing	43, 69, 70, 71, 158, 352, 404	217	2	2
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	11, 69, 70, 71, 158, 352, 404	11, 217	2	2
Polychaetes, other tube-dwelling (B) – see note	crushing, dislodging	11, 69, 70, 71, 158, 352, 404	11, 217	2	1
Sponges (B)	breaking, dislodging, displacing	11, 70, 71, 228, 352, 404	11	2	2
Substrate: Boulder					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Boulder, piled (G)	displacement	none	none	2	3
Boulder, scattered, in sand (G)	displacement	11, 43, 352	11	0	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	11, 352	none	2	2
Ascidians (B)	breaking, crushing, dislodging, displacing	11, 352	11	2	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	none	none	2	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	11, 352	11	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	11, 352	11	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	43, 352	217	2	3
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	11, 352	11, 217	2	2
Polychaetes, other tube-dwelling (B) – see note	crushing, dislodging	11, 352	11, 217	2	1
Sponges (B)	breaking, dislodging, displacing	11, 352	11, 217	2	2

Note: Only references 217 and 225 are specific to tube-dwelling amphipods, the rest are derived from entries in database coded as prey/amphipods. Similarly, references for epifaunal bivalves/ scallops and other tube-dwelling polychaetes are based on database entries for epifaunal bivalves/mussels and polychaetes/F. implexa.

Table 25 – Scallop dredge susceptibility summary for structural features.

Feature	*Substrates evaluated*	*Score*	*Notes*
Amphipods, tube-dwelling	Mud, sand	1	See trawls
Anemones, actinarian	Granule-pebble,	2	See trawls

Feature	Substrates evaluated	Score	Notes
	cobble, boulder		
Anemones, cerianthid burrowing	Mud, sand, granule-pebble	2	See trawls
Ascidians	Sand, granule-pebble, cobble, boulder	2	*Molgula arenata* removed from sand in linear patterns by scallop dredges on Stellwagen Bank (11), degree of impact assumed to be same as trawls
Bedforms	Sand	2	Multiple tows reduced frequency of sand waves in treatment areas compared to control areas (359), no information for single tows.
Biogenic burrows	Mud, sand	2	Multiple tows reduced frequency of amphipod tube mats in treatment areas compared to control areas (359), no information for single tows.
Biogenic depressions	Mud, sand	2	Multiple tows reduced frequency of biogenic depressions in treatment areas compared to control areas (359), no information for single tows.
Boulder, piled	Boulder	2	No information, see trawls.
Boulder, scattered in sand	Boulder	0	Single tows plowed boulders (43), but probability of burial is assumed to be low (see trawls).
Brachiopods	Granule-pebble, cobble, boulder	2	See trawls
Bryozoans	Granule-pebble, cobble, boulder	1	See trawls
Cobble, pavement	Cobble	1	Single tows dislodged cobbles (43)
Cobble, piled	Cobble	3	
Cobble, scattered in sand	Cobble	1	See trawls
Corals, sea pens	Mud, sand	2	See trawls
Granule-pebble, pavement	Granule-pebble	1	
Granule pebble, scattered in sand	Granule-pebble	1	Single tows overturned and buried gravel fragments (43)
Hydroids	Mud, sand, granule-pebble, cobble, boulder	1	See trawls
Macroalgae	Granule-pebble, cobble, boulder	1	See trawls
Mollusks, epifaunal bivalve, *Modiolus modiolus*	Mud, sand	1	See trawls
	Granule-	2	

Feature	*Substrates evaluated*	*Score*	*Notes*
	pebble, cobble, boulder		
Mollusks, epifaunal bivalve*, Placopecten magellanicus*	Sand, granule-pebble, cobble	2	Scallop dredge efficiency estimated to be 54% per tow (Gedamke et al. 2005), approximately 30% of scallops slightly buried after passage of 8 m dredge (42). Even if removal rates per tow are high (>50%), shucked shells returned to bottom still provide habitat value, so loss of functional value was assumed to be 25-50%.
Polychaetes, *Filograna implexa*	Sand, granule-pebble, cobble, boulder	2	See trawls
Polychaetes, other tube-dwelling	Granule-pebble, cobble, boulder	2	See trawls
Sediments, surface and subsurface	Mud, sand	2	Single tow lowered mud sediment surface 2 cm, mixed finer sediment to 5-9 cm, increasing mean grain size in upper 5 cm (236). Skids left furrows 2 cm deep in mixed mud/sand bottom, depression from tow bar, marks made by rings in chain belly of dredge (42, 43). Multiple tows in mud/muddy sand caused loss of fine sediments and reduced food value in top few cm (391). In sand, single tows re-suspended sand (43), multiple tows re-worked top 2-6 cm of sediments (359). Effects expected to be especially consequential in mud due to presence of biogenic matrix and because mud is more easily re-suspended by turbulence than sand (see trawls).
Shell deposits	Sand, granule-pebble	1	Individual dredge tows dispersed shell fragments in troughs between sand waves (11), degree of impact assumed to be same as trawls.
Sponges	Sand, granule-pebble, cobble, boulder	2	Significantly more sponges at shallow sites undisturbed by trawls and scallop dredges on Georges Bank two years after area was closed, but not at deeper sites (404); for before/after impact experiments, see trawls.

4.2.3 Hydraulic clam dredges

Susceptibility and recovery are only evaluated for hydraulic clam dredges for sand and granule-pebble substrates because this gear cannot be operated in mud or in rocky habitats (NEFSC 2002, Wallace and Hoff 2005). This is because hydraulic dredges harvest clams by injecting pressurized water into sandy sediments to a depth of 8-10 inches, rather than dragging over the sediment surface like bottom trawls and scallop dredges. Water pressures vary from 50 lbs per square inch (psi) in coarse sand to 110 psi in finer sediments (NEFSC 2002). In the absence of much published information on the degree to which benthic habitat features are susceptible to this gear, professional judgment relied on the presumption that these dredges have a more severe immediate impact on surface and sub-surface habitat features than other fishing gears used in the Northeast region.

Table 26 – Hydraulic clam dredge matrices. Susceptibility (S) values are coded as follows: 0: 0-10%; 1: >10-25%; 2: >25-50%; 3: >50%. Recovery (R) values are coded as follows: 0: <1 year; 1: 1-2 years; 2: 2-5 years; 3: >5 years. The literature column indicates those studies idenfied during the literature review as corresponding to that combination of gear, feature, energy, and substrate. The studies referenced here were intended to be inclusive, so any particular study may or may not have directly informed the S or R score. Any literature used to estimate scores is referenced in Table 27 (Hydraulic clam dredge S), Table 31 (Geo R), and Table 32 (Bio R).

Gear: Hydraulic					
Substrate: Sands					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Bedforms (G)	smoothing	none	n/a	3 (high energy only)	0 (high energy only)
Biogenic burrows (G)	filling, crushing	none	121	3	1 (high), 2 (low)
Biogenic depressions (G)	filling	none	none	3	0
Sediments, surface/subsurface (G)	resuspension, compression, geochem, fluidization and resorting	140, 232, 373	121	3	1 (high), 2 (low)
Shell deposits (G)	burying, crushing, displacing	none	121	2	1 (high), 2 (low)
Amphipods, tube-dwelling (B) – see note	crushing	140, 373	122	3	0
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	none	none	3	3
Ascidians (B)	breaking, crushing, dislodging, displacing	none	none	3	1
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	none	none	3 (low energy only)	2 (low energy only)
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	3	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	287	none	2	3
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B) – see note	breaking, crushing	287	none	1	2
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	none	none	3	2
Sponges (B)	breaking, crushing, dislodging, displacing	none	none	3	2
Substrate: Granule-pebble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Granule-pebble, pavement (G)	burial, mixing, homogenization	none	none	3 (high energy only)	2 (high energy only)
Granule-pebble, scattered, in sand (G)	burial, mixing	none	None	3	1 (high), 2 (low)
Shell deposits (G)	burying, crushing, displacing	none	none	2	1 (high), 2 (low)
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	none	none	3	2
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	none	none	3	3

Ascidians (B)	breaking, crushing, dislodging, displacing	none	none	3	1 (high), 2 (low)
Brachiopods (B)	breaking, crushing, dislodging, displacing	none	none	3	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	none	none	3	1 (high), 2 (low)
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	3	1 (high), 2 (low)
Macroalgae (B)	breaking, dislodging	none	none	3 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	3	3
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B) – see note	breaking, crushing	none	none	1	2
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	none	none	3	2
Polychaetes, other tube-dwelling (B)	crushing, dislodging	none	none	3	1 (high), 2 (low)
Sponges (B)	breaking, dislodging, displacing	none	none	3	2

Note: All references for tube-dwelling amphipods are derived from entries in database coded as prey/amphipods. Similarly, references for epifaunal bivalves/ scallops are based on database entries for epifaunal bivalves/mussels.

Table 27 – Hydraulic dredge gear susceptibility summary for structural features.

Feature	*Substrates evaluated*	*Score*	*Notes*
Amphipods, tube-dwelling	Sand	3	Assume pulverizing effect of water pressure would cause 100% destruction of tubes which are soft and attached to bottom, releasing animals into water column where they would be highly susceptible to predation
Anemones, actinarian	Granule-pebble	3	Anemones would be removed from substrate, some might re-attach and survive
Anemones, cerianthid burrowing	Sand, granule-pebble	3	Would expect that most anemones (and tubes) in the path of the dredge would be uprooted due to the depth that pressurized water penetrates into the seabed. Impact could be considerable for uprooted anemones since they are soft bodied and cannot re-bury.
Ascidians	Sand, granule-pebble	3	Tunicates presumed to be highly susceptible to downward effects of water pressure because they are soft-bodied.
Bedforms	Sand	3	Assume that due to fluidizing action of the gear, any smaller bedforms would be completely smoothed. Although larger sand waves might only partially damaged, > 50% susceptibility of feature still expected.
Biogenic burrows	Sand	3	Density of burrows reduced by up to 90%, smoothing of seafloor, after 12 overlapping tows (not 100% replicated) (121)
Biogenic depressions	Sand	3	Any depressions in path of gear would be filled in as sand is fluidized and re-settles in dredge path (see surface sediments)
Brachiopods	Granule-pebble	3	Assume that brachiopods attached to gravel in path of dredge would be removed from substrate.
Bryozoans	Granule-pebble	3	See brachiopods.
Corals, sea pens	Sand	3	Assume nearly complete up-rooting of sea pens in dredge path, some of which could re-bury and survive (102)
Granule-pebble, pavement	Granule-pebble	3	Assume that granule-pebble pavement would be affected similarly to scattered granule-pebble.

Feature	*Substrates evaluated*	*Score*	*Notes*
Granule-pebble, scattered, in sand	Granule-pebble	3	Assume that most granule-pebble in path of dredge would be buried due to re-sorting of sediment (see sub-surface sediment).
Hydroids	Sand, granule-pebble	3	Hydroids are very susceptible to effects of this gear (delicate, soft-bodied)
Macroalgae	Granule-pebble	3	Algae in dredge path would be buried or dislodged from substrate with high mortalities.
Mollusks, epifaunal bivalve, *Modiolus modiolus*	Sand Granule-pebble	2 3	Some mussels dislodged from bottom might re-settle and survive outside dredge paths if they can attach to other mussels or to granule-pebble substrate, but available hard substrate in dredge path would be buried under sand.
Mollusks, epifaunal bivalve, *Placopecten magellanicus*	Sand, granule-pebble	1	Assume most scallops caught in clam dredges are discarded, undamaged, and return to bottom
Polychaetes, *Filograna implexa*	Granule-pebble	3	Assume that *F. implexa* are highly susceptible to breakage/crushing action of water pressure.
Polychaetes, other tube-dwelling	Granule-pebble	3	Assume that most granule-pebble in path of dredge that could be used as substrate would be buried due to re-sorting of sediment (see sub-surface sediment).
Sediments, surface and subsurface	Sand	3	Action of this gear fluidizes sediment to depth of 30 cm in bottom of trench and 15 cm in sides (373), compromising functional value of sedimentary habitat for infauna. In addition, resorting of sediments was observed in dredge path – coarser sediments at bottom (232). Dredges create steep-sided trenches 8-30 cm deep with sediment mounds along edges (140, 244, 245, 256, 287, 373). In path of dredge, assume that nearly all of finer surface sediments will be suspended and re-settle outside dredge path, thus functional value will be compromised substantially.
Shell deposits	Sand	2	Shell deposits in path of dredge would likely be somewhat susceptible to burial in dredge paths and by sand that is re-suspended and settles outside of dredge path, but lighter shell fragments re-settle on top of trench (232), so impact may be <50%.
Sponges	Sand, granule-pebble	3	Assume that most granule-pebble in path of dredge that could be used as substrate would be buried due to re-sorting of sediment (see sub-surface sediment).

4.2.4 Fixed gears

Regardless of gear type, groundline movement during setting, soaking, and hauling was assumed to be the primary effect of fixed gears on the seabed. In addition, for trap gear, the possible crushing effect of the trap was considered. Data are sparse regarding the extent to which gears are dragged across the seabed during setting and hauling, or how much they move due to wave action during soaking. This is further discussed in the area swept modeling section (6.0).

4.2.4.1 Demersal longline and sink gillnet

Below, Table 28 shows demersal longline and sink gillnet S/R values, grouped by substrate and then by feature. High and low energy scores for a given feature-gear-substrate combination are the same, except as noted. These gears are considered separately at first but ultimately assigned the same scores, so they are presented together below. No literature specific to the effects of either gear type on seabed features was available.

Table 28 – Demersal longline and sink gillnet matrices. Susceptibility (S) values are coded as follows: 0: 0-10%; 1: >10-25%; 2: >25-50%; 3: >50%. Recovery (R) values are coded as follows: 0: <1 year; 1: 1-2 years; 2: 2-5 years; 3: >5 years. The literature column indicates those studies idenfied during the literature review as corresponding to that combination of gear, feature, energy, and substrate. The studies referenced here were intended to be inclusive, so any particular study may or may not have directly informed the S or R score. Any literature used to estimate scores is referenced in Table 30 (Fixed gear S), Table 31 (Geo R), and Table 32 (Bio R).

Gear: Longline/Gillnet					
Substrate: Mud					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Biogenic burrows (G)	filling, crushing	none	none	1	0
Biogenic depressions (G)	filling	none	none	0	0
Sediments, surface/subsurface (G)	resuspension, compression, geochem, mixing, sorting	none	none	0	0
Amphipods, tube-dwelling (B)	crushing	none	none	1	0
Anemones, ceríanthid burrowing (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	none	none	1 (low energy only)	0 (low energy only)
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	0	0
Substrate: Sand					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Bedforms (G)	smoothing	none	n/a	0 (high energy only)	0 (high energy only)
Biogenic burrows (G)	filling, crushing	none	none	1	0
Biogenic depressions (G)	filling	none	none	1	0
Sediments, surface/subsurface (G)	resuspension, compression, geochem, mixing, sorting	none	none	0	0
Shell deposits (G)	displacing, burying, crushing	none	none	0	0
Amphipods, tube-dwelling (B)	crushing	none	none	1	0
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Ascidians (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	none	none	1 (low energy only)	0 (low energy only)

Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	0	0
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B)	breaking, crushing	none	none	0	0
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Sponges (B)	breaking, crushing, dislodging, displacing	none	none	0	1
Substrate: Granule-pebble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Granule-pebble, pavement (G)	burial, mixing, homogenization	none	n/a	0 (high energy only)	0 (high energy only)
Granule-pebble, scattered, in sand (G)	burial, mixing	none	none	0	0
Shell deposits (G)	burying, crushing, displacing	none	none	0	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Ascidians (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	0	0
Mollusks, epifaunal bivalve, P*lacopecten magellanicus* (B)	breaking, crushing	none	none	0	0
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Polychaetes, other tube-dwelling (B)	crushing, dislodging	none	none	1	1
Sponges (B)	breaking, dislodging, displacing	none	none	1	1
Substrate: Cobble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Cobble, pavement (G)	burial, mixing, homogenization	none	n/a	0 (high energy only)	0 (high energy only)
Cobble, piled (G)	smoothing, displacement	none	none	1	3
Cobble, scattered in sand (G)	burial, mixing, displacement	none	none	0	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Ascidians (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)

Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	0	0
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B)	breaking, crushing	none	none	0	0
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Polychaetes, other tube-dwelling (B)	crushing, dislodging	none	none	1	1
Sponges (B)	breaking, dislodging, displacing	none	none	1	1
Substrate: Boulder					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Boulder, piled (G)	displacement	none	none	0	3
Boulder, scattered, in sand (G)	displacement	none	none	0	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Ascidians (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Macroalgae (B)	breaking, crushing, dislodging, displacing	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	0	0
Polychaetes, *Filograna implexa* (B)	crushing, dislodging	none	none	1	2
Polychaetes, other tube-dwelling (B)	breaking, dislodging, displacing	none	none	1	1
Sponges (B)	breaking, crushing, dislodging, displacing	none	none	1	1

4.2.4.2 Lobster and deep-sea red crab traps

Below, Table 29 shows trap gear S/R values, grouped by substrate and then by feature. High and low energy scores for a given feature-gear-substrate combination are the same, except as noted. The scores are slightly different from the longline/gillnet scores. In particular, susceptibility of 1 vs. 0 was estimated for biogenic depressions, surface/subsurface sediments, and mussels for trap gears.

Table 29 – Lobster and deep-sea red crab trap matrices. Susceptibility (S) values are coded as follows: 0: 0-10%; 1: >10-25%; 2: >25-50%; 3: >50%. Recovery (R) values are coded as follows: 0: <1 year; 1: 1-2 years; 2: 2-5 years; 3: >5 years. The literature column indicates those studies idenfied during the literature review as corresponding to that combination of gear, feature, energy, and substrate. The studies referenced here were intended to be inclusive, so any particular study may or may not have directly informed the S or R score. Any literature used to estimate scores is referenced in Table 30 (Fixed gear S), Table 31 (Geo R), and Table 32 (Bio R).

Gear: Trap					
Substrate: Mud					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Biogenic burrows (G)	filling, crushing	none	none	1	0
Biogenic depressions (G)	filling	none	none	1	0

Sediments, surface/subsurface (G)	resuspension, compression, geochem, mixing, sorting	none	none	1	0
Amphipods, tube-dwelling (B)	crushing	none	none	1	0
Anemones, ceriantid burrowing (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	102	102	1 (low energy only)	0 (low energy only)
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	0	0
Substrate: Sand					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Bedforms (G)	smoothing	none	none	0 (high energy only)	0 (high energy only)
Biogenic burrows (G)	filling, crushing	none	none	1	0
Biogenic depressions (G)	filling	none	none	1	0
Sediments, surface/subsurface (G)	resuspension, compression, geochem, mixing, sorting	none	none	1	0
Shell deposits (G)	crushing	none	none	0	0
Amphipods, tube-dwelling (B)	crushing	none	none	1	0
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	184	none	1	2
Ascidians (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Corals, sea pens (B)	breaking, crushing, dislodging, displacing	none	none	1 (low energy only)	0 (low energy only)
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	0	0
Mollusks, epifaunal bivalve*, Placopecten magellanicus* (B)	breaking, crushing	none	none	0	0
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Sponge (B)	breaking, crushing, dislodging, displacing	none	none	0	1
Substrate: Granule-pebble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Granule-pebble, pavement (G)	burial, mixing, homogenization	none	n/a	0 (high energy only)	0 (high energy only)
Granule-pebble, scattered, in sand (G)	burial, mixing	none	none	0	0
Shell deposits (G)	burying, crushing, displacing	none	none	0	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Anemones, cerianthid burrowing (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Ascidians (B)	breaking, crushing, dislodging, displacing	102	102	1	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	102	102	1	1

Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	1	0
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B)	breaking, crushing	none	none	0	0
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	102	102	1	2
Polychaetes, other tube-dwelling (B)	crushing, dislodging	102	102	1	1
Sponges (B)	breaking, dislodging, displacing	102	102	1	1
Substrate: Cobble					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Cobble, pavement (G)	burial, mixing, homogenization	none	n/a	0 (high energy only)	0 (high energy only)
Cobble, piled (G)	smoothing, displacement	none	none	1	3
Cobble, scattered in sand (G)	burial, mixing, displacement	none	none	0	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Ascidians (B)	breaking, crushing, dislodging, displacing	102	102	1	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	102	102	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)
Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	1	0
Mollusks, epifaunal bivalve, *Placopecten magellanicus* (B)	breaking, crushing	none	none	0	0
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	102	102	1	2
Polychaetes, other tube-dwelling (B)	crushing, dislodging	102	102	1	1
Sponges (B)	breaking, dislodging, displacing	102	102	1	1

Substrate: Boulder					
Feature name and class – G (Geological) or B (Biological)	**Gear effects**	**Literature high**	**Literature low**	**S**	**R**
Boulder, piled (G)	displacement	none	none	0	3
Boulder, scattered, in sand (G)	displacement	none	none	0	0
Anemones, actinarian (B)	breaking, crushing, dislodging, displacing	none	none	1	2
Ascidians (B)	breaking, crushing, dislodging, displacing	102	102	1	1
Brachiopods (B)	breaking, crushing, dislodging, displacing	Add	Add	1	2
Bryozoans (B)	breaking, crushing, dislodging, displacing	102	102	1	1
Hydroids (B)	breaking, crushing, dislodging, displacing	none	none	1	1
Macroalgae (B)	breaking, dislodging	none	n/a	1 (high energy only)	1 (high energy only)

Mollusks, epifaunal bivalve, *Modiolus modiolus* (B)	breaking, crushing, dislodging, displacing	none	none	1	0
Polychaetes, *Filograna implexa* (B)	breaking, crushing, dislodging, displacing	102	102	1	2
Polychaetes, other tube-dwelling (B)	crushing, dislodging	102	102	1	1
Sponges (B)	breaking, dislodging, displacing	102	102	1	1

4.2.4.3 Fixed gear susceptibility summary

Fixed gear susceptibility was generally similar across gear types, and susceptibility values are lower than those determined for trawls and dredges. Little research was available on which to base the fixed gear susceptibility values, but those papers that were used are referenced in the matrices for each gear type. Table 30 summarizes the rationale behind the structural feature susceptibility values for all the fixed gears. Recovery scores for all gear types are combined into two tables at the conclusion of the matrix results section (Table 31 – geological, Table 32 - biological). In some cases, faster recovery was expected to follow a fixed gear impact as compared to a mobile gear impact, because the gear effects are different between fixed and mobile gears. These differences are noted in the recovery summary table.

Table 30 – Fixed gears susceptibility summary for all structural features. When applicable, reasons for differences in values between gear types and/or substrates are summarized.

Feature	*Substrates evaluated*	*Score*	*Susceptibility*
Amphipods, tube-dwelling	Mud, sand	1	The percentage of amphipods impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur.
Anemones, actinarian	Granule-pebble, cobble, boulder	1	The percentage of anemones impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur.
Anemones, cerianthid burrowing	Mud, sand, granule-pebble	1	The percentage of burrowing anemones impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur.
Ascidians	Sand, granule-pebble, cobble, boulder	1	The percentage of tunicates impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur. Study 102 found evidence of tunicate detachment likely from setting and hauling back traps.
Bedforms	Mud, sand	0	Currently there is no evidence that any fixed gears will alter bed forms. Gear will sit atop bedforms.
Biogenic burrows	Mud, sand	1	All three gears can collapse a burrow, especially the anchor for longline and gillnet gears. However, unlikely that the longline, gillnet or trap bottom lines will cause significant damage within 1 meter of the line/net.
Biogenic depressions	Mud, sand	0 (mud), 1 (sand)	All three gears can cause damage to biogenic depressions, especially the anchor (gillnet/longlines). However, unlikely that the longline or gillnet will cause significant damage within 1 meter of the line/net.
Boulder, piled	Boulder	0	Fixed gears do not impact this geological feature.

Feature	*Substrates evaluated*	*Score*	*Susceptibility*
Boulders, scattered in sand	Boulder	0	Fixed gears do not impact this geological feature.
Brachiopods	Granule-pebble, cobble, boulde	1	The percentage of brachiopds impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur.
Bryozoans	Granule-pebble, cobble, boulde	1	The percentage of erect bryozoans impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur. Study 102 found some damage to large individuals of the ross coral, *Pentapora foliacea* likely caused by hauling traps.
Cobble, pavement	Cobble	0	Fixed gears do not impact this geological feature.
Cobble, piled	Cobble	1	Fixed gear could dislodge piled cobbles if dragged across them.
Cobble, scattered in sand	Cobble	0	Fixed gears do not impact this geological feature.
Corals, sea pens	Mud, sand	1	The percentage of sea pens impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur. Study 102 found that sea pens off the coast of Great Britain bent but did not break under the weight of crustacean traps. However, traps used in NE US are much heavier and likely would cause at least some damage.
Granule-pebble, pavement	Granule-pebble	0	Fixed gears do not impact this geological feature.
Granule-pebble, scattered in sand	Granule-pebble	0	Fixed gears do not impact this geological feature.
Hydroids	Mud, sand, granule-pebble, cobble, boulder	1	The percentage of hydroids impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur. Study 184 found lower hydroid biomass in areas that were fished heavily.
Macroalgae	Granule-pebble, cobble, boulde	1	Fixed gear impacts on macroalgae are likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur.
Mollusks, epifaunal bivalve	Mud, sand, granule-pebble, cobble, boulder	0	Long-line and gillnet gears likely do not impact this biological feature. Traps are likely to crush some bivalves that exist on hard substrates such as mussels.
Polychaetes, *Filograna implexa*	Sand, granule-pebble, cobble, boulder	1	Colonial tube worms are very fragile, and consequently are susceptible to damage via contact with anchors, gillnets, bottom lines, and traps. However, it is unlikely that more than 25% of colonial tube worm aggregations would be removed within the 1 m swath of potential impact adjacent to a gillnet, long-line, or trap bottom line.

Feature	*Substrates evaluated*	*Score*	*Susceptibility*
Polychaetes, other tube-dwelling	Granule-pebble, cobble, boulder	1	Colonial tube worms are very fragile, and consequently are susceptible to damage via contact with anchors, gillnets, bottom lines, and traps. However, it is unlikely that more than 25% of colonial tube worm aggregations would be removed within the 1 m swath of potential impact adjacent to a gillnet, long-line, or trap bottom line.
Sediments, surface and subsurface	Mud, sand	0, 1 (traps)	Sediment impacts expected to be limited; some compression due to traps, so score of 1
Shell deposits	Mud, sand, granule-pebble, cobble, boulder	0	Fixed gears do not impact this geological feature.
Sponges	Mud, sand, granule-pebble, cobble, boulder	0	The percentage of sponges impacted by fixed gear is likely very low except for direct contact with the trap or anchors. It is unlikely that much damage will occur within 1 m of the groundline/net, though some abrasion could occur. Study 102 found evidence of sponge detachment likely from setting and hauling back traps.

4.2.5 Recovery– all gear types

In general, recovery values are determined to be more dependent on the intrinsic characteristics of the features themselves than on the gear type causing the impact or on the substrate, except in cases where gear impacts are thought to vary substantially between gear types. Thus, for most features, recovery varies slightly between the following three groupings: trawls/scallop dredges, hydraulic dredges, and fixed gears. Recovery values are allowed to vary by high and low energy, however, for biological features, recovery scores are typically the same between energy environments, with the exception of some of the hydraulic dredge scores in granule-pebble. Recovery of lost habitat value provided by structure-forming features or bottom sediments is interpreted to mean the estimated time (in years) that it would take to restore the functional value provided by the feature before it is disturbed. Because disturbance can cause the partial or complete removal of geological features, complete removal of organisms, or damage to organisms that remain in place, recovery times for biological features are evaluated – as much as possible – in terms of how long it would take to replace organisms of the same size and aggregations of organisms (e.g., mussel beds, amphipod tube mats) of the same density and areal coverage, by means of reproduction and growth. Some of the required information is available from experimental studies and comparisons of benthic communities in areas open and closed to commercial fishing, and some is based on life histories (growth, reproductive strategies, longevity) of the affected organisms. In most cases there is not enough information available to make very informed decisions, so recovery scores required a considerable amount of professional judgment. Another complicating problem is that many biological features (e.g., mussels) included a number of species with different recovery potentials, so overall R scores tended towards intermediate values.

Table 31 – Recovery summary for all geological features, by, substrate, gear type, and energy.

Feature	*Substrate**	*Gear type**	*Recovery score high energy*	*Recovery summary high energy*	*Recovery score low energy*	*Recovery summary low energy*
Bedforms	Sand	Trawls, scallop dredges	0	Sand ripples re-formed by tidal currents within hrs/days, sand waves by storms that occur at least once a year	n/a	This feature was assumed not to occur in a low energy environment.
Bedforms	Sand	Hydraulic dredges	0	Dredge tracks still visible after 2 mos (287), no longer visible after 11 wks (373), nearly indistinct after 24 hrs (245), complete recovery of physical features after 40 days (140)	n/a	This feature was assumed not to occur in a low energy environment.
Bedforms	Sand	Fixed gears	0	Bedforms estimated to have very low susceptibility to fixed gears, so recovery is not really required	n/a	This feature was assumed not to occur in a low energy environment.
Biogenic burrows	Mud, sand	Trawls, scallop dredges	0	Assume recovery <1 yr because organisms creating depressions are mobile, will move quickly into trawl/dredge path	0	Same as high energy: depends on number/activity of organisms, no reason to think it will vary by energy level
Biogenic burrows	Sand, granule pebble	Hydraulic dredge	1	Slower re-colonization by organisms (clams?) that live deeper in sediment?	2	No recovery after 3 yrs due to high mortality of organisms (clams) that make burrows (121)
Bedforms	Mud, sand	Fixed gears	0	Burrows estimated to have very low susceptibility to fixed gears, so recovery is not really required	0	Burrows estimated to have very low susceptibility to fixed gears, so recovery is not really required
Biogenic depressions	Mud, sand	All	0	Assume recovery <1 yr because organisms creating depressions are mobile, will move quickly into trawl/dredge path	0	Same as high energy: depends on number/activity of organisms, no reason to think it will vary by energy level
Boulder, piled	Boulder	Trawls, scallop dredges, fixed gears	3	Assume any disturbance would be permanent	3	Assume any disturbance would be permanent

Feature	*Substrate**	*Gear type**	*Recovery score high energy*	*Recovery summary high energy*	*Recovery score low energy*	*Recovery summary low energy*
Boulders, scattered in sand	Boulder	Trawls, scallop dredges, fixed gears	0	If the cobble/boulder is rolled over or buried, the depression underneath it would need to be recreated, but we estimated the time required for this would be under one year (R=0). This is consistent with the recovery times estimated for the burrow and depression features in the mud and sand substrates, except for hydraulic dredge fishing, which doesn't apply to cobble and boulder-dominated areas.	0	If the cobble/boulder is rolled over or buried, the depression underneath it would need to be recreated, but we estimated the time required for this would be under one year (R=0). This is consistent with the recovery times estimated for the burrow and depression features in the mud and sand substrates, except for hydraulic dredge fishing, which doesn't apply to cobble and boulder-dominated areas.
Cobble, pavement	Cobble	Trawls, scallop dredges, fixed gears	0	Assume pavement re-forms quickly as overlying sand is removed by currents, wave action	n/a	This feature was assumed not to occur in a low energy environment.
Cobble, piled	Cobble	Trawls, scallop dredges, fixed gears	3	Assume any disturbance would be permanent	3	Assume any disturbance would be permanent
Cobble, scattered in sand	Cobble	Trawls, scallop dredges, fixed gears	0	Similar to boulder, if cobble is rolled or dragged, it does not change its ability to provide structure, so recovery doesn't really apply and thus was set to zero.	0	Similar to boulder, if cobble is rolled or dragged, it does not change its ability to provide structure, so recovery doesn't really apply and thus was set to zero.
Granule-pebble, pavement	Granule-pebble	Trawls, scallop dredges, fixed gears	0	Assume pavement re-forms quickly as overlying sand is removed by currents, wave action	n/a	This feature was assumed not to occur in a low energy environment.
Granule-pebble, pavement	Granule-pebble	Hydraulic dredges	2	Sediments homogenized, coarser sediments end up deeper in trenches (232); pavement might never reform?	n/a	This feature was assumed not to occur in a low energy environment.

Feature	***Substrate****	***Gear type****	***Recovery score high energy***	***Recovery summary high energy***	***Recovery score low energy***	***Recovery summary low energy***
Granule pebble, scattered in sand	Granule-pebble	Trawls, scallop dredges	0	Assume primary action of both gears is displacement, not burial. Assume any buried granules/pebbles would be uncovered quickly by currents, wave action.	2	Storms are less frequent in deeper water; furrows left in pebble bottom by rockhoppers still prominent a year later (111, but 200-300 m deep)
Granule pebble, scattered in sand	Granule-pebble	Fixed gears	0	Scattered granule-pebble estimated to have very low susceptibility to fixed gears, so recovery is not really required	0	Scattered granule-pebble estimated to have very low susceptibility to fixed gears, so recovery is not really required
Granule pebble, scattered in sand	Granule-pebble	Hydraulic dredges	1	Coarser sediments end up deeper in trenches (232); slower recovery than trawls and scallop dredges since granules-pebbles would be buried deeper by a hydraulic dredge.	2	Storms that would re-expose granules/pebbles are less frequent in deeper water
Sediments, surface and subsurface	Mud	Trawls	0	No data, assume faster recovery in high energy. Although resuspended sediment may be transported away in high energy, it is assumed that the sediment would be replaced by transport from elsewhere.	0	Recovery of bottom roughness in 6 mos (372), all geochemical sediment properties recovered within 3.5 mos (338). Recovery of door tracks takes 1-2 yrs in low energy (372,277), but door impacts less important because such a small proportion of area swept by trawl gear. Resuspension would have limited effects, because resuspended sediment will remain in area.
Sediments, surface and subsurface	Mud	Scallop dredges	0	No recovery of fine sediments 6 mos after dredging (391-multiple tows, recovery not checked after 1 yr)	0	No data, so assume same recovery as trawls
Sediments, surface and subsurface	Mud, Sand	Fixed gears	0	Estimated to have very low susceptibility to fixed gears, so recovery is not really required	0	Estimated to have very low susceptibility to fixed gears, so recovery is not really required

Feature	*Substrate**	*Gear type**	*Recovery score high energy*	*Recovery summary high energy*	*Recovery score low energy*	*Recovery summary low energy*
Sediments, surface and subsurface	Sand	Trawls	0	Lost fine sediments replaced very quickly (within hours or days) by bottom currents, or less than a year by turbulence from wave action	0	Door tracks not visible or faintly visible in SS sonar records, recovery of seafloor topography within a year (325), compacted sediments recovered within 5 mos (336)
Sediments, surface and subsurface	Sand	Scallop dredges	0	Same as trawls	0	Recovery of food value of sediments within 6 mos, but no recovery of lost fine sediments (391)
Sediments, surface and subsurface	Sand	Hydraulic dredge	1	Trenches no longer visible a day to three months after dredging (245, 246, 287, 373), also see trawls. Top 20 cm of sand in trenches still fluidized after 11 wks, but not examined after that (373).	2	Trenches no longer visible after 1 yr (121), but replacement of lost fine sediment would take longer in low energy environments. Acoustic reflectance of trenches still different than surrounding seabed after 3 yrs (121)
Shell deposits	Sand, granule-pebble, cobble	Trawls, scallop dredges	1	Shells are much heavier than sand, so if they are dispersed it could take 1-2 yrs for storms to re-aggregate them.	2	Assume it would take 2-5 yrs in low energy because storms would have to be more severe to produce bottom turbulence in deeper water.
Shell deposits	Sand, gr-pebble	Hydraulic dredges	1	Assume shells buried in trench would remain buried, but new ones would "recruit" to sediment surface within 1-2 yrs	2	Over time, empty shells collect in dredge tracks (121). Similar to trawls, s dredges, assume it would take 2-5 yrs in low energy because storms would have to be more severe to produce bottom turbulence in deeper water.
Shell deposits	Sand, granule-pebble, cobble	Fixed gears	0	Gear would not completely remove or crush shells, so deposit would remain largely intact and recovery would not be required	0	Gear would not completely remove or crush shells, so deposit would remain largely intact and recovery would not be required

Table 32 – Recovery summary for all biological features, by, substrate and gear type.

Feature	*Substrate*	*Gear type*	*Recovery score*	*Recovery summary (same scoresfor low and high energy, except as noted)*
Amphipods,	Mud, sand	Trawls,	0	*A. abdita* are short-lived, highly seasonal occurrence

Feature	*Substrate*	*Gear type*	*Recovery score*	*Recovery summary (same scoresfor low and high energy, except as noted)*
tube-dwelling		scallop dredges		(several times a year), tube mats re-form within months following benthic recruitment of juveniles (MacKenzie et al 2006)
Amphipods, tube-dwelling	Sand	Hydraulic dredges	0	See above
Amphipods, tube-dwelling	Mud, sand	Fixed gears	0	See above
Anemones, actinarian	Granule-pebble, cobble, boulder	Trawls, scallop dredges	2	Recovery could take >7 yr (see Witman 1998, referenced in 404), colonized cobble in settlement trays on GB within 2.5 yrs (Collie et al 2009)
Anemones, actinarian	Granule-pebble	Hydraulic clam dredge	2	See above
Anemones, actinarian	Granule-pebble, cobble, boulder	Fixed gears	2	See above
Anemones, cerianthid burrowing	Mud, sand, granule-pebble	Trawls, scallop dredges	2	Apparently long-lived (>10 yrs?), but If animal is still alive, assume damaged tube can be repaired/replaced fairly quickly; recovery score is a “compromise” between 1-2 yrs for tube repair and 5-10 yrs (?) to replace animal.
Anemones, cerianthid burrowing	Sand, granule-pebble	Hydraulic clam dredge	3	Assume impact is removal of animal, not damage to tube, so recovery time is longer than for other gears (see above)
Anemones, cerianthid burrowing	Mud, sand, granule-pebble	Fixed gears	2	See trawls, scallop dredges
Ascidians	Sand, granule-pebble, cobble, boulder	Trawls, scallop dredges	1	Later colonizers than bryozoans, accounted for 6% of patch space 15 mos after all organisms were removed from rock surface (30m, Cashes Ledge in GOM, Witman 1998). *Molgula arenata* removed in linear patterns by scallop dredges on Stellwagen Bank (sand), widely distributed over bottom a year later (11), but not known whether they had returned to pre-disturbance densities. Assume recovery would be mostly complete within 1-2 years
Ascidians	Sand, granule-pebble	Hydraulic clam dredge	1, except 2 in low energy granule-pebble	See above, except that longer recovery in low energy granule pebble because substrate on which organisms settle (granules, pebbles) highly susceptible also
Ascidians	Sand, granule-pebble, cobble, boulder	Fixed gears	1	See above
Brachiopods	Granule-pebble, cobble, boulder	Trawls, scallop dredges	2	*Terebratulina septentrionalis* is relatively short-lived (1-5 ys), so “lost” individuals would be replaced in 2-5 years.
Brachiopods	Granule-pebble	Hydraulic clam dredge	2	See above
Brachiopods	Granule-pebble, cobble, boulder	Fixed gears	2	See above
Bryozoans	Granule-pebble, cobble,	Trawls, scallop	1	Recovered within 2 yrs after CAII (eastern George Bank) was closed, grow/recolonize rapidly, life spans typically <1 yr

Feature	*Substrate*	*Gear type*	*Recovery score*	*Recovery summary (same scoresfor low and high energy, except as noted)*
	boulder	dredges		(see #404). Two species were first colonizers of rocky substrate on Cashes Ledge, accounting for most of patch space after 15 mos (Witman 1998). At 50m site on Cashes Ledge, bryozoans covered >50% rock substrate within a year and approached 100% by second year (Sebens et al 1988).
Bryozoans	Granule-pebble	Hydraulic clam dredge	1, except 2 in low energy granule-pebble	See above, except that longer recovery in low energy granule pebble because substrate on which organisms settle (granules, pebbles) highly susceptible also
Bryozoans	Granule-pebble, cobble, boulder	Fixed gears	1	See above
Corals, sea pens	Mud, sand	Trawls, scallop dredges, hydraulic clam dredges (sand only)	2 (high energy only)	Sea pens (Stylatula spp) in mud (180-360m) on west coast are sessile, slow-growing, long-lived (up to 50 yrs) species that are likely to recover slowly from physical disturbance (164), but sea pens are sometimes able to "re-root" if removed from bottom (see below).
Corals, sea pens	Mud, sand	Fixed gears	0 (high energy only)	Full recovery from bending, smothering, some from uprooting, from pot fishing (in mud) within days, don't retract when pots drop on them (102); however, little known about lifespan, growth rates
Hydroids	Mud, sand, granule-pebble, cobble, boulder	Trawls, scallop dredges	1	Life histories similar to bryozoans (live 10 days-1 yr), some species are perennial but exhibit seasonal regression, spatial extent of recovery restricted by limited larval dispersal, or absence of pelagic medusa stage (404). On Stellwagen Bank (coarse sand), no recovery of hydroid (*Corymorpha pendula)* a year after removal by trawls and scallop dredges (11)
Hydroids	Sand, granule-pebble	Hydraulic clam dredge	1, except 2 in low energy granule-pebble	See above, except that longer recovery in low energy granule pebble because substrate on which organisms settle (granules, pebbles) highly susceptible also
Hydroids	Mud, sand, granule-pebble, cobble, boulder	Fixed gears	1	See above
Macroalgae	Granule-pebble, cobble, boulder	Trawls, scallop dredges	1	All macroalgae in NE region are perennials, so some re-growth and replacement of lost plants occurs within a year, but assume that full growth and recovery of lost structure would take 1-2 years, maybe longer for large laminarians.
Macroalgae	Granule-pebble	Hydraulic clam dredge	1	See above
Macroalgae	Granule-pebble, cobble, boulder	Fixed gears	1	See above
Mollusks, epifaunal	Mud, sand, granule-	Trawls, scallop	3	*Mytilus edulis* can reach full growth within a year in optimum conditions, but otherwise 2-5 years are needed,

Feature	*Substrate*	*Gear type*	*Recovery score*	*Recovery summary (same scoresfor low and high energy, except as noted)*
bivalve, *Modiolus modiolus*	pebble, cobble, boulder	dredges		*Modiolus* is a long-lived species (some individuals live 25 years or more) and inhabits colder water, presumably with slower growth rate. Recovery of mussel beds – which have greater habitat value – may be longer than for individuals.
Mollusks, epifaunal bivalve *,* *Modiolus modiolus*	Sand, granule-pebble	Hydraulic clam dredge	3	See above
Mollusks, epifaunal bivalve , *Modiolus modiolus*	Mud, sand, granule-pebble, cobble, boulder	Fixed gears	0	Minimal susceptibility to disturbance, therefore recovery was assumed to be complete within a year.
Mollusks, epifaunal bivalve , *Placopecten magellanicus*	Sand, granule-pebble, cobble, boulder	Trawls, scallop dredges	2	Scallop biomass increased 200x in prime, gravel pavement habitat in closed area on Georges Bank 7 years after area was closed to fishing, much higher than 9-14x increase for all GB closed areas combined (157)
Mollusks, epifaunal bivalve *,* *Placopecten magellanicus*	Sand, granule-pebble	Hydraulic clam dredge	2	
Mollusks, epifaunal bivalve *,* *Placopecten magellanicus*	Sand, granule-pebble, cobble, boulder	Fixed gears	0	Scallops not susceptible to fixed gears, therefore R=0
Polychaetes, *Filograna implexa*	Sand, granule-pebble, cobble, boulder	Trawls, scallop dredges	2	*Filograna* colonized cobble in settlement trays on GB within 2.5 yrs (Collie et al 2009), on pebble pavement (eastern GB) full recovery within 5 yrs following closure of area (71)
Polychaetes, *Filograna implexa*	Granule-pebble	Hydraulic clam dredges	2	See above
Polychaetes, *Filograna implexa*	Granule-pebble, cobble, boulder	Fixed gears	2	See above
Polychaetes, other tube-dwelling	Granule-pebble, cobble, boulder	Trawls, scallop dredges	1	Because tubes are less fragile than *Filograna* tubes, assume they are less susceptible to damage from these two gears and therefore recover more quickly.
Polychaetes, other tube-dwelling	Granule-pebble	Hydraulic clam dredges	1, except 2 in low energy granule-pebble	See above, except that longer recovery in low energy granule pebble because substrate on which organisms settle (granules, pebbles) highly susceptible also
Polychaetes, other tube-dwelling	Granule-pebble, cobble, boulder	Fixed gears	1	Slower recovery time based on lower susceptibility to fixed gears
Sponges	Sand, granule-pebble, cobble, boulder	Trawls, scallop dredges	2	With one exception, value is consistent with literature. On eastern GB, recovery in closed area (CAII) within 5 yrs (esp *Polymastia, Isodictya*), colonization of gravel 2.5 yrs after

Feature	*Substrate*	*Gear type*	*Recovery score*	*Recovery summary (same scoresfor low and high energy, except as noted)*
				closure with increase in sponge cover after 4.5 yrs (71) . Significantly higher incidence of sponge (*S. ficus*)/shell fragment microhabitats inside S part of CAII after 4.5 yrs (225). No recovery from single tows after a year in Gulf of Alaska (111). Aperiodoc recruitment and perennial life cycles, life spans >5 yrs account for relatively slow recovery times (404). Exception is study 382 (shallow water in Georgia) which reports full recovery of large sponges from damage and return to pre-trawl densities (single tows) within a year.
Sponges	Sand, granule-pebble	Hydraulic clam dredge	2	See above
Sponges	Sand granule-pebble, cobble, boulder	Fixed gears	1	Slower recovery time based on lower susceptibility to fixed gears, higher probability that disturbance would damage or remove parts of sponge rather than remove whole animal.

4.2.6 Summary of vulnerability assessment results

The following series of figures show the average percent reduction in functional value of features and average recovery time in years. The results are summarized by gear type, feature class (geological or biological), substrate, and energy. Longlines and gillnets are grouped together due to equality of S/R scores. In all cases, the S and R scores are converted to percentages and years, respectively, and then the percentages and years for individual features are averaged, with all features weighted equally. Because the SASI model selects percentages and years randomly from the range of possible values according to the S or R score, the figures below are based on random values, as follows:

R=0, years = 1
R=1, years = 1 to 2
R=2, years = 2 to 5
R=3, years = 5 to 10

S=0, % = 0 to 10
S=1, % = 10 to 25
S=2, % = 25 to 50
S=3, % = 50 to 100

The table below each figure summarizes the mean suceptiblity and recovery scores according to substrate, energy, and feature class.

Note that scales vary between gear types depending on the range of values in the data. Slight differences in figures between gear types where average S and R scores are the same reflect the random assignment of years and percentages within each R or S category.

Table 33 – Summary of susceptibility and recovery scores for trawl gear.

Trawl					
		Average S Score		Average R Score	
Substrate	Energy	Geological	Biological	Geological	Biological
Mud	High	2.0	1.3	0.0	1.5
	Low	2.0	1.4	0.0	1.6
Sand	High	1.8	1.5	0.2	1.6
	Low	1.8	1.6	0.5	1.7
Granule-pebble	High	1.0	1.7	0.3	1.7
	Low	1.0	1.7	2.0	1.7
Cobble	High	1.7	1.6	1.0	1.6
	Low	2.0	1.7	1.5	1.7
Boulder	High	1.0	1.7	1.5	1.6
	Low	1.0	1.8	1.5	1.7

Table 34 – Summary of susceptibility and recovery scores for scallop dredge gear.

Scallop Dredge					
		Average S Score		Average R Score	
Substrate	Energy	Geological	Biological	Geological	Biological
Mud	High	2.0	1.3	0.0	1.5
	Low	2.0	1.4	0.0	1.6
Sand	High	1.8	1.6	0.2	1.6
	Low	1.8	1.7	0.5	1.7
Granule-pebble	High	1.0	1.8	0.3	1.7
	Low	1.0	1.8	2.0	1.7
Cobble	High	1.7	1.7	1.0	1.6
	Low	2.0	1.8	1.5	1.7
Boulder	High	1.0	1.7	1.5	1.6
	Low	1.0	1.8	1.5	1.7

Table 35 – Summary of susceptibility and recovery scores for hydraulic dredge gear.

Hydraulic Dredge					
		Average S Score		Average R Score	
Substrate	Energy	Geological	Biological	Geological	Biological
Sand	High	2.8	2.6	0.6	1.8
	Low	2.8	2.7	1.5	1.8
Granule-pebble	High	2.7	2.8	1.3	1.8
	Low	2.5	2.8	2.0	2.2

Table 36 – Summary of susceptibility and recovery scores for longline and gillnet gears.

Longline, Gillnet					
		Average S Score		Average R Score	
Substrate	Energy	Geological	Biological	Geological	Biological
Mud	High	0.3	0.8	0.0	0.8
	Low	0.3	0.8	0.0	0.6
Sand	High	0.4	0.6	0.0	0.9
	Low	0.5	0.7	0.0	0.8
Granule-pebble	High	0.0	0.8	0.0	1.2
	Low	0.0	0.8	0.0	1.2
Cobble	High	0.3	0.8	1.0	1.1
	Low	0.5	0.8	1.5	1.1
Boulder	High	0.0	0.9	1.5	1.2
	Low	0.0	0.9	1.5	1.2

Table 37 – Summary of susceptibility and recovery scores for trap gear.

Trap					
		Average S Score		Average R Score	
Substrate	Energy	Geological	Biological	Geological	Biological
Mud	High	1.0	0.8	0.0	0.8
	Low	1.0	0.8	0.0	0.6
Sand	High	0.6	0.6	0.0	0.9
	Low	0.8	0.7	0.0	0.8
Granule-pebble	High	0.0	0.9	0.0	1.2
	Low	0.0	0.9	0.0	1.2
Cobble	High	0.3	0.9	1.0	1.1
	Low	0.5	0.9	1.5	1.1
Boulder	High	0.0	1.0	1.5	1.2
	Low	0.0	1.0	1.5	1.2

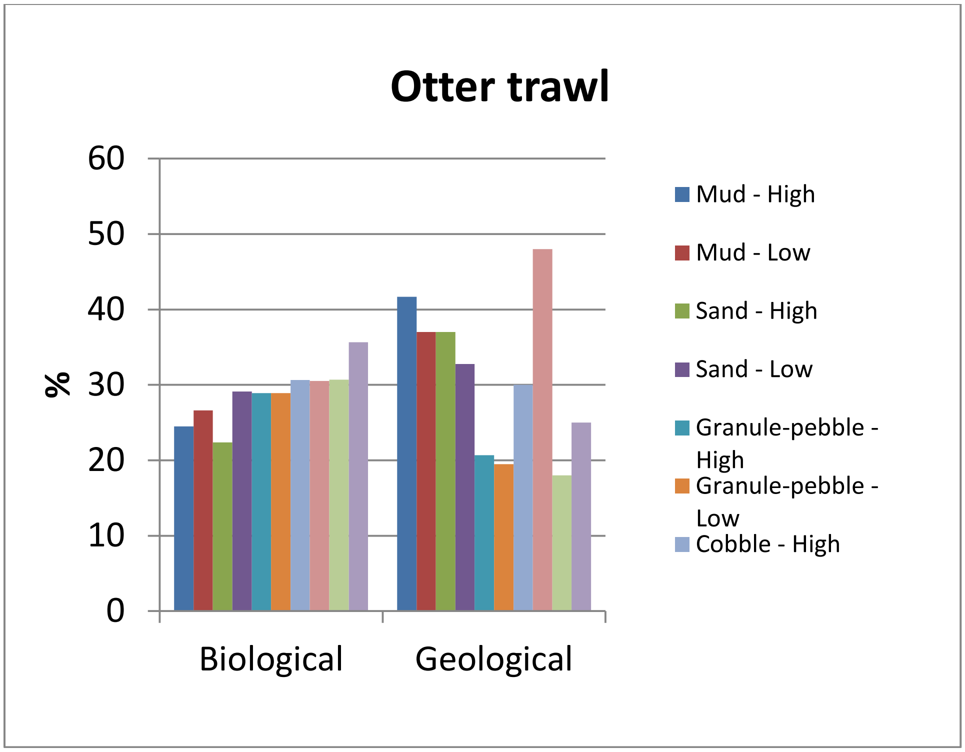

Figure 3 – Susceptibility of geological and biological features to trawl impacts according to substrate and energy.

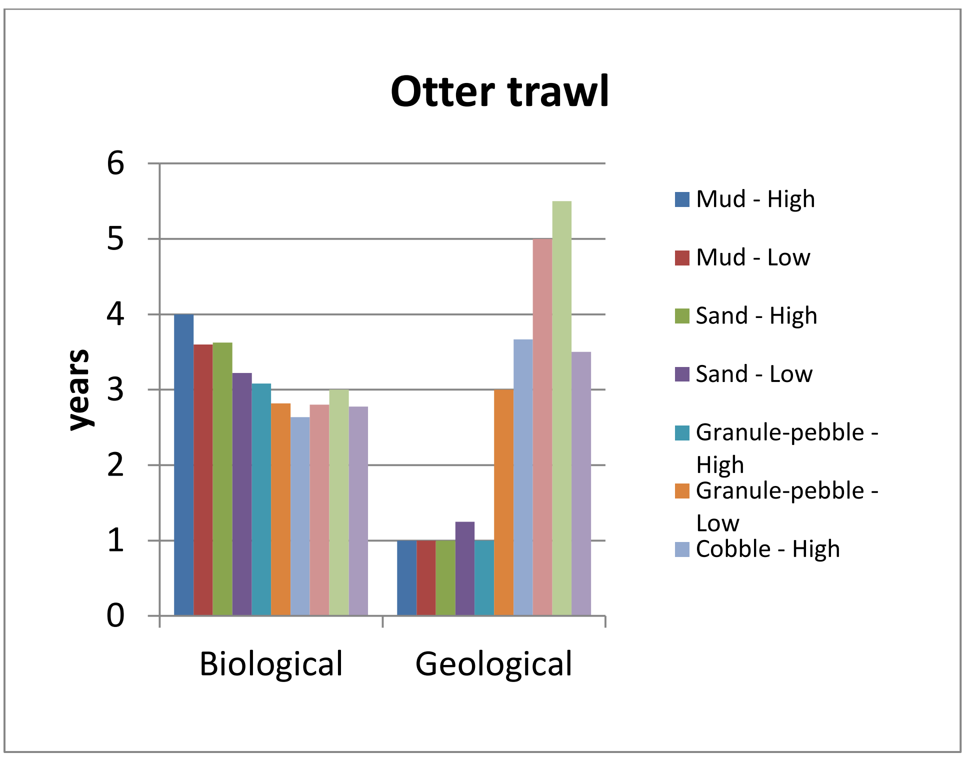

Figure 4 – Recovery of geological and biological features following trawl impacts according to substrate and energy.

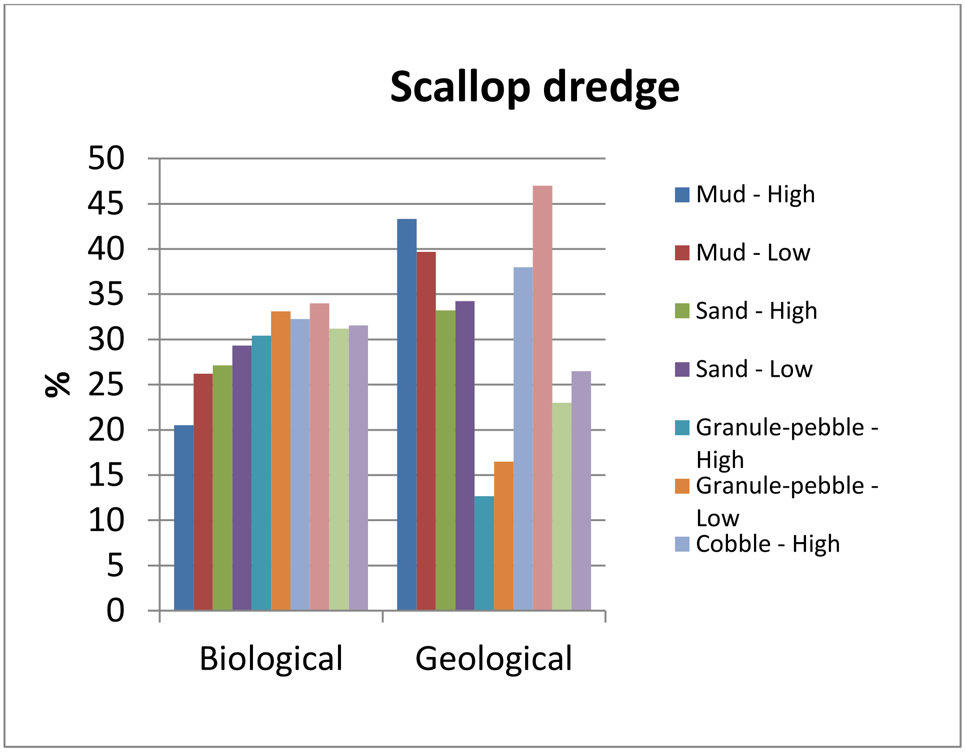

Figure 5 – Susceptibility of geological and biological features to scallop dredge impacts according to substrate and energy.

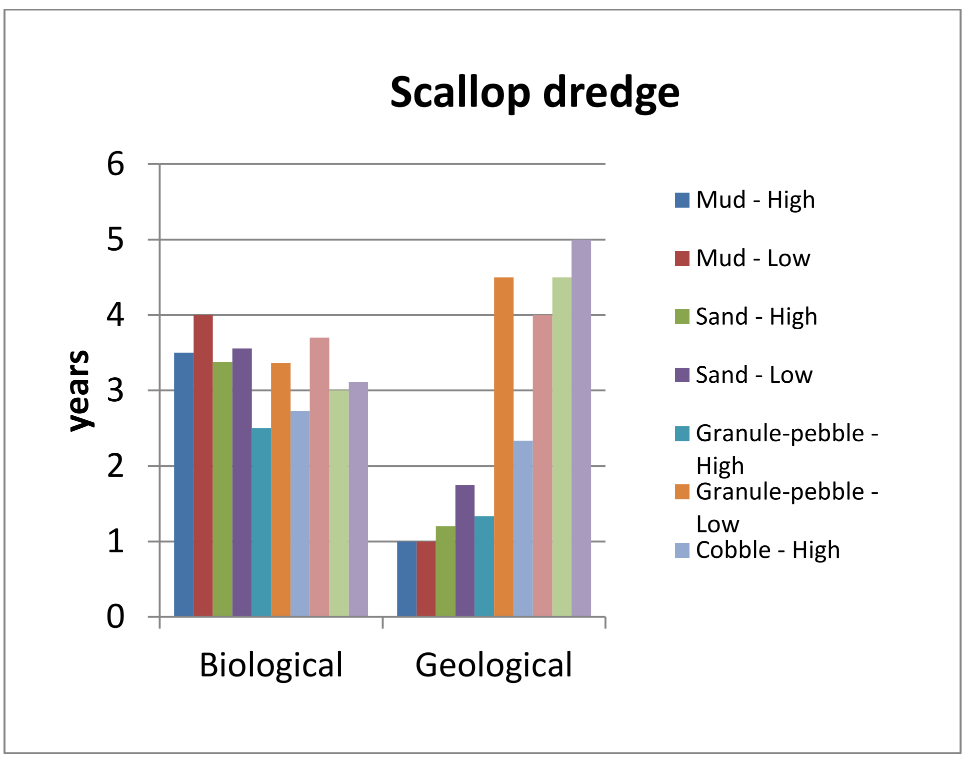

Figure 6 – Recovery of geological and biological features following scallop dredge impacts according to substrate and energy.

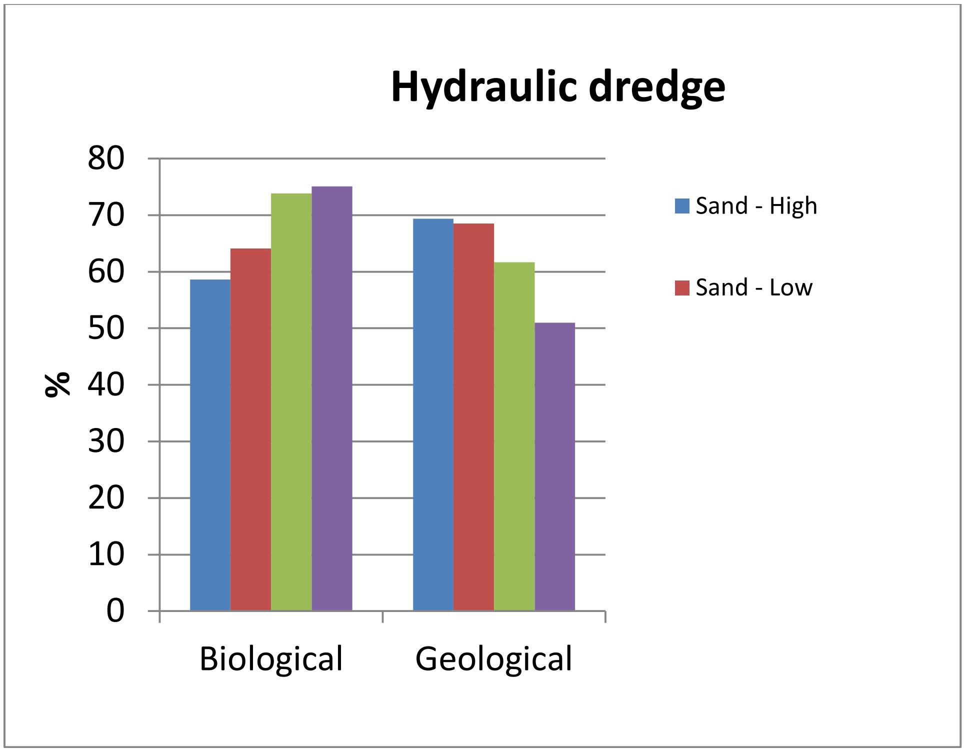

Figure 7 – Susceptibility of geological and biological features to hydraulic dredge impacts according to substrate and energy.

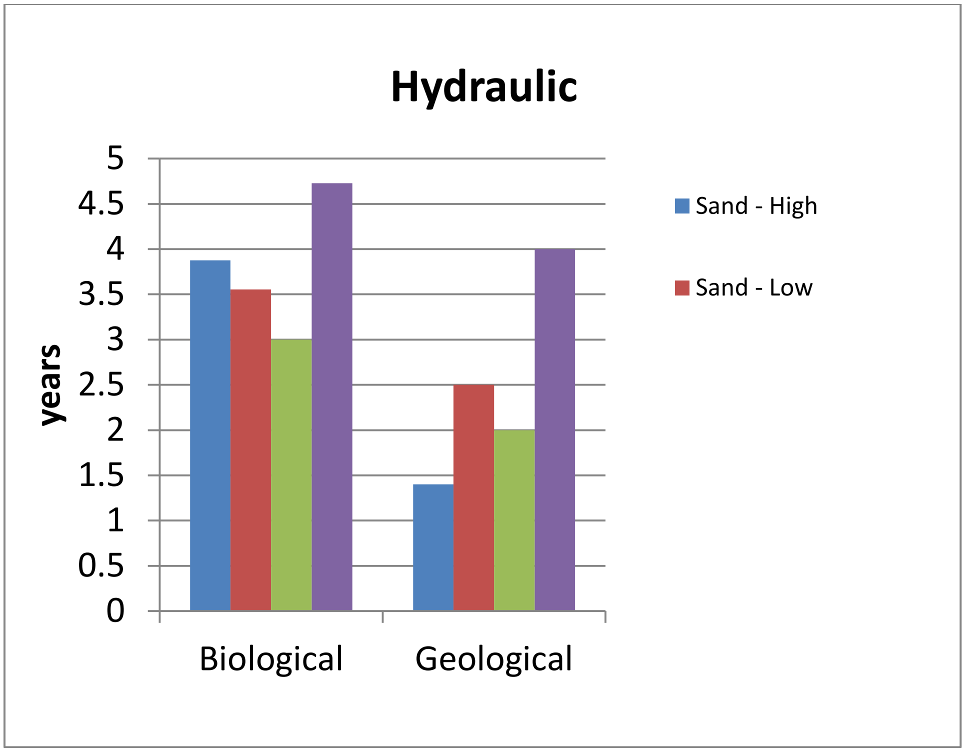

Figure 8 – Recovery of geological and biological features following hydraulic dredge impacts according to substrate and energy.

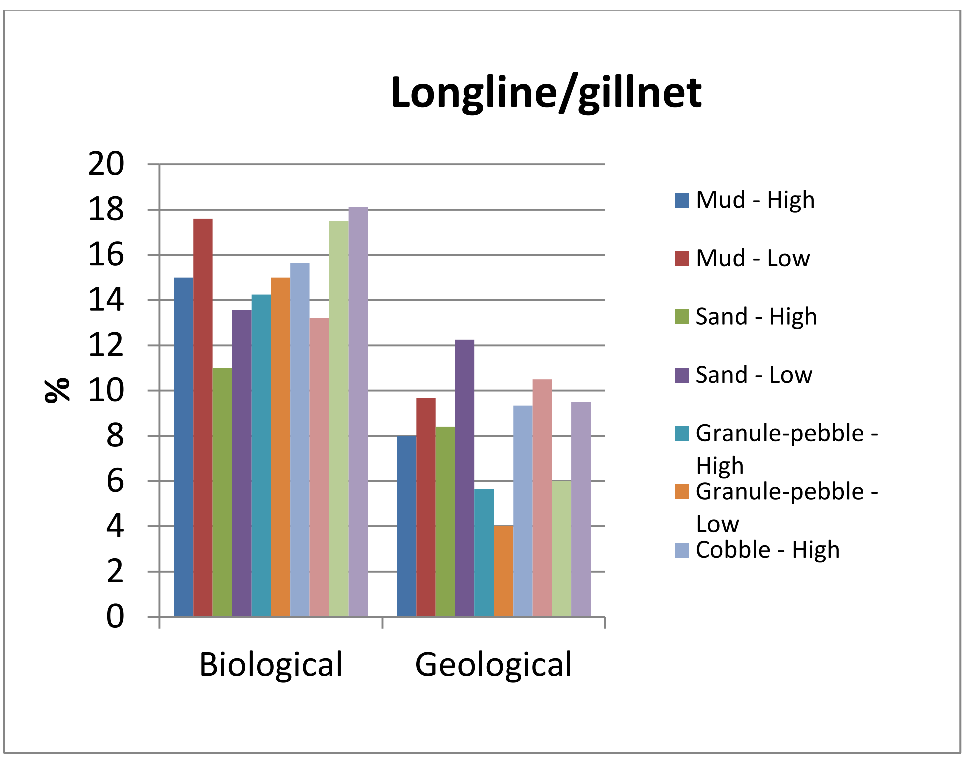

Figure 9 – Susceptibility of geological and biological features to longline and gillnet impacts according to substrate and energy

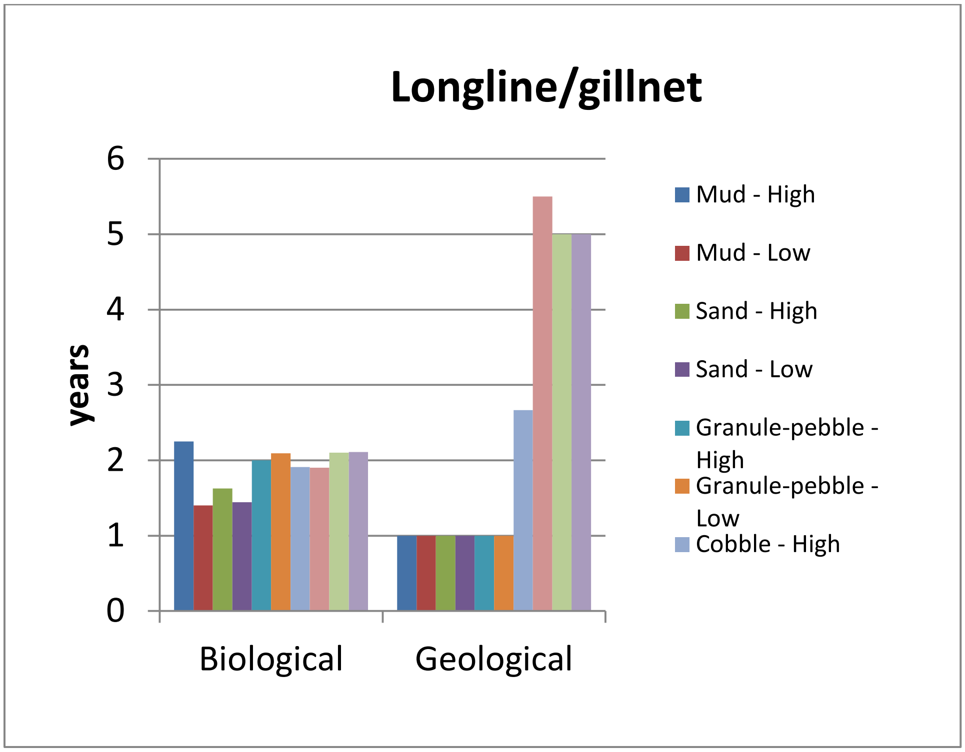

Figure 10 – Recovery of geological and biological features following longline and gillnet impacts according to substrate and energy

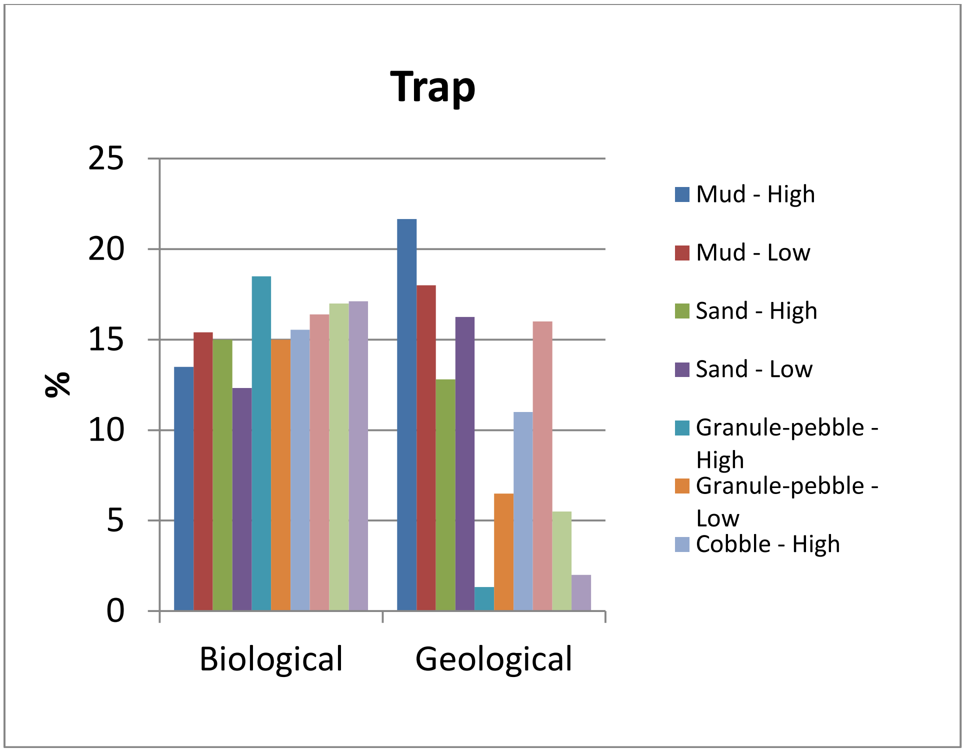

Figure 11 – Susceptibility of geological and biological features to trap impacts according to substrate and energy

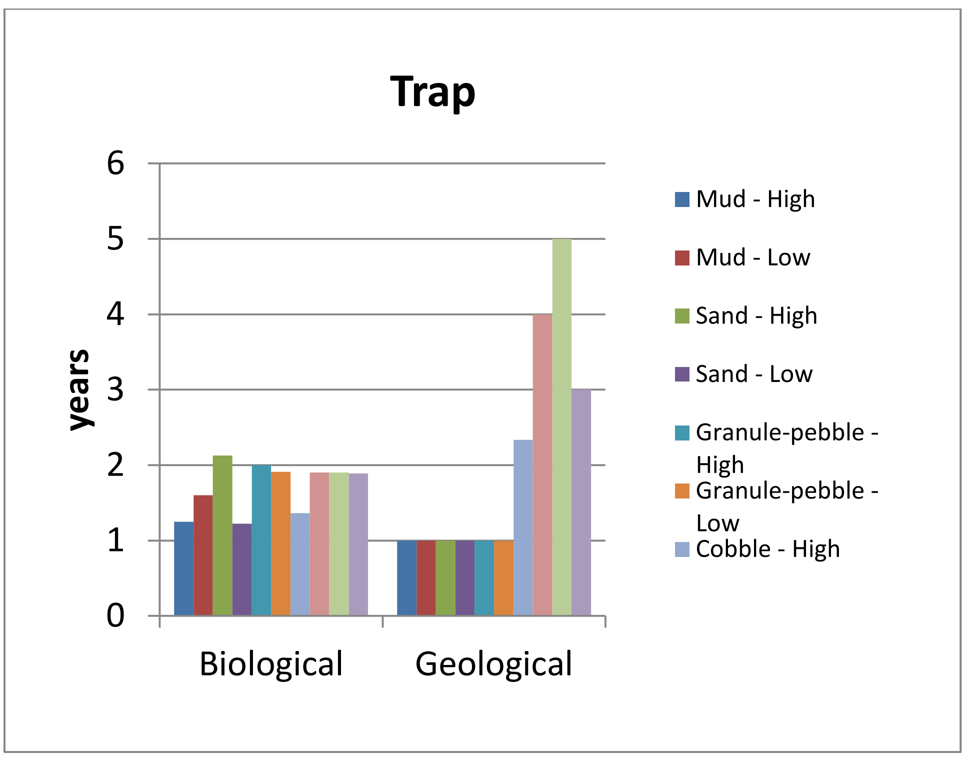

Figure 12 – Recovery of geological and biological features following trap impacts according to substrate and energy

4.3 Discussion

The impacts of fishing on marine ecosystems have been documented by scientists and remain a focus for scientists and fishery managers alike. Fishing can alter marine ecosystems by disturbing the seafloor substrate and removing the features that provide shelter and food for managed species. For instance, bottom-tending gears can remove or damage features such as cobble piles or erect sessile invertebrates that create refugia for juvenile fish. Fishing can also have negative impacts on the prey species that federally managed fish species forage on, such as crustaceans and other benthic invertebrates that are crushed or displaced by fishing gear.

Being able to assess the vulnerability of marine ecosystems to impacts from fishing is of fundamental importance to marine resource managers charged with sustaining the valuable goods and services that ecosystems provide. The SASI model is intended to assess the adverse effects of fishing gear on benthic habitat. Its end product is a spatially-referenced, quantitative measure of the adverse effects of fishing on seabed structural features.

To enable the often tennuous connection between the effects of fishing and the utilization of benthic habitats by commercial fish species, fish habitat is divided into components--geological and biological--which are further subdivided into features. Structural features identified include bedforms, biogenic burrows, sponges, macroalgae, etc. (see sections 2.1 and 2.2 related to geological and biological features, respectively). These features may either provide shelter for managed species directly, or provide shelter for their prey. The geological and biological features are distinguished as being non-living and living, respectively. While both components (geological, biological) are assumed to occur in every habitat type, the presence or absence of particular features is assumed to vary based on substrate type and natural disturbance (energy) regime. Thus, ten habitat types in the vulnerability assessment are distinguished by dominant substrate, level of natural disturbance, and the presence or absence of various features.[6]

The matrix-based vulnerability assessment organizes quantitative estimates of both the magnitude of the impacts that result from the physical interaction of fish habitats and fishing gears (susceptibility), and the duration of recovery following those interactions. Susceptibility (S) is defined as the percentage of total habitat features encountered by fishing gear during a hypothetical single pass fishing event that have their functional value reduced, with values ranging from 0 (0-10% impacted) to 3 (>50% impacted). Because functional value is difficult to assess directly, feature removal is used as a proxy for reduction in functional value. The time required for those features to recover their

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[6] The substrate and energy classifications used are described in the introduction to section 3.0.

pre-impact functional value (R) is assigned a value ranging from 0 (<1 year) to 3 (5-10 years). It should be reiterated that the VA is only used to estimate adverse (vs. positive) effects, and that only impacts associated with the seabed (vs. the seabed and the water column) are considered, and that given the minimum one year timestep of the SASI model, the VA is not intended to capture seasonal variation in relative abundance, susceptibility, or recovery rates of features.

4.3.1 Literature review

Efforts to assess the vulnerability of fish habitats to impacts from fishing remain challenged by (1) a limited amount of information regarding the locations and types of bottom substrates and (2) a lack of clear understanding of specifically how fishing activities affect these substrates. The formality of the VA approach served to highlight these gaps in knowledge. When information is not available on a particular gear type's effects on a specific biological or geological feature, S and R parameter estimates are derived from studies of other gear types or similar features.

In total, the PDT drew from 97 studies of the impacts of fishing gear on habitats, in addition to numerous other sources relevant to the feature descriptions. Only studies with information relevant to Northwest Atlantic fishing gears and substrate features are included, although the list did include studies from other regions of the world. About half of the 97 studies utilized in the assessment are experimental in nature, but only about 25 of these are before/after impact studies directly applicable to the assessment of the susceptibility of habitat features to the effects of single tows or sets. Others are comparative in nature (e.g., evaluations of habitat conditions in areas open and closed to fishing, or where fishing intensity was heavy versus light). While these provided useful information, they are less informative in terms of assigning susceptibility and recovery scores.

Over 70 of the gear-impact studies focused on the effects of demersal trawling on biological and geological substrate features. Most of these considered 'generic' otter trawls, making it difficult to discern the effects of modified otter trawls (e.g., raised footrope or squid trawls) on substrate features. In addition, very few studies provided enough details regarding specific trawl design, configuration, and fishing procedures, which would have been required to assign S and R scores for individual trawl types.[7]

Studies of the remaining gear types are more limited: of the 97 utilized in this assessment, 17 are applicable to scallop dredges, 11 to hydraulic dredges, and 5 to fixed

[7] However, the SASI model can account for modifications to fishing gear by changing the conditioning factor (the contact index) that estimates the amount of bottom habitat contacted (see section 7.0).

gear. In particular, the literature review emphasized the paucity of existing studies on fixed gear effects on fish habitat. The exceptions to this are Eno et al 2001, Kaiser et al 2000, Fossa et al 2002, Grehan et al 2005, and Mortensen et al 2005, although the latter three focused on deep-sea coral impacts only. A recommendation for future gear effects work would be to study fixed gear impacts on geological and biological seabed structures. This work could be combined with measurements of the area of seabed actually contacted by fixed gears during deployment, which was identified as a related issue during parameterization of the area swept models.

4.3.2 Susceptibility

Feature susceptibilities varied by gear type (see Table 33- Table 37 for a summary). Across all gears, geological and biological features are generally most susceptible to impacts from hydraulic dredges as compared to other gear types (average scores for all features in a particular substrate and energy environment ranged from 2.5-2.8 out of 3). Otter trawl and scallop dredge S scores ranged from 1.0 to 2.0. Scores for these two gears are assumed to be the same across all features, substrates, and energies, with the exception of the bivalve mollusk/scallop feature itself, which was estimated to have a slightly higher susceptibility to scallop dredges. This assumption of similarity between the gears seems reasonable since the disturbance caused by both gears is similar: aside from the trawl doors, both gears cause a scraping and smoothing of bottom features and a re-suspension of fine sediments, and these effects are primarily limited to the sediment surface. Furthermore, the scallop dredge impacts literature (there are only three studies that directly evaluated dredging effects, and they are limited to geological impacts) does not provide compelling support for coding S and R values for the two gear types differently. Fixed gear (traps, longlines, and gillnets) susceptibility scores generally did not differ much if at all between gear types, but are the lower on average than the mobile gear scores, ranging from 0 to 1.

For trawls, scallop dredges, and fixed gears, mud, sand, and cobble features are more susceptible, while granule-pebble and boulder features are less susceptible. Average susceptibility scores for hydraulic dredges are slightly higher in sand than in granule-pebble substrates.

Differences in average biological susceptibility between substrates are fairly subtle. For each gear type, impacts on biological features generally did not differ much among substrates, although there was a slight trend toward higher average S scores in coarser substrates in all gear types. These differences in average scores are due to the different suite of features inferred to areas dominated by gravel substrates.

Higher S scores reflect a higher proportion of features with >25% encountered estimated to have a reduction in functional habitat value. For trawls and scallop dredges, there was a larger proportion of high S scores (S=2 or 3) for geological features, especially in mud and cobble, than for biological features; for hydraulic dredges, however, there was very little difference between feature classes. Susceptibility scores did not vary by energy, though the lack of a difference is likely due to insufficient information on the relative effects of energy regime on impacts, rather than on a true difference in the susceptibility and recovery of features found in high vs. low energy environments. Average susceptibility scores for a substrate did vary slightly by energy regime in some cases, due exclusively to the different features inferred to high vs. low energy environments.

4.3.3 Recovery

Geological feature recovery values are slightly higher (i.e., recovery times are longer) for hydraulic dredges than for the other two mobile gears fished in similar habitats (sand and granule-pebble). Average recovery values are more similar for biological features across the three mobile gear types, although in a few cases estimated recovery times are longer for hydraulic dredge gear. This was due to differences in gear effects associated with hydraulic dredges as compared to scallop dredges or otter trawls. As compared to mobile gears, fixed gears had slightly lower average recovery scores across both geological and biological features.

For each gear type, recovery values are consistently higher on geological components of habitat in coarse grained substrates than in sand and mud substrates, reflecting the increased contribution of features with recovery times of 2-5 and 5-10 years. Energy regime had little impact on recovery scores, with the exception of features recovering much more quickly from mobile gear impacts in granule pebble substrates in high (0.3-1.3) than in low (2.0) energy regimes. Average recovery scores for all biological features found in a habitat type did not differ among substrates or energy regimes for the mobile gears, but are slightly lower in mud and sand than in coarser substrates for fixed gears.

4.3.4 Potential sources of bias in the Vulnerability Assessment

In cases where there isn't clear support for a difference in scores, there was a tendancy to assign the same scores between features, or within features between gear types and/or energies. For example, average recovery values for biological features are more similar across gear types and substrates than are susceptibility values. This may be attributed somewhat to a lack of quantitative information on the recovery rates of benthic habitat features from gear impacts. There was also a tendency to avoid categorizing features as a zero (little to no impact/recovery within a year) or as a three (greater than 50% impact/recovery time greater than five years) unless there was sufficient evidence in support of this ranking, biasing relatively unsupported feature scoring towards median impacts withing our range. This potential bias may wash out true differences in vulnerability between features, homogenizing estimated effects across gears and substrates. Another challenge is that less than one third of the studies examined recovery times of biological and/or geological features following impact, and many of these only considered recovery in the short term. The use of a maximum recovery duration of ~10 years is as much a function of what is not found in the literature as what is.

Another major assumption of the VA is the independence of fishing events. The S and R estimates reflect effects of single, independent gear encounters. This implies that the functional relationship between habitat area impacted and the number of tows is linear and uniform, such that there is no difference in the magnitude of the impact of the first and any subsequent tows. Although the cumulative effects of fishing can be evaluated by adding multiple fishing events together over time, the recovery vector assumes that recovery from an individual event is independent of subsequent fishing events. It likely is not. However, the direction of bias from this depends on whether the first pass is relatively more damaging than subsequent passes, in which case impacts would be overestimated if the same exact feature are impacted multiple times, or if cumulative seabed impact is actually a non-linear concave function.

While the VA is limited by the lack of data available on fishing gear impacts on benthic habitat—especially the effects of, and recovery from, individual tows or sets—it offers a quantitative approach to examine and compare impacts by gear on both the geological and biological features common to substrates in the Northwest Atlantic. Together with the spatial components of the SASI model, the VA transforms gear impacts on benthic habitat into a common currency, i.e. vulnerability-adjusted area swept. It also accounts for both the spatial and temporal components of fishing impacts, which allows for both simulated fishing efforts to assess vulnerability and realized efforts that examine the impacts from past fishing activities. The VA also provides a framework that can be enhanced as future studies that address the above limitations are conducted. Finally, if assessments are developed to estimate vulnerability related to other anthropogenic perturbations in the Northwest Atlantic, they could be used collectively with the gear impact VA to assess the total vulnerability of benthic habitat to multiple human activities, which would be valuable for ongoing and future marine spatial planning efforts in the region.

5.0 Fishing gears evaluted

Many types of fishing gears are used throughout the region. To make the scope of this analysis more manageable, only seabed impacts from bottom-tending gears that account for significant landings, revenue, and/or days at sea are evaluated.

Key fishing gears are identified out of 45 gear types associated with landings of federal or state-managed species as reported in National Marine Fisheries Service Vessel Trip Reports (VTR) from 1996-2008. By gear type and year, landed pounds, percent of total landed pounds, revenue, percent of total revenue, days absent, and percent of total days absent are summarized (Table 38, Table 39, Table 40, Table 42, Table 43, Table 44). Eight gear types individually accounted for roughly 1% or greater of landings, revenues and/or days absent: ocean quahog/surf clam dredge, sea scallop dredge, sink gillnet, bottom longline, bottom otter trawl (combining fish, scallop, and shrimp), midwater otter trawl, lobster pot, and purse seine. Of these, midwater otter trawls and purse seines are not evaluated in the Vulnerability Assessment due to low or no bottom contact.

Table 45 relates the gear types evaluated in the Vulnerability Assessment to gear type names from the VTR database. In some cases, two separate VTR gear types are combined to create one Vulnerability Assessment category, while in other cases VTR gear types are disaggregated due to trip characteristics.

Table 38 – Landed pounds by gear type (1,000 lbs, source: NMFS vessel trip reports)

GEARNM	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
CARRIER VESSEL	0	0	0	0	0	0	0	0	0	0	0	0	69
CASTNET	0	0	0	0	5	1	0	15	142	479	60	93	3
DIVING GEAR	443	259	245	181	132	132	82	34	23	12	1	3	1
DREDGE, SCALLOP-CHAIN MAT	0	0	0	0	0	0	0	0	0	37	151	3,981	3,529
DREDGE, URCHIN	152	192	206	246	185	151	103	71	72	191	117	25	145
DREDGE,MUSSEL	383	352	17	27	1	0	0	0	0	60	236	570	6
DREDGE,OCEAN QUAHOG/SURF CLAM	6,377	619	4,704	686	1,845	1,580	1,183	538	1,066	1,079	979	862	533
DREDGE,OTHER	373	438	341	486	468	593	350	370	395	321	148	263	243
DREDGE,SCALLOP,SEA	19,180	18,303	16,985	25,245	31,935	45,529	50,169	54,404	62,008	54,664	53,257	55,352	43,766
FYKE NET	0	0	0	0	0	0	0	0	36	1	2	1	0
GILL NET,DRIFT,LARGE MESH	86	84	83	66	125	21	25	380	593	904	888	1,290	922
GILL NET,DRIFT,SMALL MESH	409	535	1,018	874	1,352	1,396	1,228	464	604	354	175	357	148
GILL NET,RUNAROUND	161	79	565	448	635	508	538	855	642	685	666	362	354
GILL NET,SINK	50,253	47,034	50,396	44,430	39,060	37,950	37,109	41,421	37,067	32,726	25,083	99,100	38,104
HAND LINE/ROD & REEL	2,353	2,071	2,645	2,337	2,561	3,622	2,935	2,177	1,939	1,402	953	1,441	893
HAND RAKE	0	0	0	0	20	4	0	184	55	115	146	150	70
HARPOON	119	71	93	102	250	107	50	53	15	8	7	6	8
HAUL SEINE	0	0	0	0	0	0	10	7	2	0	0	2	0
LONGLINE, PELAGIC	430	537	395	130	210	209	241	191	339	87	23	135	100
LONGLINE,BOTTOM	9,245	10,081	9,481	9,626	7,197	6,522	4,267	3,366	4,782	4,326	2,648	3,174	2,768
MIXED GEAR	624	487	608	81	55	0	0	0	0	0	0	0	0
OTHER GEAR	8,296	7,205	1,914	230	956	33	5	1	1	1	0	14	0
OTTER TRAWL, BEAM	1	0	2	7	40	144	523	529	1,182	776	269	640	477
OTTER TRAWL,BOTTOM,FISH	235,333	229,592	250,298	220,968	215,631	225,020	200,721	198,906	247,918	196,598	161,113	166,036	164,161
OTTER TRAWL,BOTTOM,OTHER	323	790	828	438	634	27	0	0	0	0	0	0	32
OTTER TRAWL,BOTTOM,SCALLOP	1,395	935	2,063	2,060	2,395	3,547	3,660	3,367	3,072	1,854	956	1,345	1,039
OTTER TRAWL,BOTTOM,SHRIMP	18,159	15,212	9,162	6,140	9,104	4,447	3,261	3,142	5,080	4,347	4,300	9,820	10,576
OTTER TRAWL,MIDWATER	122,712	107,547	107,606	92,927	93,445	101,565	74,885	67,292	56,550	58,375	56,250	32,207	13,145
PAIR TRAWL,BOTTOM	43	81	127	374	45	49	113	0	9	711	18	0	240
PAIR TRAWL,MIDWATER	1,942	18,231	37,783	45,639	83,675	139,422	136,552	193,334	217,663	199,218	188,610	118,141	145,731
POT, CONCH/WHELK	464	504	841	1,191	1,817	1,850	1,834	2,210	1,503	1,400	952	3,543	1,632
POT, EEL	0	0	0	0	0	0	0	0	0	0	0	2	0
POT, HAG	3,447	3,401	2,493	3,759	3,767	3,251	2,416	1,950	3,396	1,479	796	2,541	4,961
POT,CRAB	1,052	1,052	869	698	1,546	3,963	3,517	3,567	4,251	3,953	2,525	3,062	2,317
POT,FISH	1,283	1,643	1,709	2,081	1,668	862	1,239	2,404	1,195	1,442	1,264	1,380	836
POT,LOBSTER	20,362	22,221	21,493	24,847	26,015	24,589	23,321	21,087	21,559	20,577	14,757	20,005	21,197
POT,OTHER	242	101	321	503	158	10	4	2	3	3	0	169	259
POT,SHRIMP	72	18	12	26	574	266	111	286	84	202	129	202	273
POTS, MIXED	105	92	88	75	5	0	0	0	0	0	0	0	0
PURSE SEINE	81,689	110,605	58,520	83,012	83,307	78,248	66,817	55,910	47,509	50,838	51,868	101,744	111,240
SEINE, STOP	0	0	0	0	0	0	3	23	11	5	5	4	0
SEINE,DANISH	6,121	10,444	10,217	7,896	1,950	1,631	4,985	2,294	3,034	8	1,876	755	234
SEINE,SCOTTISH	269	268	221	135	235	278	125	170	104	11	0	0	0
TRAP	2,189	1,684	835	907	492	633	1,273	858	598	334	455	821	203
WEIR	0	0	50	326	262	278	570	271	330	0	0	19	0
total	*596,087*	*612,768*	*595,234*	*579,204*	*613,757*	*688,438*	*624,225*	*662,133*	*724,832*	*639,583*	*571,683*	*629,617*	*570,215*

Table 39 – Percent of total landed pounds by gear type (source: NMFS vessel trip reports)

GEARNM	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
CARRIER VESSEL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CASTNET	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
DIVING GEAR	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DREDGE, SCALLOP-CHAIN MAT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%	0.6%
DREDGE, URCHIN	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DREDGE,MUSSEL	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
DREDGE,OCEAN QUAHOG/SURF CLAM	1.1%	0.1%	0.8%	0.1%	0.3%	0.2%	0.2%	0.1%	0.1%	0.2%	0.2%	0.1%	0.1%
DREDGE,OTHER	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%
DREDGE,SCALLOP,SEA	3.2%	3.0%	2.9%	4.4%	5.2%	6.6%	8.0%	8.2%	8.6%	8.5%	9.3%	8.8%	7.7%
FYKE NET	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
GILL NET,DRIFT,LARGE MESH	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%
GILL NET,DRIFT,SMALL MESH	0.1%	0.1%	0.2%	0.2%	0.2%	0.2%	0.2%	0.1%	0.1%	0.1%	0.0%	0.1%	0.0%
GILL NET,RUNAROUND	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
GILL NET,SINK	8.4%	7.7%	8.5%	7.7%	6.4%	5.5%	5.9%	6.3%	5.1%	5.1%	4.4%	15.7%	6.7%
HAND LINE/ROD & REEL	0.4%	0.3%	0.4%	0.4%	0.4%	0.5%	0.5%	0.3%	0.3%	0.2%	0.2%	0.2%	0.2%
HAND RAKE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HARPOON	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HAUL SEINE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LONGLINE, PELAGIC	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LONGLINE,BOTTOM	1.6%	1.6%	1.6%	1.7%	1.2%	0.9%	0.7%	0.5%	0.7%	0.7%	0.5%	0.5%	0.5%
MIXED GEAR	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTHER GEAR	1.4%	1.2%	0.3%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTTER TRAWL, BEAM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.1%	0.0%	0.1%	0.1%
OTTER TRAWL,BOTTOM,FISH	39.5%	37.5%	42.1%	38.2%	35.1%	32.7%	32.2%	30.0%	34.2%	30.7%	28.2%	26.4%	28.8%
OTTER TRAWL,BOTTOM,OTHER	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTTER TRAWL,BOTTOM,SCALLOP	0.2%	0.2%	0.3%	0.4%	0.4%	0.5%	0.6%	0.5%	0.4%	0.3%	0.2%	0.2%	0.2%
OTTER TRAWL,BOTTOM,SHRIMP	3.0%	2.5%	1.5%	1.1%	1.5%	0.6%	0.5%	0.5%	0.7%	0.7%	0.8%	1.6%	1.9%
OTTER TRAWL,MIDWATER	20.6%	17.6%	18.1%	16.0%	15.2%	14.8%	12.0%	10.2%	7.8%	9.1%	9.8%	5.1%	2.3%
PAIR TRAWL,BOTTOM	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
PAIR TRAWL,MIDWATER	0.3%	3.0%	6.3%	7.9%	13.6%	20.3%	21.9%	29.2%	30.0%	31.1%	33.0%	18.8%	25.6%
POT, CONCH/WHELK	0.1%	0.1%	0.1%	0.2%	0.3%	0.3%	0.3%	0.3%	0.2%	0.2%	0.2%	0.6%	0.3%
POT, EEL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POT, HAG	0.6%	0.6%	0.4%	0.6%	0.6%	0.5%	0.4%	0.3%	0.5%	0.2%	0.1%	0.4%	0.9%
POT,CRAB	0.2%	0.2%	0.1%	0.1%	0.3%	0.6%	0.6%	0.5%	0.6%	0.6%	0.4%	0.5%	0.4%
POT,FISH	0.2%	0.3%	0.3%	0.4%	0.3%	0.1%	0.2%	0.4%	0.2%	0.2%	0.2%	0.2%	0.1%
POT,LOBSTER	3.4%	3.6%	3.6%	4.3%	4.2%	3.6%	3.7%	3.2%	3.0%	3.2%	2.6%	3.2%	3.7%
POT,OTHER	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POT,SHRIMP	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POTS, MIXED	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PURSE SEINE	13.7%	18.1%	9.8%	14.3%	13.6%	11.4%	10.7%	8.4%	6.6%	7.9%	9.1%	16.2%	19.5%
SEINE, STOP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SEINE,DANISH	1.0%	1.7%	1.7%	1.4%	0.3%	0.2%	0.8%	0.3%	0.4%	0.0%	0.3%	0.1%	0.0%
SEINE,SCOTTISH	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
TRAP	0.4%	0.3%	0.1%	0.2%	0.1%	0.1%	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%
WEIR	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 40 **– Revenue by gear type (1,000 dollars, all values converted to 2007 dollars; source: NMFS vessel trip reports)**

GEARNM	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
CARRIER VESSEL	0	0	0	0	0	0	0	0	0	0	0	0	10
CASTNET	0	0	0	0	3	1	0	7	56	281	123	61	1
DIVING GEAR	371	356	177	175	147	94	81	78	81	58	12	8	5
DREDGE, SCALLOP-CHAIN MAT	0	0	0	0	0	0	0	0	0	343	1,411	25,507	22,934
DREDGE, URCHIN	112	128	127	208	153	114	67	52	57	105	109	22	104
DREDGE,MUSSEL	201	292	11	18	1	0	0	0	0	53	180	408	3
DREDGE,OCEAN QUAHOG/SURF CLAM	8,075	565	4,002	684	1,450	1,565	880	667	1,549	4,560	5,199	3,933	1,564
DREDGE,OTHER	1,240	1,546	1,307	2,736	1,731	880	401	770	867	931	107	841	1,142
DREDGE,SCALLOP,SEA	131,362	119,704	94,851	145,839	183,848	210,929	241,939	271,784	354,412	441,855	375,956	357,267	294,304
FYKE NET	0	0	0	0	0	0	0	0	33	2	1	1	0
GILL NET,DRIFT,LARGE MESH	71	165	96	97	113	8	12	294	89	627	419	863	325
GILL NET,DRIFT,SMALL MESH	349	397	870	807	1,144	1,048	872	295	548	239	124	267	64
GILL NET,RUNAROUND	83	48	364	246	368	292	326	508	430	576	230	318	284
GILL NET,SINK	39,512	36,256	41,337	47,440	51,961	48,154	45,766	47,559	41,851	43,885	37,653	40,061	36,401
HAND LINE/ROD & REEL	8,325	5,110	5,580	5,925	6,860	8,996	7,331	4,153	2,885	1,752	1,721	2,088	1,059
HAND RAKE	0	0	0	0	12	2	0	160	26	210	66	400	55
HARPOON	945	509	568	646	1,945	735	315	311	61	31	41	11	28
HAUL SEINE	0	0	0	0	0	0	3	4	1	0	0	1	0
LONGLINE, PELAGIC	1,213	1,377	819	412	809	592	469	342	807	99	106	199	172
LONGLINE,BOTTOM	8,172	8,228	8,932	8,356	5,446	5,327	4,166	3,296	5,092	5,483	3,916	4,092	2,660
MIXED GEAR	408	501	339	122	50	0	0	0	0	0	0	0	0
OTHER GEAR	6,859	5,419	2,783	534	1,426	107	6	0	1	0	3	9	0
OTTER TRAWL, BEAM	16	0	4	16	50	153	529	743	1,278	1,108	413	449	616
OTTER TRAWL,BOTTOM,FISH	226,763	204,184	219,144	207,375	207,206	218,814	201,782	197,663	208,425	195,431	164,913	161,524	137,823
OTTER TRAWL,BOTTOM,OTHER	388	835	1,409	556	1,171	34	0	0	0	0	0	0	14
OTTER TRAWL,BOTTOM,SCALLOP	10,700	6,458	8,727	12,013	13,055	15,155	14,690	13,319	13,276	10,163	6,160	5,787	4,176
OTTER TRAWL,BOTTOM,SHRIMP	19,461	20,154	12,458	12,308	17,184	8,906	7,607	5,117	3,922	3,295	3,804	10,393	10,206
OTTER TRAWL,MIDWATER	14,874	13,815	13,853	9,682	10,877	9,085	7,667	7,802	6,541	7,142	9,572	4,299	1,722
PAIR TRAWL,BOTTOM	220	371	162	482	178	182	228	0	22	109	15	3	510
PAIR TRAWL,MIDWATER	146	1,343	3,837	3,581	6,436	10,716	12,850	19,184	23,303	22,325	27,302	12,650	16,625
POT, CONCH/WHELK	179	218	425	791	1,005	1,111	1,261	1,022	724	1,087	825	1,597	649
POT, EEL	0	0	0	0	0	0	0	0	0	0	2	2	0
POT, HAG	1,492	1,716	1,404	2,300	1,898	2,127	1,459	1,134	894	1,062	613	1,807	2,103
POT,CRAB	716	786	603	681	1,138	2,647	1,697	2,083	2,198	2,613	1,458	2,679	916
POT,FISH	2,078	3,100	3,116	3,539	2,823	1,724	2,337	3,335	2,741	3,415	3,812	3,355	2,041
POT,LOBSTER	85,360	84,729	75,724	98,900	94,390	85,325	83,106	77,726	76,865	82,172	74,433	67,879	51,629
POT,OTHER	178	147	257	285	163	38	16	3	5	16	0	261	175
POT,SHRIMP	49	19	15	34	572	311	147	247	60	158	67	78	132
POTS, MIXED	193	231	139	128	12	0	0	0	0	0	0	0	0
PURSE SEINE	10,895	13,188	9,672	12,660	13,717	17,850	14,744	12,172	5,925	14,564	9,310	30,185	18,841
SEINE, STOP	0	0	0	0	0	0	1	10	9	4	4	4	0
SEINE,DANISH	2,219	5,137	4,763	4,228	1,110	1,211	2,670	978	1,364	5	630	437	51
SEINE,SCOTTISH	369	354	334	187	230	265	163	174	110	17	0	0	0
TRAP	1,629	1,001	473	840	582	628	1,021	714	410	519	636	604	181
WEIR	0	0	15	112	135	206	326	202	181	0	0	14	0
total	*585,223*	*538,387*	*518,697*	*584,943*	*631,399*	*655,332*	*656,935*	*673,908*	*757,099*	*846,295*	*731,346*	*740,364*	*609,525*

Table 41 – Percent of total revenues by gear type (source: NMFS vessel trip reports)

GEARNM	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
CARRIER VESSEL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CASTNET	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DIVING GEAR	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DREDGE, SCALLOP-CHAIN MAT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	3.4%	3.8%
DREDGE, URCHIN	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DREDGE,MUSSEL	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
DREDGE,OCEAN QUAHOG/SURF CLAM	1.4%	0.1%	0.8%	0.1%	0.2%	0.2%	0.1%	0.1%	0.2%	0.5%	0.7%	0.5%	0.3%
DREDGE,OTHER	0.2%	0.3%	0.3%	0.5%	0.3%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.1%	0.2%
DREDGE,SCALLOP,SEA	22.4%	22.2%	18.3%	24.9%	29.1%	32.2%	36.8%	40.3%	46.8%	52.2%	51.4%	48.3%	48.3%
FYKE NET	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
GILL NET,DRIFT,LARGE MESH	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%
GILL NET,DRIFT,SMALL MESH	0.1%	0.1%	0.2%	0.1%	0.2%	0.2%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
GILL NET,RUNAROUND	0.0%	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%
GILL NET,SINK	6.8%	6.7%	8.0%	8.1%	8.2%	7.3%	7.0%	7.1%	5.5%	5.2%	5.1%	5.4%	6.0%
HAND LINE/ROD & REEL	1.4%	0.9%	1.1%	1.0%	1.1%	1.4%	1.1%	0.6%	0.4%	0.2%	0.2%	0.3%	0.2%
HAND RAKE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
HARPOON	0.2%	0.1%	0.1%	0.1%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HAUL SEINE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LONGLINE, PELAGIC	0.2%	0.3%	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%
LONGLINE,BOTTOM	1.4%	1.5%	1.7%	1.4%	0.9%	0.8%	0.6%	0.5%	0.7%	0.6%	0.5%	0.6%	0.4%
MIXED GEAR	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTHER GEAR	1.2%	1.0%	0.5%	0.1%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTTER TRAWL, BEAM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.1%	0.1%	0.1%	0.1%
OTTER TRAWL,BOTTOM,FISH	38.7%	37.9%	42.2%	35.5%	32.8%	33.4%	30.7%	29.3%	27.5%	23.1%	22.5%	21.8%	22.6%
OTTER TRAWL,BOTTOM,OTHER	0.1%	0.2%	0.3%	0.1%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTTER TRAWL,BOTTOM,SCALLOP	1.8%	1.2%	1.7%	2.1%	2.1%	2.3%	2.2%	2.0%	1.8%	1.2%	0.8%	0.8%	0.7%
OTTER TRAWL,BOTTOM,SHRIMP	3.3%	3.7%	2.4%	2.1%	2.7%	1.4%	1.2%	0.8%	0.5%	0.4%	0.5%	1.4%	1.7%
OTTER TRAWL,MIDWATER	2.5%	2.6%	2.7%	1.7%	1.7%	1.4%	1.2%	1.2%	0.9%	0.8%	1.3%	0.6%	0.3%
PAIR TRAWL,BOTTOM	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
PAIR TRAWL,MIDWATER	0.0%	0.2%	0.7%	0.6%	1.0%	1.6%	2.0%	2.8%	3.1%	2.6%	3.7%	1.7%	2.7%
POT, CONCH/WHELK	0.0%	0.0%	0.1%	0.1%	0.2%	0.2%	0.2%	0.2%	0.1%	0.1%	0.1%	0.2%	0.1%
POT, EEL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POT, HAG	0.3%	0.3%	0.3%	0.4%	0.3%	0.3%	0.2%	0.2%	0.1%	0.1%	0.1%	0.2%	0.3%
POT,CRAB	0.1%	0.1%	0.1%	0.1%	0.2%	0.4%	0.3%	0.3%	0.3%	0.3%	0.2%	0.4%	0.2%
POT,FISH	0.4%	0.6%	0.6%	0.6%	0.4%	0.3%	0.4%	0.5%	0.4%	0.4%	0.5%	0.5%	0.3%
POT,LOBSTER	14.6%	15.7%	14.6%	16.9%	14.9%	13.0%	12.7%	11.5%	10.2%	9.7%	10.2%	9.2%	8.5%
POT,OTHER	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POT,SHRIMP	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POTS, MIXED	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PURSE SEINE	1.9%	2.4%	1.9%	2.2%	2.2%	2.7%	2.2%	1.8%	0.8%	1.7%	1.3%	4.1%	3.1%
SEINE, STOP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SEINE,DANISH	0.4%	1.0%	0.9%	0.7%	0.2%	0.2%	0.4%	0.1%	0.2%	0.0%	0.1%	0.1%	0.0%
SEINE,SCOTTISH	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
TRAP	0.3%	0.2%	0.1%	0.1%	0.1%	0.1%	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%
WEIR	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 42 – Days absent by gear type (source: NMFS vessel trip reports)

GEARNM	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
CARRIER VESSEL	0	0	0	0	0	0	0	0	0	0	0	0	1
CASTNET	0	0	0	0	21	3	0	11	13	135	28	53	6
DIVING GEAR	219	131	136	116	80	112	79	58	64	28	10	15	14
DREDGE, SCALLOP-CHAIN MAT	0	0	0	0	0	0	0	0	0	34	119	4,320	3,894
DREDGE, URCHIN	107	115	135	157	131	91	54	47	32	17	14	13	24
DREDGE,MUSSEL	58	54	34	39	2	1	0	0	0	2	10	32	1
DREDGE,OCEAN QUAHOG/SURF CLAM	702	396	373	507	468	894	746	336	496	1,979	2,176	2,553	1,865
DREDGE,OTHER	1,624	1,363	2,002	1,973	872	331	190	253	208	216	186	257	220
DREDGE,SCALLOP,SEA	109,552	92,014	117,521	97,355	82,237	75,244	76,528	74,358	70,777	68,084	65,721	78,181	55,904
FYKE NET	0	0	0	0	0	0	1	0	28	4	8	6	0
GILL NET,DRIFT,LARGE MESH	403	103	434	49	82	10	13	379	658	591	546	809	407
GILL NET,DRIFT,SMALL MESH	360	513	985	1,401	1,276	1,057	666	306	462	206	94	224	103
GILL NET,RUNAROUND	179	70	434	489	685	476	648	800	683	506	429	443	486
GILL NET,SINK	61,044	48,126	53,873	57,506	65,451	69,240	55,734	54,454	50,288	45,468	33,627	41,899	41,166
HAND LINE/ROD & REEL	6,282	6,533	8,559	7,654	7,016	9,065	8,752	7,542	6,609	5,251	4,023	6,243	3,570
HAND RAKE	0	0	0	0	40	35	14	46	25	36	50	43	17
HARPOON	78	88	115	159	225	243	143	93	19	7	7	16	12
HAUL SEINE	0	0	0	0	0	0	12	4	5	0	0	5	0
LONGLINE, PELAGIC	3,564	2,450	2,061	730	1,675	1,657	1,785	1,271	1,964	704	127	831	914
LONGLINE,BOTTOM	13,108	12,749	16,061	10,894	7,575	6,713	6,832	5,411	5,986	5,881	3,993	5,373	4,355
MIXED GEAR	1,834	398	509	253	104	0	0	0	0	0	0	0	0
OTHER GEAR	9,698	6,955	5,267	580	1,611	144	24	1	3	2	1	13	0
OTTER TRAWL, BEAM	9	3	162	48	134	347	912	2,121	2,805	1,576	485	522	852
OTTER TRAWL,BOTTOM,FISH	437,190	376,357	400,592	399,583	367,867	394,397	355,604	329,149	314,677	315,865	233,359	266,620	239,546
OTTER TRAWL,BOTTOM,OTHER	1,002	1,838	2,448	381	852	112	0	0	0	0	0	0	16
OTTER TRAWL,BOTTOM,SCALLOP	3,654	4,119	5,802	5,211	3,991	4,327	4,234	3,976	4,395	5,052	3,493	3,656	1,723
OTTER TRAWL,BOTTOM,SHRIMP	13,677	18,956	15,949	17,802	16,790	11,428	9,406	5,178	6,717	4,418	4,611	9,756	10,235
OTTER TRAWL,MIDWATER	4,859	4,475	4,005	2,651	3,219	3,527	2,830	1,733	1,761	2,157	1,475	1,132	784
PAIR TRAWL,BOTTOM	140	478	298	474	151	410	570	0	37	12	52	0	1,317
PAIR TRAWL,MIDWATER	39	419	652	1,191	1,842	3,514	3,118	4,184	4,142	4,626	3,488	2,335	3,331
POT, CONCH/WHELK	212	212	300	326	591	653	620	564	519	524	401	665	618
POT, EEL	0	0	0	0	0	0	0	0	0	0	0	2	0
POT, HAG	489	591	420	523	615	579	463	257	257	287	197	495	761
POT,CRAB	212	312	341	402	566	822	507	701	1,084	953	706	844	607
POT,FISH	1,603	1,995	2,644	2,705	1,887	1,587	1,882	2,662	2,502	2,932	2,331	3,030	1,967
POT,LOBSTER	39,561	39,198	41,904	43,058	43,225	42,503	38,609	38,713	38,910	33,631	25,351	35,547	32,904
POT,OTHER	89	156	93	202	58	23	8	3	6	3	0	79	84
POT,SHRIMP	78	41	11	16	246	200	95	108	121	76	75	92	89
POTS, MIXED	256	213	247	174	27	0	0	0	0	0	0	0	0
PURSE SEINE	1,791	2,496	1,599	1,166	1,513	997	1,143	922	968	775	606	1,480	1,768
SEINE, STOP	0	0	0	0	0	0	2	6	7	6	4	3	0
SEINE,DANISH	36	72	63	60	15	17	27	10	28	4	12	13	2
SEINE,SCOTTISH	442	499	470	479	467	378	229	176	207	34	2	0	0
TRAP	741	561	777	492	221	284	667	1,136	966	855	750	1,272	170
WEIR	0	0	5	60	80	102	119	104	76	0	0	29	0
total	714,892	625,049	687,281	656,866	613,908	631,523	573,266	537,073	518,505	502,937	388,567	468,901	409,733

Table 43 – Percent of days absent by gear type (source: NMFS vessel trip reports)

GEARNM	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
CARRIER VESSEL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CASTNET	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DIVING GEAR	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DREDGE, SCALLOP-CHAIN MAT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.9%	1.0%
DREDGE, URCHIN	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DREDGE,MUSSEL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DREDGE,OCEAN QUAHOG/SURF CLAM	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.4%	0.6%	0.5%	0.5%
DREDGE,OTHER	0.2%	0.2%	0.3%	0.3%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%
DREDGE,SCALLOP,SEA	15.3%	14.7%	17.1%	14.8%	13.4%	11.9%	13.3%	13.8%	13.7%	13.5%	16.9%	16.7%	13.6%
FYKE NET	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
GILL NET,DRIFT,LARGE MESH	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.2%	0.1%
GILL NET,DRIFT,SMALL MESH	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%
GILL NET,RUNAROUND	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
GILL NET,SINK	8.5%	7.7%	7.8%	8.8%	10.7%	11.0%	9.7%	10.1%	9.7%	9.0%	8.7%	8.9%	10.0%
HAND LINE/ROD & REEL	0.9%	1.0%	1.2%	1.2%	1.1%	1.4%	1.5%	1.4%	1.3%	1.0%	1.0%	1.3%	0.9%
HAND RAKE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HARPOON	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HAUL SEINE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LONGLINE, PELAGIC	0.5%	0.4%	0.3%	0.1%	0.3%	0.3%	0.3%	0.2%	0.4%	0.1%	0.0%	0.2%	0.2%
LONGLINE,BOTTOM	1.8%	2.0%	2.3%	1.7%	1.2%	1.1%	1.2%	1.0%	1.2%	1.2%	1.0%	1.1%	1.1%
MIXED GEAR	0.3%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTHER GEAR	1.4%	1.1%	0.8%	0.1%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTTER TRAWL, BEAM	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.4%	0.5%	0.3%	0.1%	0.1%	0.2%
OTTER TRAWL,BOTTOM,FISH	61.2%	60.2%	58.3%	60.8%	59.9%	62.5%	62.0%	61.3%	60.7%	62.8%	60.1%	56.9%	58.5%
OTTER TRAWL,BOTTOM,OTHER	0.1%	0.3%	0.4%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OTTER TRAWL,BOTTOM,SCALLOP	0.5%	0.7%	0.8%	0.8%	0.7%	0.7%	0.7%	0.7%	0.8%	1.0%	0.9%	0.8%	0.4%
OTTER TRAWL,BOTTOM,SHRIMP	1.9%	3.0%	2.3%	2.7%	2.7%	1.8%	1.6%	1.0%	1.3%	0.9%	1.2%	2.1%	2.5%
OTTER TRAWL,MIDWATER	0.7%	0.7%	0.6%	0.4%	0.5%	0.6%	0.5%	0.3%	0.3%	0.4%	0.4%	0.2%	0.2%
PAIR TRAWL,BOTTOM	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
PAIR TRAWL,MIDWATER	0.0%	0.1%	0.1%	0.2%	0.3%	0.6%	0.5%	0.8%	0.8%	0.9%	0.9%	0.5%	0.8%
POT, CONCH/WHELK	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%
POT, EEL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POT, HAG	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.1%	0.1%	0.1%	0.2%
POT,CRAB	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%	0.2%	0.1%
POT,FISH	0.2%	0.3%	0.4%	0.4%	0.3%	0.3%	0.3%	0.5%	0.5%	0.6%	0.6%	0.6%	0.5%
POT,LOBSTER	5.5%	6.3%	6.1%	6.6%	7.0%	6.7%	6.7%	7.2%	7.5%	6.7%	6.5%	7.6%	8.0%
POT,OTHER	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POT,SHRIMP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POTS, MIXED	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PURSE SEINE	0.3%	0.4%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.3%	0.4%
SEINE, STOP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SEINE,DANISH	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SEINE,SCOTTISH	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
TRAP	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.1%	0.2%	0.2%	0.2%	0.2%	0.3%	0.0%
WEIR	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 44 - Fishing gears used in estuaries and bays, coastal waters, and offshore waters of the EEZ, from Maine to North Carolina. The gear is noted as bottom tending, federally regulated, and/or evaluated using SASI.

Gear	*Estuary or Bay*	*Coastal 0-3 Miles*	*Offshore 3-200 Miles*	*Contacts Bottom*	*Federally Regulated*	*SASI evaluated?*
Bag Nets	X	X	X		X	
By Hand	X	X			X	
Cast Nets	X	X	X			
Clam Kicking	X			X		
Diving Outfits	X	X	X			
Dredge Clam	**X**	**X**	**X**	**X**	**X**	**Yes**
Dredge Conch	X			X		
Dredge Crab	X	X		X		
Dredge Mussel	X	X		X		
Dredge Oyster, Common	X			X		
Dredge Scallop, Bay	X			X		
Dredge Scallop, Sea		**X**	**X**	**X**	**X**	**Yes**
Dredge Urchin, Sea		X	X	X		
Floating Traps (Shallow)	X	X		X	X	
Fyke And Hoop Nets, Fish	X	X		X		
Gill Nets, Drift, Other			X		X	
Gill Nets, Drift, Runaround			X		X	
Gill Nets, Sink/Anchor, Other	**X**	**X**	**X**	**X**	**X**	**Yes**
Gill Nets, Stake	X	X	X	X	X	
Haul Seines, Beach	X	X		X		
Haul Seines, Long	X	X		X		
Haul Seines, Long(Danish)		X	X	X	X	
Hoes	X			X		
Lines Hand, Other	X	X	X		X	
Lines Long Set With Hooks		**X**	**X**	**X**	**X**	**Yes**
Lines Long, Reef Fish		X	X	X	X	
Lines Long, Shark		X	X		X	
Lines Troll, Other		X	X		X	
Lines Trot With Baits		X	X		X	
Otter Trawl Bottom, Crab	X	X	X	X		
Otter Trawls, Beam	X	X	X	X	X	
Otter Trawl Bottom, Fish	**X**	**X**	**X**	**X**	**X**	**Yes**
Otter Trawl Bottom, Scallop		**X**	**X**	**X**	**X**	**Yes**
Otter Trawl Bottom, Shrimp	**X**	**X**	**X**	**X**	**X**	**Yes**
Otter Trawl Midwater		X	X		X	
Pots And Traps, Conch	X	X		X		
Pots and Traps, Crab, Blue Peeler	X	X		X		
Pots And Traps, Crab, Blue	X	X		X		
Pots And Traps, Crab, Other	**X**	**X**	**X**	**X**	**X**	**Yes**
Pots And Traps, Eel	X	X		X		
Pots and Traps, Lobster Inshore	X	X		X		

Gear	Estuary or Bay	Coastal 0-3 Miles	Offshore 3-200 Miles	Contacts Bottom	Federally Regulated	SASI evaluated?
Pots and Traps, Lobster Offshore			**X**	**X**	**X**	**Yes**
Pots and Traps, Fish	X	X	X	X	X	
Pound Nets, Crab	X	X		X		
Pound Nets, Fish	X	X		X		
Purse Seines, Herring		X	X		X	
Purse Seines, Menhaden		X	X			
Purse Seines, Tuna		X	X		X	
Rakes	X			X		
Reel, Electric or Hydraulic		X	X		X	
Rod and Reel	X	X	X		X	
Scottish Seine		X	X	X	X	
Scrapes	X			X		
Spears	X	X	X			
Stop Seines	X			X		
Tongs and Grabs, Oyster	X			X		
Tongs Patent, Clam Other	X			X		
Tongs Patent, Oyster	X			X		
Trawl Midwater, Paired		X	X		X	
Weirs	X			X		

Table 45 – Bottom-tending gear types evaluated in the Vulnerability Assessment.

Vulnerability assessment gear type	*Fishing vessel trip report gear type(s)*
Generic otter trawl	Otter trawl, bottom, fish; Otter trawl, scallop; Otter trawl, haddock separator; Otter trawl, other
Squid trawl*	Otter trawl, bottom, fish; Otter trawl, other
Raised-footrope trawl*	Otter trawl, bottom, fish; Otter trawl, other
Shrimp trawl	Otter trawl, bottom, shrimp
New Bedford-style scallop dredge	Dredge, scallop, se; Dredge, scallop-chain mat
Hydraulic clam dredge	Dredge, ocean quahog/surf clam
Lobster and deep-sea red crab trap	Pot, crab; Pot, lobster
Demersal longline	Longline, bottom
Sink gill net	Gill net, sink

*Effort related to squid and raised footrope trawl trips was disaggregated based on composition of landings.

The following Vulnerability Assessment gear types are described in this section: demersal otter trawl (including a generic otter trawl category plus shrimp, squid, and raised footrope trawls), New Bedford-style scallop dredge, hydraulic clam dredge, lobster and deep-sea red crab trap, sink gill net, and demersal longline. Unless otherwise noted, the following descriptions are based on Sainsbury (1996), DeAlteris (1998), Everhart and Youngs (1981), and the report of a panel of science and fishing industry representatives on the effects of fishing gear on marine habitats in the region (NREFHSC 2002), updated in Stevenson et al. (2004). Additional amplifying information was provided by the Council's Habitat Advisory Panel. In practice, there is nearly infinite variety in the ways in which gear can be rigged and fished, so these descriptions are necessarily an oversimplification.

5.1 Demersal otter trawls

Demersal, or bottom, otter trawls are towed along the seafloor to catch a variety of species throughout the region. They account for a higher proportion of the catch of federally-managed species than any other gear type. Use of demersal otter trawls in the region is managed under several federal FMPs developed by the NEFMC and MAFMC, including Northeast Multispecies; Atlantic Sea Scallop; Monkfish; Small Mesh Multispecies; Atlantic Mackerel, Squids, and Butterfish; Dogfish; Skates; and Summer Flounder, Scup, and Black Sea Bass. Otter trawling is also managed under various interstate FMPs developed by the ASMFC, including Northern Shrimp.

Trawl gear components include the warps, which attach the gear to the vessel; the doors, which hold the net open under water, the ground cables and bridles, which attach the door to the wings of the net; and the net itself. The top opening of the net, or headrope, is rigged with floats, and the lower opening, or groundrope, is rigged with a sweep, which varies in design depending on the target species (*e.g.*, whether they are found on or off the bottom) as well as the roughness and hardness of the bottom. The net terminates in a codend, which has a drawstring opening that can be untied easily to dump the catch on deck. Three components of the otter trawl typically come in contact with the seafloor: the doors; the ground cables and lower bridles; and the footrope and sweep. Chafing gear may be attached to the codend to avoid damage caused by seabed contact, although this is not believed to be a regular occurrence (S. Eayrs, personal communication).

The traditional otter board, or door, is a flat, rectangular wooden structure with steel fittings and a steel "shoe" along the leading and bottom edges that prevents damage as the door drags over the bottom. In the Northeast Region, wooden doors have been largely replaced by more hydrodynamically efficient, steel doors. Two types of steel doors commonly used in the region are the V-shaped "Thyboron" door and the cambered (or curved) "Bison" door. Either type of door can be slotted to allow some water to flow through the door, reducing drag in the water. Steel "shoes" can be added at the bottom of the door to aid in keeping it upright and take the wear from bottom contact. The sizes and weights of trawl doors used in the Northeast region vary according to the size and type of trawl, and the size and horsepower of the vessel. Large steel doors 43-54 ft^2 (4-5 m^2) weigh between 1500-2200 lb (700-1000 kg) at the surface. The effective weight (buoyancy) of the doors on the seabed during fishing is somewhat less due to hydrostatic forces acting on the doors.

The attachment point of the warps on the doors creates the towing angle, which in turn generates the hydrodynamic forces needed to push the door outward and downward, thus spreading the wings of the net. The non-traditional door designs increase the spreading force of the door by increasing direct pressure on the face of the door and/or by creating more suction on the back of the door. On fine-grained sediments, the doors create a silt cloud that aids in herding fish into the mouth of the net. On rocky or more irregular bottom, trawl doors impact rocks in a jarring manner and can jump distances of 3-6 ft (1-2 m) (Carr and Milliken 1998).

Steel ground cables attach the doors to the wings of the net. Each ground cable runs from a door to the upper and lower bridles, which attach to the top and bottom of the net wing. Thus, both the ground cables and the lower bridles contact the bottom. In New England, fixed rubber roller disks (sometimes called cookies) are attached to the ground cables and lower bridles to assist the passage of the trawl over the bottom. Depending upon bottom conditions, towing speed, and fish behavior, ground cables and bridles vary in length.

As mentioned above, sweep type varies by target species and substrate. In New England, two types of sweep are used on smooth bottom (Mirarchi 1998). In the traditional chain sweep, loops of chain are suspended from a steel cable, with only 2-3 links of the chain touching bottom. Contact of the chain with the bottom allows the trawl to skim a few inches above the bottom to catch species such as squid and scup. Another type of smooth bottom sweep uses a heavy chain with rubber cookies instead of a cable, and is used to catch flounder. The cookies vary in diameter from 4 to 16 in (10 to 41 cm) and do not rotate (Carr and Milliken 1998). This type of sweep is always in contact with the bottom.

On rough bottoms, roller and rockhopper sweeps are used (Carr and Milliken 1998). On the roller sweeps, vertical rubber rollers as large as 36 in (91 cm) in diameter are placed at intervals along the sweep. Although the rollers are free to rotate, because the sweep is shaped in a curve, only the rollers that are located at or near the center of the sweep actually "roll" over the bottom; the others are oriented at increasing angles to the direction of the tow and do not rotate freely as they are dragged over the bottom. In New England, roller sweeps have been largely replaced with rockhopper sweeps that use larger diameter fixed rollers, and are designed to "hop" over rocks as large as 1 m in diameter. Small rubber "spacer" disks are placed in between the larger rubber disks in both types of sweep. Rockhopper gear is no longer used exclusively on hard bottom habitats, but is actually quite versatile and used in a variety of habitat types (Carr and Milliken 1998).

A number of different types of bottom otter trawls are designed to catch certain species of fish on specific bottom types and at particular times of year. Bottom trawls designed to catch groundfish, scallops, shrimp, and squid are differentiated below. The raised footrope trawl is also described.

5.1.1 Generic otter trawls (including groundfish and scallop trawls)

The generic otter trawl category includes groundfish trawls and scallop trawls. Groundfish trawls can be divided into two classes, those rigged to target flatfish, and those rigged to target fish that rise off bottom. Flatfish trawls are designed with a low net opening between the headrope and the footrope and more ground rigging (i.e., rubber cookies and chain) on the sweep (Mirarchi 1998). This design allows the sweep to follow the contours in the bottom in order to encourage flatfish, which lie in contact with the seafloor, to swim off the bottom and into the net. It is used on smooth mud and sand. A high-rise or fly net with larger mesh has a wide net opening and is used to catch demersal fish that rise higher off the bottom, e.g. haddock and cod (NREFHSC 2002). Trawls used on gravel or rocky bottom, or on mud or sand bottom with occasional boulders, may be rigged with rockhopper gear, intended to get the sweep over irregularities in the bottom without damaging the net.

Scallop trawls are used on sandy bottoms, typically in waters from Long Island south to the Virginia coast. Vessels typically use wooden doors, and fishing usually occurs in waters less than 40 fathoms (approximately 75 m) deep. Cable lengths vary from 3:1 to 5:1 ratios of cable to depth. Typical scallop trawls are 55 or 65 ft (17 or 20 m) two seam nets with body and wings constructed of 5 in, 4mm or 5mm braided poly webbing. Wings are 20 to 25 ft (6-8 m) long cut on an 8:1 or 10:1 taper, while the body and belly sections are 20 to 23 ft (6-7 m) long and are cut on a 10:1 taper. Body and belly sections are identical with no overhang and both top and bottom lines are hung on 5/8 inch combination cable. Varying numbers of 8 inch (20 cm) hard plastic floats are used on the headrope, while the footrope is lined with 0.375 in to 0.5 in (1-1.3 cm) loop chain either single or double looped along the entire length. Some fishermen also use tickler chains ahead of the trawl to help kick up scallops from the seabed. No trawl extensions are used and the tailbag sections are 60 meshes around by 50 meshes deep and are constructed of 5 in^2, 4mm or 5mm, braided, double poly webbing. A whisker-type chaffing gear is used along the underside of the trawl and bag to reduce wear. Scallop trawls are not disaggregated in the Vulnerability Assessment; scallop trawl effort is evaluated together with groundfish trawls under the groundfish trawl matrix.

5.1.2 Shrimp trawls

The northern shrimp trawl fishery is prosecuted primarily in the western Gulf of Maine on mud and muddy sand substrates in depths between 20 and 100 fathoms (37-183 m). The fishery is seasonal, beginning in December and extending as late as May. Gear used in the northern shrimp fishery is required by regulation to include a Nordmore grate to minimize bycatch of other bottom dwelling species, and is generally thought to be rigged for lighter contact on bottom (also for bycatch reduction). Footropes range in length from 40-100 ft (12-30 m), but most are 50-90 ft (15-27 m). Regulations require that northern shrimp trawls may not be used with ground cables and that the “legs” of the bridles not exceed 90 ft (27 m). Shrimp trawls use 12 in (30.5 cm) or greater rockhoppers, and 1 ¾ and 2 in mesh in the codend and the body of the net, respectively. Trawling is generally restricted to daylight hours, when shrimp are lower in the water column. Tow times may typically be two hours.

5.1.3 Squid trawls

Bottom otter trawls used to catch species like squid and scup that swim over the bottom are rigged very lightly, with loops of chain suspended from the sweep (Mirarchi 1998). This gear is designed to skim along the seafloor with only two or three links of each loop of chain touching the bottom.

5.1.4 Raised footrope trawls

The raised-footrope trawl is designed capture small mesh species (silver hake, red hake, and dogfish). Raised-footrope trawls can be rigged with or without a chain sweep. If no sweep is used, drop chains must be hung at defined intervals along the footrope. In trawls with a sweep, chains connect the sweep to the footrope. Both configurations are designed to make the trawl fish about 0.45 - 0.6 m (1.5 - 2 ft) above the bottom (Carr and Milliken 1998). Although the doors of the trawl still ride on the bottom, underwater video and observations in flume tanks have confirmed that the sweep in the raised footrope trawl has much less contact with the sea floor than does the traditional cookie sweep that it replaces (Carr and Milliken 1998).

Floats of approx 8 in (20 cm) in diameter are attached to the entire length of the headrope, with a maximum spacing of 4 ft (1.2 m) between floats. The ground gear is bare wire. The top and bottom legs are equal in length, and net fishes with no extensions. The total length of ground cables and legs must not be greater than 240 ft (73 m) from the doors to wing ends. The sweep and its rigging, including drop chains, must be made entirely of bare chain with a maximum diameter of 0.3 in (0.8 cm). No wrapping or cookies are allowed on the drop chains or sweep.

5.2 New Bedford-style scallop dredges

The New Bedford-style scallop dredge is the primary gear used in the Georges Bank and Mid-Atlantic sea scallop fishery. The use of scallop dredges in federal waters of the Northeast Region is managed under the federal Atlantic Sea Scallop FMP, developed by the NEFMC in consultation with the MAFMC.

In the Northeast Region, scallop dredges are used in high- and low-energy sand environments, and high-energy gravel environments. Although gravel exists in low-energy environments of deepwater banks and ridges in the GOM, the fishery is not prosecuted there.

A New Bedford-style scallop dredge consists of a chain bag and a steel towing frame. The bag is made of two sheets of 4 in (10 cm) metal rings. The upper portion of the bag includes a 10 in mesh twine top designed to allow fish to escape, and the lower portion is rigged with chafing gear. During fishing, the bag drags on the substrate. The frame consists of a flat steel cutting bar and a pressure plate mounted above it which run parallel to the direction of the tow, and a triangular frame which connects the cutting bar and pressure plate to the single towing wire. The pressure plate generates hydrodynamic pressure, while the cutting bar rides along the surface of the substrate. Shoes on the right and left sides of the cutting bar ride along the substrate surface and are intended to take much of the wear. A sweep chain is attached to each shoe and to the forward portion of the bottom panel of the ring bag (Smolowitz 1998). Tickler chains run from side to side between the frame and the ring bag, and, in hard-bottom scalloping, a series of rock chains run from front to back to prevent large rocks from getting into the bag.

New Bedford-style dredges are typically 15 ft (4.5 m) wide; one or two of them are towed by single vessels at speeds of 4-5 knots (7.4-9.3 $km \cdot hr^{-1}$). Towing times are highly variable, depending on the density of marketable-sized sea scallops at any given location, and may be as short as 10 minutes or as long as an hour. New Bedford-style dredges used along the Maine coast are typically smaller than those used elsewhere in the fishery, and dredges used on hard bottoms are heavier and stronger than dredges used on sand.

5.3 Hydraulic clam dredges

Hydraulic clam dredges have been used in the Atlantic surfclam (*Spisula solidissima*) fishery for over five decades, and in the ocean quahog (*Arctica islandica*) fishery since its inception in the early 1970s. Use of this gear in the region is managed under the federal FMP for surf clams and ocean quahogs developed by the MAFMC. The gear is also used in state waters in the Mid-Atlantic region.

Hydraulic clam dredges can be operated in areas of large-grain sand, fine sand, sand with small-grain gravel, sand with small amounts of mud, and sand with very small amounts of clay. Most tows are made in large-grain sand. Surfclam/ocean quahog dredges are not fished in clay, mud, pebbles, rocks, coral, large gravel >0.5 in (> 1.25 cm), or seagrass beds.

The typical dredge is 12 ft (3.7 m) wide and about 22 ft (6.7 m) long, and uses pressurized water jets to wash clams out of the seafloor. Towing speed at the start of the tow is about 2.5 knots (4.6 $km \cdot hr^{-1}$), and declines as the dredge accumulates clams. The dredge is retrieved once the vessel speed drops below about 1.5 knots (2.8 $km \cdot hr^{-1}$), which can be only a few minutes in very dense beds. However, a typical tow lasts about 15 minutes. The water jets penetrate the sediment in front of the dredge to a depth of about 8-10 in (20-25 cm) and help to "drive" the dredge forward. The water pressure required to fluidize the sediment varies from 50 $lb \cdot in^{-2}$ (psi) in coarse sand to 110 psi in finer sediments. The objective is to use as little pressure as possible since too much pressure will blow sediment into the clams and reduce product quality. The "knife" (or "cutting bar") on the leading bottom edge of the dredge opening is 5.5 in (14 cm) deep for surfclams and 3.5 in (9 cm) for ocean quahogs. The knife "picks up" clams that have been separated from the sediment and guides them into the body of the dredge ("the cage").

5.4 Demersal longlines

A longline is a long length of line, often several miles long, to which short lengths of line ("gangions") carrying baited hooks are attached. Demersal longlining is used to catch a wide range of species on continental shelf areas and offshore banks.

Bottom longline fishing in the Northeast Region is conducted using hand-baited gear that is stored in tubs before the vessel goes fishing and by vessels equipped with automated "snap-on" or "racking" systems. The gangions are 15 in (38 cm) long and spaced 3-6 ft (0.9-1.8 m) apart. The mainline, hooks, and gangions all contact the bottom. In the Cape Cod longline fishery, up to six individual longlines are strung together, for a total length of about 1500 ft (460 m), and are deployed with 20-24 lb (9-11 kg) anchors. Each set consists of 600 to 1200 hooks. In tub trawls, the mainline is parachute cord; stainless steel wire and monofilament nylon gangions are used in snap-on systems (Leach 1998). The gangions are snapped on to the mainline as it pays off a drum and removed and rebaited when the wire is hauled. In New England, longlines are usually set for only a few hours at a time in areas with attached benthic epifauna. Longlines used for tilefish are deployed in deep water, may be up to 25 mi (40 km) long, and are set in a zigzag fashion. The mainline is stainless steel or galvanized wire. These activities are managed under federal fishery management plans.

5.5 Sink gill nets

A gill net is a large wall of netting which may be set at or below the surface, on the seafloor, or at any depth between. They are equipped with floats at the top and lead weights along the bottom. Sink, or bottom gill nets are anchored or staked in position. Fish are caught as they try to pass through the net meshes. Gill nets are highly selective because the species and sizes of fish caught are highly dependant on the mesh size of the net. They are used to catch a wide variety of species, including many federally-managed species. Bottom gill net fishing occurs in the Northeast Region in nearshore coastal and estuarine waters as well as offshore on the continental shelf. The use of sink gill nets in federal waters is managed under federal fishery management plans. The use of gill nets is restricted or prohibited in some state waters in the region.

Gill nets have three components: leadline, netting, and floatline. Leadlines used in New England are 65 lb (30 kg) per net; leadlines used in the Mid-Atlantic are slightly heavier. The netting is monofilament nylon, and the mesh size varies, depending on the target species. Nets are anchored at each end using Danforth anchors. Anchors and leadlines have the most contact with the bottom. Individual gill nets are typically 300 ft (91 m) long and 12 ft (3.6 m) high. Strings of nets may be set out in straight lines, often across the current, or in various other configurations (e.g., circles), depending upon bottom and current conditions.

In New England, bottom gill nets are fished in strings of 5-20 nets attached end to end. They are fished in two different ways, as “stand up” and “tie-down” nets (Williamson, 1998). Stand-up nets are used to catch cod, haddock, pollock, and hake and are soaked for 12-24 hrs. Tie-down nets are set with the float line tied to the lead line at 1.8 m (6 ft) intervals so the float line is close to the bottom and the net forms a limp bag in between each tie. They are left in the water for 3-4 days and used to catch flounders and monkfish. Bottom gill nets in New England are set in relation to changes in bottom topography or bottom type where fish are expected to congregate. Other species caught in bottom gill nets in New England are spiny dogfish, and skates.

In the Mid-Atlantic, sink gill nets are fished singly or in strings of just 3-4 nets. The Mid-Atlantic fishery is more of a “strike” type fishery in which nets are set on schools of fish or around distinct bottom features and retrieved the same day, sometimes more than once. They catch species such as bluefish (*Pomatomus saltatrix*), Atlantic croaker (*Micropogonias undulates*), striped bass (*Morone saxatilis*), spot (*Leiostomus xanthurus*), mullet (*Mugii* spp.), spiny dogfish (*Squalus acanthias*), smooth dogfish (*Mustelus canis*), and skates (*Leucoraja ocellata*, *Leucoraja erinacea, Raja eglanteria, Leucoraja garmani*).

5.6 Traps

Traps are used to capture lobsters, crabs, black sea bass, eels, and other bottom-dwelling species seeking food or shelter. Trap fishing can be divided into two general classifications: 1) inshore trapping in estuaries, lagoons, inlets, and bays in depths up to about 75 m (250 ft); and 2) offshore trapping using larger and heavier vessels and gear in depths up to 730 m (2400 ft) or more.

Originally, traps used to harvest American lobster (*Homarus americanus*) were constructed of wooden laths with single, and later, double, funnel entrances made from net twine. Today, roughly 95% are made from coated wire mesh. They are rectangular and are divided into two sections, the "kitchen" and the "parlor." The kitchen has an entrance on both sides of the pot and is baited. Lobsters enter either chamber then move to the parlor through a long, sloping tunnel to the parlor. Escape vents are installed in both areas of the pot to minimize the retention of sub-legal-sized lobsters. Rock crabs (*Cancer* spp.) are also harvested in lobster pots.

Lobster traps are fished as either a single trap per buoy, 2 or 3 traps per buoy, or strung together in "trawls" of up to 100 traps. Trawls are used on flatter types of bottom. Traps in trawls are connected by "mainlines" which either float off the bottom, or, in areas where they are likely to become entangled with marine mammals, sink to the bottom. Single traps are often used in rough, hard bottom areas where lines connecting traps in a trawl line tend to become entangled in bottom structures.

Soak time for lobster traps depends on season and location, ranging from 1-3 days in inshore waters in warm weather, up to several weeks in colder waters. Offshore traps are larger (>1.2 m (4 ft) long) and heavier (~45 kg (100 lb)) than inshore traps with an average of about 40 traps per trawl. They are usually deployed for a week at a time. Although the offshore component of the fishery is regulated under federal rules, American lobster is not managed under a federal fishery management plan.

Currently, three large (average 98 ft. 30 m) vessels are engaged in the deep-sea red crab (*Geryon quinquedens*) fishery, which is managed by the NEFMC (NEFMC 2010). Traditional deep-sea red crab traps are wood and wire traps that are 48 in long, 30 in wide, and 20 in high (1.20 x 0.75 x 0.5 m) with a top entry funnel or opening. A second style of trap, which is now used exclusively, is conical in shape, 4 ft (1.3 m) in diameter at the base and 22 in (0.45 m) high with a top entry funnel or opening. Vessels use an average of 560 traps that are deployed in trawls of 75-180 traps per trawl along the continental slope at depths of 1300-2600 ft (400-800 m) (NEFMC 2002).

6.0 Estimating contact-adjusted area swept

In order to (1) quantify fishing effort in like terms and (2) compare the relative effects of different fishing gears, fishing effort inputs to the SASI model are converted to area swept. The area swept by each gear component may be estimated individually. Estimating the contribution of individual gear components separately allows the SASI model to tease out the relative contribution that each component may make toward the area swept by the gear as a whole. Area swept is summed across gear components at the level of the tow, gillnet set, line of hooks, line of traps, etc. Individual tows, sets, etc. are then summed to obtain area swept estimates at the trip level, and all trips for that gear type are summed to generate annual estimates by gear type. These estimates are spatially-specific, and binned at the 100 km^2 grid cell level as described in section **Error! Reference source not found.**. The following sections describe the methods used to estimate area swept, including (1) models and assumptions, and (2) data and parameterization.

6.1 Area swept model specification

Simple quantitative models convert fishing effort data to area swept. These models provide an estimate of contact-adjusted area swept, measured in km^2. Regardless of gear type, the area swept models have three requirements:

- total distance towed, or, in the case of fixed gears, total length of the gear;
- width of the individual gear components; and
- contact indices for the various gear components.

The contact index is a key feature of SASI, because it allows the model to 'reward' gears that are modified to reduce seabed contact (e.g. those designed to skim over the seabed, or with raised ground gear). This contact index is a measure of the overall contact width of the various gear components that makes an allowance for the fact that the entire width of the gear may not be in contact with the seabed.

Note that the fishing gears employed in the region and the gears used in impacts studies may be constructed of different materials and rigged or fished in a variety of different ways; the contact indices specified here are oversimplifications. Contact indices are categorically specified by gear type, and may be revised in the future to accommodate additional data and/or new or modified gear types. Currently, contact indices do not vary by substrate, although this level of complexity could be added to the SASI model if and when additional research allows for more explicit treatment of this index.

These models do not explicitly incorporate an estimate of the weight of gear in the water, primarily because estimates of in-use gear component weights are not available. Also, the weight of the gear is accounted for within the SASI model in two ways. First, if the gear component is sufficiently buoyant such that bottom contact is reduced, this will result in a lower contact index value. Second, the quality of the gear-seabed interaction is directly incorporated into the susceptibility estimates, which are based on the results of actual or experimental fishing effects evaluations using real gear configurations/hydrodynamic conditions.

6.1.1 Demersal otter trawl

A demersal trawl has four components that potentially contribute to seabed impact: the otter boards, the ground cables, the sweep, and the net. Because the net follows directly behind the sweep, it is not included in the effective gear width calculation. Thus, the SASI model for a demersal trawl simplifies to

$$A_{trawl}(km^2) = d_t\left[\left(2\cdot w_o\cdot c_o\right)+\left(2\cdot w_c\cdot c_c\right)+\left(w_s\cdot c_s\right)\right],$$

where:

d_t	=	distance towed in one tow (km)
w_o	=	effective width of an otter board (m), which equals otter board length (km)·sin (α_o), where α_o = angle of attack
c_o	=	contact index, otter board
w_c	=	effective width of a ground cable (km), which equals ground cable length (km)·sin(α_c), where α_c = angle of attack
c_c	=	contact index, ground cables
w_s	=	effective width of sweep (km)
c_s	=	contact index, sweep

The angle of attack (α) of an otter board can be determined at sea by measuring the scratch marks on the shoe of the otter board at the completion of a tow. If this is not possible, an assumed value of α can be utilized ranging between 30° and 50° (Gomez and Jimenez 1994). An intermediate value of 40° is selected for SASI. The angle of attack of a ground cable varies along its length, and cannot be accurately measured at sea. This angle is typically assumed to range between 10° and 20 ° (Gomez and Jimenez 1994, Baranov 1969). An intermediate value of 15° is selected for SASI. The effective width of a sweep can only be measured at sea using acoustic mensuration sensors. Effective headrope width is generally accepted as being approximately 50% of nominal headrope width; for the sweep, which is shorter, this value drops to between 40-45%. A single model is used for all otter trawl types, including groundfish, shrimp, squid, and raised footrope. Nominal and contact adjusted area swept are represented graphically below (Figure 13). The contact indices assumed for the various trawl types are shown in Table 46.

The demersal otter trawl SASI model assumes the following:

- Seabed contact does not change within a tow
- Otter board angle of attack is constant during a tow
- Ground cables are straight along their entire length
- The effect of towing speed on seabed contact is accommodated by d_t

Figure 13 – Area swept schematic (top down view). The upper portion shows nominal area swept, and the lower portion shows contact adjusted area swept. Contact indices will vary according to Table 46; the figure below is for illustrative purposes only.

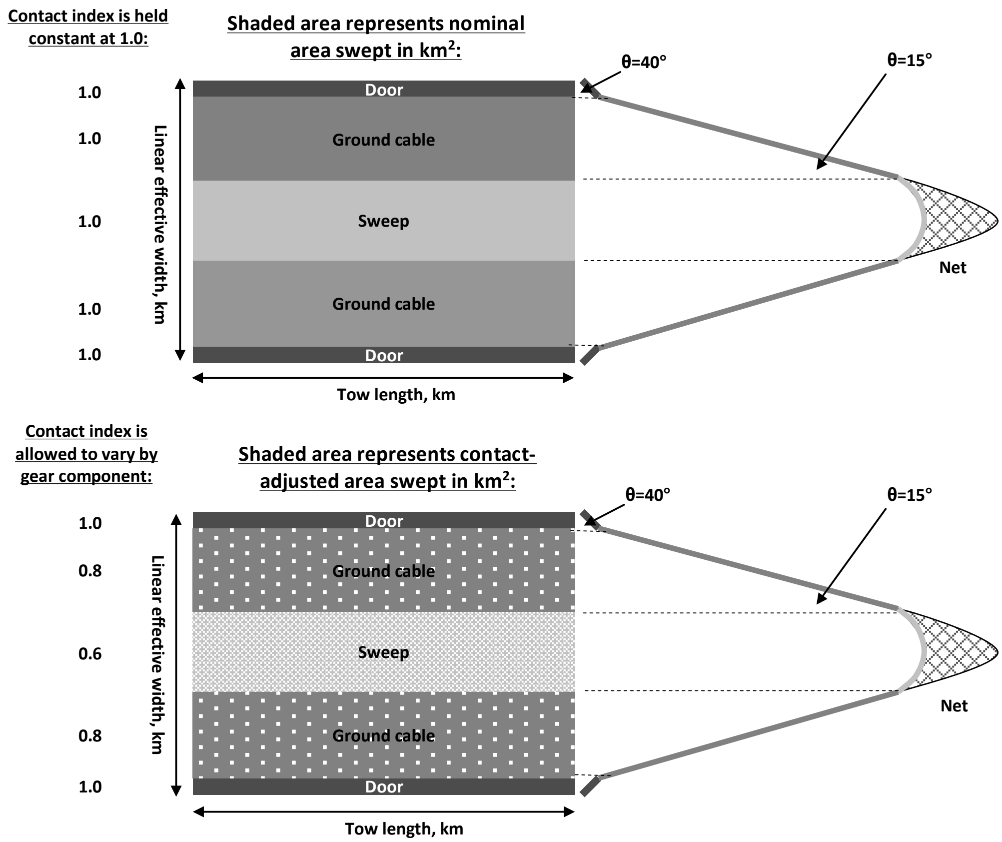


Table 46 - Contact indices for trawl gear components

Gear type	*Component*	*Contact index*
Generic otter trawl	Doors	1.00
Generic otter trawl	Ground cable	0.95
Generic otter trawl	Sweep	0.90
Squid trawl	Doors	1.00
Squid trawl	Ground cable	0.95
Squid trawl	Sweep	0.50
Shrimp trawl	Doors	1.00
Shrimp trawl	Ground cable	0.90
Shrimp trawl	Sweep	0.95
Raised footrope trawl	Doors	1.00
Raised footrope trawl	Ground cable	0.95
Raised footrope trawl	Sweep	0.05

6.1.2 New Bedford-style scallop dredge

A scallop dredge has five key components that potentially contribute to seabed impact. They are: the contact shoes; the dredge bale arm including cutting bar; the bale arm rollers; the chain sweep; and the ring bag and club stick. However, additional dredge components do not add width to the area swept because they follow one behind the other as the gear is towed. Therefore, the dredge model shown below does not consider the potential impact of individual components of a dredge, but groups them together.

Given these simplifying assumptions, the scallop dredge SASI model is

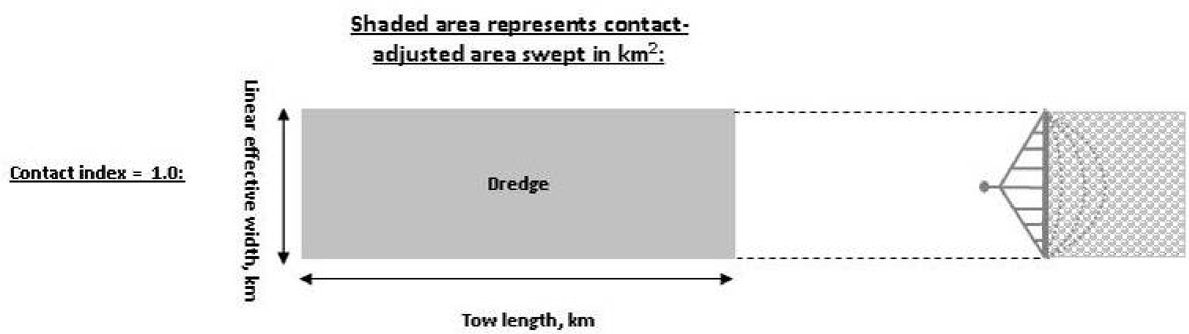
$$A_{scallop}(km^2) = d_t(w \cdot c),$$

where:

- d_t = distance towed in one tow (km)
- w = effective width of widest dredge component (km)
- c = contact index, all dredge components

If two dredges are used simultaneously, the effective width is the sum of the individual dredge widths. A diagrammatic representation of area swept for scallop dredges is provided below (Figure 14). The contact index is set to 1.0, which means that nominal area swept and contact-adjusted area swept are equal.

Figure 14 – Area swept schematic for scallop dredge gear (top down view). Since the contact index is 1.0, nominal area swept and contact-adjusted area swept are equivalent.



Similar to the otter trawl model, the scallop dredge SASI calculation assumes the following:

- Seabed contact does not change within a tow
- The effect of towing speed on seabed contact is accommodated by d_t

6.1.3 Hydraulic clam dredge

Similar to the scallop dredge model, the hydraulic clam dredge model shown below does not consider the potential impact of individual components of a dredge, but groups them together. The area swept model for hydraulic clam dredge is

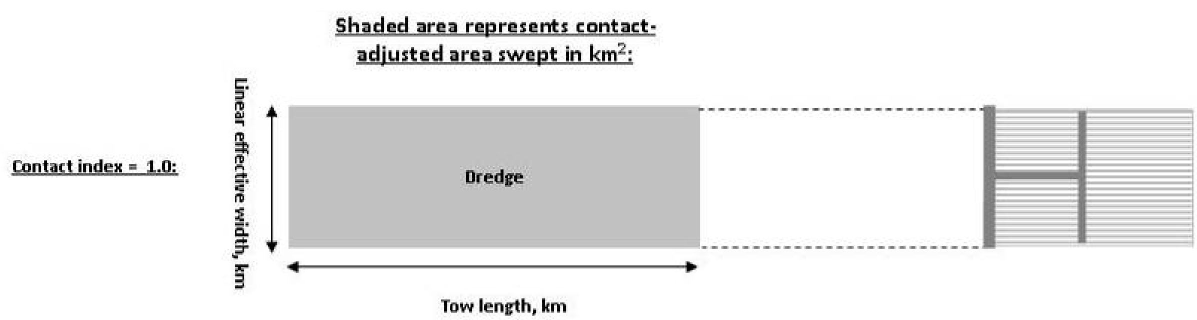
$$A_{hydraulic}(km^2) = d_t(w \cdot c),$$

where:

d_t = distance towed in one tow (km)
w = effective width of widest dredge component (km)
c = contact index, all dredge components

If multiple dredges are used simultaneously, the effective width is the sum of the individual dredge widths. Nominal and contact adjusted area swept are represented graphically below (Figure 15). The contact index is set to 1.0, which means that nominal area swept and contact-adjusted area swept are equal.

Figure 15 – Area swept schematic for hydraulic dredge gear (top down view). Since the contact index is 1.0, nominal area swept and contact-adjusted area swept are equivalent.



The hydraulic dredge area swept calculation assumes the following:

- Seabed contact does not change within a tow
- The effect of towing speed on seabed contact is accommodated by d_t

6.1.4 Demersal longline and sink gillnet

A demersal longline or gillnet has two key components that potentially contribute to seabed impact: the weights and either the mainline (longline) or the footline (gillnets). For longline gear, any impacts of the gangions and hooks are ignored.

The area swept model for a demersal longline or gillnet is

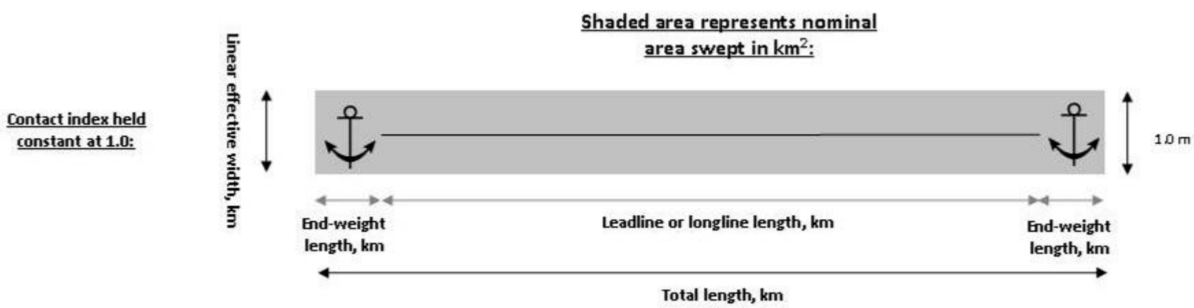
$$A_{longline/gillnet}(km^2) = 2(d_w \cdot l_w \cdot c_w) + (d_l \cdot l_l \cdot c_l),$$

where:

d_w = distance end-weight moves over the seabed (km)
w_w = length of end-weight (km)
c_s = contact index, end-weight
d_l = distance longline or leadline moves over the seabed (km)
l_l = length of longline or leadline (km)
c_l = contact index, longline or leadline

The distance that each gear component moves is a function of movements over the seabed both while the gear is fishing (soaking) and during the setting and hauling processes, although the extent of these movements is unknown. The d_w and d_l parameters are intended to capture both types of movement (i.e. lateral and perpendicular to the long axis of the gear). For both the end weights and the longlines/leadlines, this distance is assumed to be one meter (i.e. d_w and d_l are specified as 0.001 km (1.0 m)), and is assumed to be sufficient to capture any movement both laterally and perpendicular to the mainline. Nominal and contact adjusted area swept are represented graphically below (Figure 16). Seabed contact is assumed to be 1.0 for all gear components.

Figure 16 – Area swept schematic for longline or gillnet gear (top down view). Since the contact index is 1.0, nominal area swept and contact-adjusted area swept are equivalent.



6.1.5 Lobster and deep-sea red crab traps

The area swept model for a line or trawl of *n* lobster traps, accounting for each individual trap and ground line between traps is

$$A_{trap}(km^2) = \sum_{1}^{n}\left[d_{tn} \cdot l_{tn} \cdot c_{tn}\right] + \sum_{1}^{n-1}\left[d_{gn} \cdot l_{gn} \cdot c_{gn}\right],$$

where:

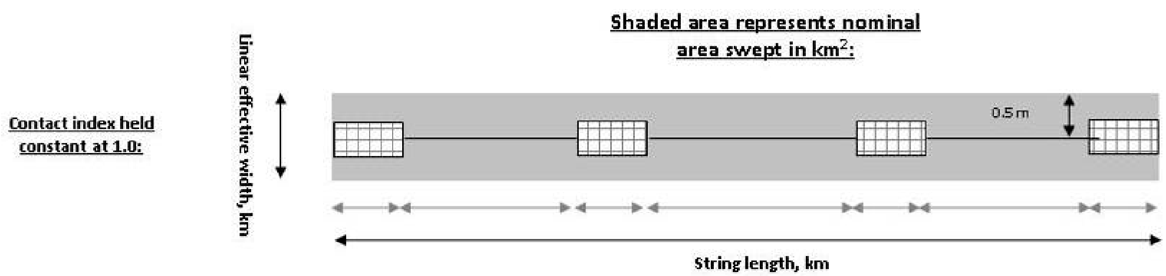
- n = Number of traps
- $n-1$ = Number of groundlines between traps
- d_{tn} = lateral distance *n*th trap moves over the seabed (km)
- l_{tn} = length of *n*th trap (km)
- c_{tn} = contact index, *n*th trap
- d_{gn} = lateral distance the *n*th ground line moves over the seabed (km)
- l_{gn} = length of *n*th ground line (km)
- c_{gn} = contact index, *n*th groundline

Similar to longlines and gillnets, the distance that each gear component moves is a function of movements over the seabed both while the gear is fishing (soaking) and during the setting and hauling processes, although the extent of these movements is unknown. The d_{tn} and d_{gn} parameters are intended to capture both types of movement (i.e. lateral and perpendicular to the long axis of the gear). For both the traps and the groundlines, these distances are assumed to be one meter. If d_{tn} and d_{gn} are specified as 0.001 km (1.0 m), and all traps and segments of groundline are assumed to be the same length, the equation simplifies to

$$A_{trap}(km^2) = (0.001 \cdot n \cdot l_{tn} \cdot c_{tn}) + (0.001 \cdot (n-1) \cdot l_{gn} \cdot c_{gn}).$$

Nominal and contact adjusted area swept are represented graphically below (Figure 17). The seabed contact index is assumed to be 1.0 for lines and traps.

Figure 17 – Area swept schematic for trap gear (top down view). Since the contact index is 1.0, nominal area swept and contact-adjusted area swept are equivalent.



6.2 Data and parameterization

This section describes the data sources used and assumptions made when calculating nominal area swept for each gear type. The contact indices specified in the previous section are then applied to these raw estimates to generate *A*, the contact-adjusted swept area. Note that the information below pertains to the realized effort model runs ($Z_{realized}$) and practicability runs (which use Z_{net}). To facilitate comparison between them, the Z_{∞} runs use the same A values regardless of gear types in all grid cells.

The general requirements for the area swept calculations are: gear width (km), tow length or distance the gear moves over the seabed (km), and number of tows or soaks per year. Ideally, all of the parameters would be specified for every trip in a single data source. However, VTR data are the only synoptic data source for vessel activity, area fished, and catch for commercial fisheries, and this data set does not include information on tow duration or tow speed, or on the dimensions of some gear components. Data from the at sea observer program are then used to specify some parameters. For example, the observer program collects specific information about trawl net configurations and dimensions, as well as towing speeds. In some cases, these parameters are specified annually in order to account for changes over time. It is important to remember that observer data is only a sample, and may not be representative of overall fishery.

6.2.1 Demersal otter trawl

As shown above, the model for otter trawl contact-adjusted area swept for a single tow is

$$A_{trawl}(km^2) = d_t\left[(2 \cdot w_o \cdot c_o) + (2 \cdot w_c \cdot c_c) + (w_s \cdot c_s)\right].$$

The area swept for an individual tow is summed across all tows in a trip, and all trips during a particular year. Thus, to calculate *A* the data required include: gear width for each of the three components (w_o, w_c, w_s), distance towed (d_t), trips per year, and for each trip, tows per trip. For mobile gears including otter trawls, tow length is always a derived value that combines tow speed (km/hour) and tow duration (hours). Effective width of a trawl tow includes the three gear components: otter boards, ground cables and sweep.

Estimating the effective linear width of otter boards

The parameter w_o , the effective width of an otter board (m), is modeled as otter board length (m) times sin (α_o), where α_o = angle of attack (assumed to be 40 °). Otter board weight data is collected through the observer program, but dimensions are not. Using commercially available data on the size and weight of otter boards for two different door designs (Thyboron Type II and Bison, both distributed by Trawlworks, Inc of Narragansett RI), a linear relationship between otter board weight and otter board length is established (Table 47). The type and brand of otter boards used in the fishery are not reported, and it is not known if this sample is representative of the gear used on observed trips, or in the fishery as a whole.

Table 47 – Linear regression of otter board length on otter board weight

Analysis of variance

	Degrees of freedom	Sum of Squares	Mean square	F	Probability
Model	1	3573531	3573631	303.61	< 0.0001
Error	24	282493	11771		
Corrected total	25	3856124			

R^2: 0.9267 Adj R^2: 0.9237

Parameter estimates

Variable	Degrees of freedom	Parameter estimate	Standard error	t value	Probability
Intercept	1	1223.66251	49.12562	24.91	< 0.0001
Average weight	1	0.83332	0.04783	17.42	< 0.0001

This relationship provides an estimate of otter board length for each observed trip, as follows:

Otter board width (inches) = 1223.7 + (0.8 * otter board weight in pounds)

This relationship is applied to fishing trips by constructing a relationship between reported door weight and a variable or variables common between both observer and VTR datasets. Several relationships are investigated. A significant and relatively strong linear relationship exists between door weight and a combination of gross tonnage and horsepower (Table 48).

Table 48 – Linear regression of otter board weight on vessel gross tonnage and vessel horsepower, observer data 2003-2008

Parameter estimates

Variable	Degrees of freedom	Parameter estimate	Standard error	t value	Probability
Intercept	1	70.84823	7.75592	9.13	< 0.0001
Gross tons	1	1.84431	0.09525	19.36	< 0.0001
Vessel horsepower	1	0.53446	0.02173	24.59	< 0.0001

Thus, door weight for a particular trip is calculated as:

Door weight (tons) = 70.8 + (1.8 * Vessel tonnage) + (0.5 * Vessel horsepower)

Applying this relationship to all VTR-reported trips provides an estimate of door weights. Finally, applying the modeled relationship between otter board weight and otter board length, and correcting for angle of attack, provides an estimate of the effective linear width of otter boards used for each trip.

Estimating the effective linear width of ground cables

The parameter w_c , the effective width of a ground cable (km), equals ground cable length (m) multiplied by $\sin(\alpha_c)$, where α_c = angle of attack (assumed to be 15^o). Ground cable length data are collected directly through the observer program. Relationships between ground cable length and independent variable common between both observer and VTR datasets are investigated. A significant but weak linear relationship exists between ground cable length and vessel length (Table 49).

Table 49 – Linear regression of ground cable length on vessel length

Analysis of variance

	Degrees of freedom	Sum of Squares	Mean square	F	Probability
Model	1	92928	92928	209.32	< 0.0001
Error	2960	1314125	444		
Corrected total	2961	1407054			

R^2: 0.0660 Adj R^2: 0.0657

Parameter estimates

Variable	Degrees of freedom	Parameter estimate	Standard error	t value	Probability
Intercept	1	23.34782	1.72249	13.55	< 0.0001
Length	1	0.37242	0.02574	14.47	< 0.0001

Thus, ground cable length for a particular trip is calculated as:

Ground cable length (km) = 23.3 + (0.4* Vessel length (m)) * 0.001 m/km * 2 cables/trawl

Applying this relationship to all VTR-reported trips using otter trawls provides an estimate of ground cable length, and correcting for angle of attack provides an estimate of the effective linear width of ground cables used for each trip.

Estimating tow length

Tow duration and speed are combined to generate tow lengths in kilometers. Average trawl gear speeds by year are shown below. Based on the similarity between years, the same speed is assumed for all tows in all years.

Table 50 – Trawl gear tow speeds (in knots) by year, based on observer data

YEAR	*Sample size*	*Mean*	*St Dev*
2003	7,185	3.01	0.38
2004	10,875	3.00	0.35
2005	27,129	3.01	0.33
2006	13,577	3.03	0.32
2007	15,143	3.02	0.32
2008	17,359	3.04	0.35
2009	16,582	3.03	0.32

Tow duration is also specified in the observer data.

Table 51 – Trawl gear tow duration (in hours) by year, based on observer data

YEAR	*Sample size*	*Mean*	*St Dev*
2003	7,185	3.55	1.64
2004	10,875	3.13	1.63
2005	27,129	3.34	1.57
2006	13,577	3.44	1.58
2007	15,143	3.27	1.61
2008	17,359	3.29	1.60
2009	16,582	3.16	1.64

Summarizing contact-adjusted area swept parameters

The data used to estimate contact-adjusted area swept (A) parameters are summarized in Table 52 (below).

Table 52 – Assumed trawl parameters

Parameter	*Data source/method*	*Notes*
Door width	Observer – reported in gear tables on a trip-by-trip basis, averaged across all observed trips	
Ground cable width	Observer	
Tow duration	Observer – reported in haul tables on a tow-by-	Specified annually

	tow basis, averaged across all observed trips	
Tow speed	Observer – reported in haul tables on a tow-by-tow basis, and averaged across all observed trips.	Little annual variation (see table below), so single value of 3 km is used
Sweep width	Total sweep length data are reported in the VTR. The effective linear width of the sweep is modeled as the diameter of a circle with a perimeter of two times the sweep length.	
Number of trips per year	VTR	
Number of tows per trip	VTR	

Finally, contact indices are specified separately for the four trawl gear types. This required distinguishing between the different types of trawls, which is done at the trip level by examining the VTR data, as follows:

Table 53 – Distinguishing between trawl gear types

Trawl type	*Thresholds*	*Notes*
Generic otter trawl	All trawl trips not included in other categories	Gear codes 050 (fish), 057 (haddock separator), 052 (scallop), 053 (twin trawl)
Squid trawl	75% of catch, by weight, was either *Illex* squid or *Loligo* squid	Gear code 050 plus catch weight
Shrimp trawl	Any trip with the gear type coded as shrimp gear	Shrimp gear code is 058
Raised footrope trawl	Trip must have occurred during or after 2003, in statistical area with exemptions, during months fishery was open, and have greater than 50% whiting (silver hake) in catch, by weight	

Evaluating bias with respect to at-sea observer data

As previously noted, the observer program does not sample all fisheries and gear types evenly. The distribution of trips in terms of size (horsepower, length) and fishing locations (latitude, longitude) for observer and VTR data are significantly different for trips made with trawl gears Table 54. Assuming that the VTR data are accurate and represent the true fishery, observer data may be biased upwards with respect vessel size. The magnitude and direction of bias resulting from the fishing location differences between the two datasets is unclear, though persistent variations in depth and substrate type across latitudes and longitudes may play a role in the configuration of trawl gears and their dimensions. Year effects cannot be ruled out, as these analyses include the years 1996 – 2008 while observer data is only available from 2003 onward.

Table 54 – Independent group t-test for observer-reported trips made between 2003-2008 with trawl gears, and VTR-reported trips for the same years; paired records discarded from VTR group (Class 1 = VTR, Class 2 = OBS, VHP = vessel horsepower, LEN = length, GTONS = vessel weight, Lat/Lon = Latitude/Longitude)

Variable	*class*	*N*	*Lower CL Mean*	*Mean*	*Upper CL Mean*	*Lower CL Std Dev*	*Std Dev*	*Upper CL Std Dev*	*Std Err*	*Minimum*	*Maximum*
VHP	1	1.64E+05	403.73	404.70	405.67	199.68	200.36	201.05	0.495	25.0	2985.0
VHP	2	4664	489.77	496.39	503.02	226.32	230.91	235.70	3.381	54.0	2775.0
VHP	Diff (1-2)		-97.55	-91.69	-85.84	200.59	201.27	201.95	2.989		
LEN	1	1.64E+05	56.79	56.87	56.94	14.81	14.86	14.91	0.037	18.0	138.0
LEN	2	4664	64.82	65.25	65.68	14.68	14.98	15.29	0.219	32.0	138.0
LEN	Diff (1-2)		-8.81	-8.38	-7.95	14.82	14.87	14.92	0.221		
GTONS	1	1.64E+05	64.08	64.31	64.53	46.69	46.85	47.01	0.116	0.0	476.0
GTONS	2	4664	93.22	94.75	96.27	52.19	53.25	54.36	0.780	3.0	246.0
GTONS	Diff (1-2)		-31.81	-30.44	-29.07	46.88	47.04	47.20	0.699		
Lat	1	1.17E+05	41.06	41.07	41.08	1.65	1.65	1.66	0.005	35.0	44.6
Lat	2	4658	41.09	41.13	41.17	1.35	1.38	1.41	0.020	35.2	43.9
Lat	Diff (1-2)		-0.11	-0.07	-0.02	1.64	1.64	1.65	0.025		
Lon	1	1.17E+05	71.52	71.53	71.54	1.80	1.81	1.81	0.005	65.6	77.3
Lon	2	4658	70.43	70.49	70.55	2.10	2.14	2.19	0.031	66.5	76.5
Lon	Diff (1-2)		0.99	1.04	1.10	1.81	1.82	1.83	0.027		

T-Tests

Variable	*Method*	*Variances*	*DF*	*t Value*	*Pr > |t|*
VHP	**Pooled**	Equal	1.70E+05	-30.68	<.0001
LEN	**Satterthwaite**	Unequal	4927	-37.68	<.0001
GTONS	**Pooled**	Equal	1.70E+05	-43.58	<.0001
Lat	**Pooled**	Equal	1.20E+05	-2.69	0.0071
Lon	**Pooled**	Equal	1.20E+05	38.32	<.0001

Equality of Variances

Variable	*Method*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
VHP	**Folded F**	4663	1.64E+05	1.33	<.0001
LEN	**Folded F**	4663	1.64E+05	1.02	0.4485
GTONS	**Folded F**	4663	1.64E+05	1.29	<.0001
Lat	**Folded F**	1.17E+05	4657	1.43	<.0001
Lon	**Folded F**	4657	1.17E+05	1.41	<.0001

6.2.2 New Bedford-style scallop dredge

The model for New Bedford-style scallop dredge contact-adjusted area swept for a single tow is:

$$A_{scallop}(km^2) = d_t\left(w \cdot c\right)$$

Parameter estimates

Similar to trawls, scallop tow distance is estimated by multiplying tow speed by tow duration reported in the observer data, as shown in the following tables.

Table 55 – Scallop dredge tow speeds (knots) by year, based on observer data

YEAR	*Sample size*	*Mean*	*St Dev*
2003	5,270	4.43	0.46
2004	8,306	4.46	0.39
2005	6,139	4.56	0.41
2006	6,009	4.60	0.45
2007	7,557	4.60	0.43
2008	11,349	4.70	0.33
2009	23,726	4.63	0.37

Table 56 – Scallop dredge tow duration (hours) by year, based on observer data

YEAR	*Sample size*	*Mean*	*St Dev*
2003	5,270	1.05	0.29
2004	8,306	1.11	0.31
2005	6,139	1.03	0.34
2006	6,009	1.02	0.34
2007	7,557	1.01	0.30
2008	11,349	0.96	0.21
2009	23,726	1.05	0.38

Table 57 – Assumed scallop dredge parameters

Parameter	*Data source/method*	*Notes*
Tow speed	Speeds from observed tows were averaged by year	Scallop dredge trips were assumed to tow at 4.4 knots for all years prior to 2004, 4.5 knots for trips taken in 2004, 4.6 knots for trips taken from 2005 to 2007, and 4.7 knots for trips taken in 2008.
Tow duration	Durations from observed tows were averaged by year	
Number of trips per year	VTR	
Number of tows per trip	VTR	
Number of dredges used	VTR	
Width of dredges	VTR	

6.2.3 Hydraulic clam dredge

The model for hydraulic clam dredge contact-adjusted area swept for a single tow is:

$$A_{hydraulic}(km^2) = d_t\left(w \cdot c\right)$$

Table 58 – Assumed hydraulic dredge parameters

Parameter	***Data source/methods***	***Notes***
…needs data…		

6.2.4 Demersal longline

The model for demersal longline contact-adjusted area swept for a single longline is:

$$A_{longline/gillnet}(km^2) = 2(d_w \cdot l_w \cdot c_w) + (d_l \cdot l_l \cdot c_l)$$

Table 59 – Assumed longline parameters

Parameter	***Data source/methods***	***Notes***
…needs data…		

6.2.5 Sink gillnet

The model for sink gillnet contact-adjusted area swept for a single gillnet is:

$$A_{longline/gillnet}(km^2) = 2(d_w \cdot l_w \cdot c_w) + (d_l \cdot l_l \cdot c_l)$$

Table 60 – Assumed gillnet parameters

Parameter	***Data source/methods***	***Notes***
…needs data…		

6.2.6 Traps

The model for trap gear contact-adjusted area swept for a string of traps is:

$$A_{trap}(km^2) = (0.001 \cdot n \cdot l_{tn} \cdot c_{tn}) + (0.001 \cdot (n-1) \cdot l_{gn} \cdot c_{gn})$$

Table 61 – Assumed gillnet parameters

Parameter	*Data source/methods*	*Notes*
…needs data…		

7.0 Defining habitats spatially

The spatial domain of the SASI model is US Federal waters (between 3-200 nm offshore) from Cape Hatteras to the US-Canada border. Within this region, habitats are defined based on dominant substrates and natural disturbance regime, with the latter categorized as high or low bottom energy based on water flow and water depth. Spatial substrate data are used to generate the model grid and energy is inferred from and oceanography model (flow) and a coastal relief model (depth).

7.1 Substrate data and unstructured grid

A geological substrate-based grid is selected for the SASI model for both theoretical and practical reasons. Theoretically, substrate type influences the distribution of managed species, structure-forming epifauna, and prey species by providing spatially discrete resources such as media for burrowing organisms, attachment points for vertical epifauna, etc. Practically, substrate provides a common link between empirical spatial seabed habitat data and the literature covering the effects of fishing on habitat, as most studies reference substrate as either a classification for habitat or a description of the habitats within the study areas. Further, and critically, substrate data is available at varying resolutions for the entire model domain.

Within the model domain, the collection methods, sampling resolution, and ranges of sampled substrates vary a widely over both temporal and spatial scales. To accommodate variation in sampling methods, the dominant substrate in each sample is used to represent the substrate class occurring at that particular X,Y location. Dominant substrate type is defined as the substrate type composing the largest fraction of each sample. Dominance is determined by volume, area, or frequency of occurrence, depending on the sampling methodology.

To accommodate varying spatial resolutions of substrate samples, the X,Y locations of the substrate data are tessellated to create a Voronoi diagram. In a Voronoi diagram, each polygon is convex, and defined by the perpendicular bisectors of lines drawn between geological data points such that each polygon bounds the region closer to that data point relative to all others (Thiessen and Alter 1911, Gold 1991, Okabe et al. 1992, Legendre and Legendre 1998). In other words, the midpoint of each line segment making up a Voronoi polygon is equidistant between the two closest substrate sampling locations. Voronoi diagrams have been used in terrestrial and aquatic ecological studies and are particularly useful for creating a surface from spatially clustered point data. (Isaaks and Srivastava 1989, Fortin and Dale 2005). Harris and Stokesbury (2005) used Voronoi polygons to map substrate and macroinvertebrate distributions on Georges Bank and in the Mid-Atlantic.

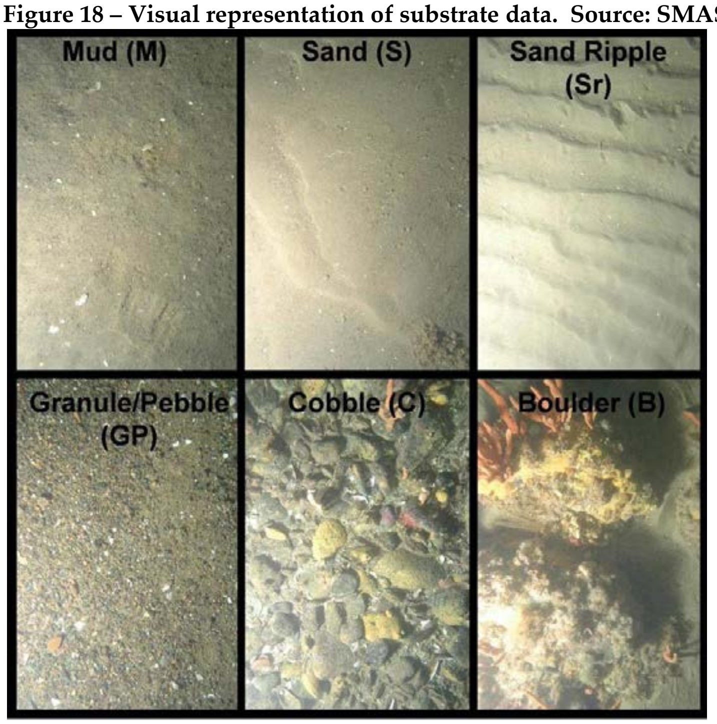
The advantage of this type of base grid is that the resulting unsmoothed surface consists of cells that maintain the spatial characteristics of their source data. For example, the sampling information associated with each data point remains accessible and where geological sampling is spare, the polygons are large. This is in contrast to mathematical interpolations (e.g. Inverse distance weighting, kriging), which result in a standardized grid despite the spatial resolution of the source data.

The geological data are organized into five classes according to particle size: mud, sand/sand ripple, granule-pebble, cobble, and boulder (Table 62, Figure 18, Wentworth 1922). Substrate data are assembled from two primary sources: the SMAST video survey (Stokesbury 2002, Stokesbury et al. 2004); and the usSEABED extracted and parsed datasets from the U.S. Geological Survey (Reid et al 2005). Only substrate data with positive location and time metadata are used. Not all data sources provide information based on sampling capable of detecting all five dominate substrate classes; for example, much of the substrate data compiled in the usSEABED database are collected using grab and coring samplers that are typically not capable of representatively sampling grain sizes larger than granule-pebble (i.e. cobbles and boulders). These sampling limitations are coded into the geological datasets R_sub value, which is a ratio of detectable substrate types to total types (5). For example, the SMAST optical survey technique R-sub = 5/5 because it detects all 5 substrate classes, while the usSEABED R_sub = 0.6 datasets 3/5 because cobbles and boulders are not detected.

Table 62 – Substrate classes by particle size range

Substrate	*Particle size range*	*Corresponding Wentworth class*
Mud	< 0.0039-0.0625 mm	Clay (< 0.0039 mm) and silt (0.0039 – 0.0625mm)
Sand	0.0625 – 2 mm	Sand (0.0625 – 2 mm)
Granule-pebble	2-64 mm	Gravel (2-4 mm) and pebble (4-64 mm)
Cobble	64 – 256 mm	Cobble (64 – 256 mm)
Boulder	> 256 mm	Boulder (> 256 mm)

Figure 18 – Visual representation of substrate data. Source: SMAST video survey.



SMAST video survey

The SMAST video survey uses a multi-stage quadrat-based sampling design and a dual-view video quadrat. Survey stations are arranged as grids based on random starting points. The resolution (distance between stations) is originally calculated to obtain estimates of the dominant macrobenthic species density (sea scallops m^{-2}) with a precision of 5 to 15% for the normal and negative binomial distributions respectively (Stokesbury 2002). At each station, four replicate video-quadrats are sampled haphazardly with a steel pyramid lander equipped with underwater cameras and lighting (for details, see Stokesbury 2002, Stokesbury et al. 2004).

The SMAST database presently includes 190,369 quadrat samples from 24,784 stations covering 65,675 km^2 of USA continental shelf including Jefferys, Cashes, Platts, and Fippenese Ledges, and Stellwagen, Jeffreys, and Georges Banks from the Northern Edge to the Great South Channel, and the Mid-Atlantic Bight from off Block Island to Norfolk Canyon. The SMAST survey uses three live-feed S-VHS underwater video cameras, two in plan-view and one in parallel-view. The two plan-view cameras sample 3.235 m^2 and 0.8 m^2 quadrats, respectively, with the small camera view nested within the large camera view. The parallel-view camera (side camera) provides a cross-quadrat view of both large and small camera sample areas and is used to validate the quadrat observations.

Each quadrat is characterized as containing silt, sand, sand ripple, granule-pebble, cobble, and/or boulder substrates based on particle diameters from the Wentworth scale (Wentworth 1922). Substrates are visually identified in real time during survey cruises using texture, color, relief and structure as observed in the three camera views. Later, all video footage is reviewed in the laboratory where analysts digitized and catalogued a still frame from the large and small camera footage at each quadrat and verified substrate identification.

There are strengths and limitations to the dataset for mapping purposes. Strengths include:

- Formal sampling design with replication.
- Multiview optic sample of sand to boulder substrates
- High spatial sampling frequency
- Annual sampling of Georges Bank and the Mid-Atlantic since 1999

Limitations include:

- Database includes only surficial geology and does not include particles finer than silt.
- Surveys do not include depths greater than 150m.

usSEABED database

The usSEABED database contains a compilation of published and unpublished sediment texture and other geologic data about the seafloor from numerous projects (Reid et al 2005). The USGS DS 118 Atlantic Coast data extend from the U.S./Canada border (northern Maine) to Key West Florida, including some Great Lakes, other lakes, and some rivers, beaches, and estuaries. The database is built using more than 150 data sources containing more than 200,000 data points distributed across the five output data files. The USGS is preparing an update to DS 118 (pers. comm. M. Arsenault USGS) and any new data for the NE region will be included in the SASI model if possible.

Extracted (numeric, lab-based) and parsed (word-based) data are used in the current analysis. Extracted data (_EXT) are from strictly performed, lab-based, numeric analyses. Most data in this file are listed as reported by the source data report; only minor unit changes are performed or assumptions made about the thickness of the sediment analyzed based on the sampler type. Typical data themes include textural classes and statistics (TXR: gravel, sand, silt, clay, mud, and various statistics), phi grain-size classes (GRZ), chemical composition (CMP), acoustic measurements (ACU), color (COL), and geotechnical parameters (GTC). The _EXT file is based on rigorous lab-determined values and forms the most reliable data sets. Limitations, however, exist due to the uncertainty of the sample tested. For example, are the analyses performed on whole samples or only on the matrix, possibly with larger particles ignored? Parsed data (_PRS) are numeric data obtained from verbal logs from core descriptions, shipboard notes, and (or) photographic descriptions are held in the parsed data set. The input data are maintained using the terms employed by the original researchers and are coded using phonetically sensible terms for easier processing by dbSEABED.

Reid et al (2005) provide the following caveats for use of the usSEABED database.

- As many reports are decades old, users of usSEABED should use their own criteria to determine the appropriateness of data from each source report for their particular purpose and scale of interest.
- In cases where no original metadata are available, metadata are created based on existing available information accompanying the data. Of particular importance, site locations are as given in the original sources, with uncertainties due to navigational techniques and datums ignored in the usSEABED compilation.
- As a caution in using the usSEABED database in depicting seabed sedimentary character or creating seafloor geologic maps, users should aware that all seafloor regions are by their nature dynamic environments and subject to a variety of physical processes such as erosion, winnowing, reworking, and sedimentation or accretion that vary on different spatial and temporal scales. In addition, as with any such database, usSEABED is comprised of samples collected and described and analyzed by many different organizations and individuals over a span of many years, providing inherent uncertainties between data points.
- Plotting the data can also introduce uncertainties that are largely unknown at this time.
- There are uncertainties in data quality associated with both the extracted data (numeric/ analytical analyses) and parsed data (word-based descriptions).
- On occasion grain-size analyses are done solely on the sand fraction, excluding coarse fractions such as shell fragments and gravel, while word descriptions of sediment samples can emphasize or de-emphasize the proportion of fine or coarse sediment fraction, or disregard other important textural or biological components.

There are strengths and limitations to the dataset for mapping purposes.

Strengths:

- As a compilation, the usSEABED database covers the model domain.
- The extracted data are based on physical examination of substrates.

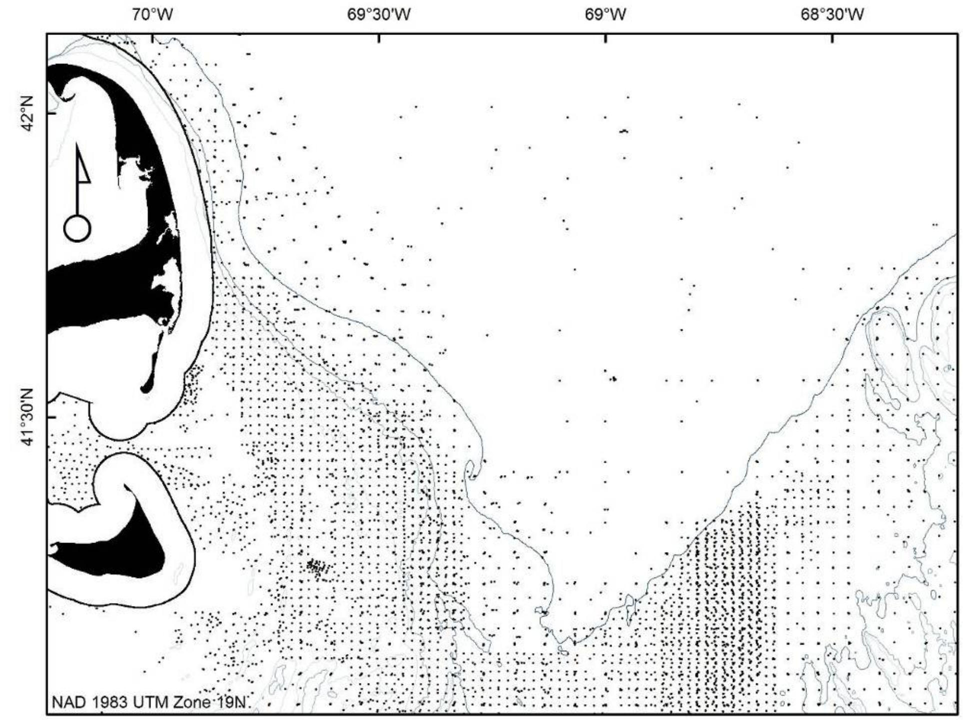
Limitations:

- The sampling design, device, and analytical methods used are temporally and spatially variable.
- Few individual studies used a formal experimental design.
- Most sampling devices used are not capable of sampling cobbles and boulders. Many devices used have sampling selectivity characteristics, which may over or under represent small or large particles.

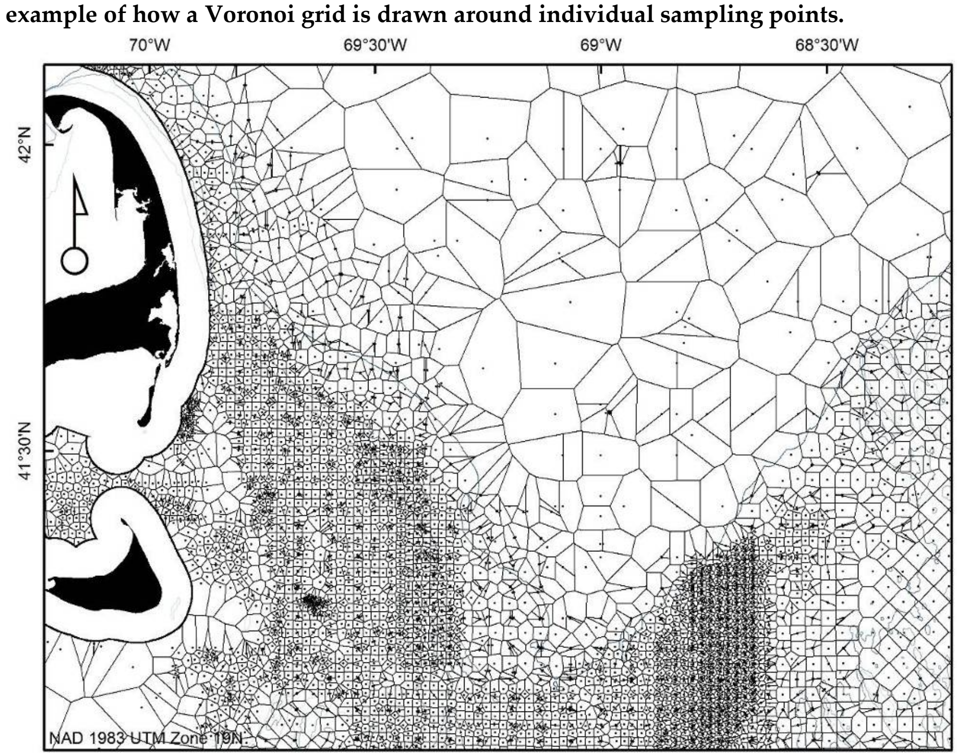
Developing the base grid

The dominant substrate in each sample is the substrate type composing the largest fraction as determined by volume, or frequency of occurrence depending on the sampling methodology. The usSEABED extracted data come from volumetric samplers so the dominant substrate is the type constituting most of the sample. The SMAST video survey samples report the frequency of substrate type occurrences at four locations along a station drift, so the dominant substrate is the most frequently occurring largest type. The dominant substrate type fields for these two data sources are merged, and the X, Y locations of the samples are tessellated to create the Voronoi diagram which serves as the base grid for the SASI model. Each polygon is given the dominant substrate attribute of its base X, Y sample point. The Voronoi tessellation process is depicted on Map 1 and Map 2. All geological data points and their sources are shown on Map 3 and Map 4, respectively. Resulting substrate coding is shown on Map 5. Substrate coding for subregions of the model domain are shown in Map 6-Map 8.

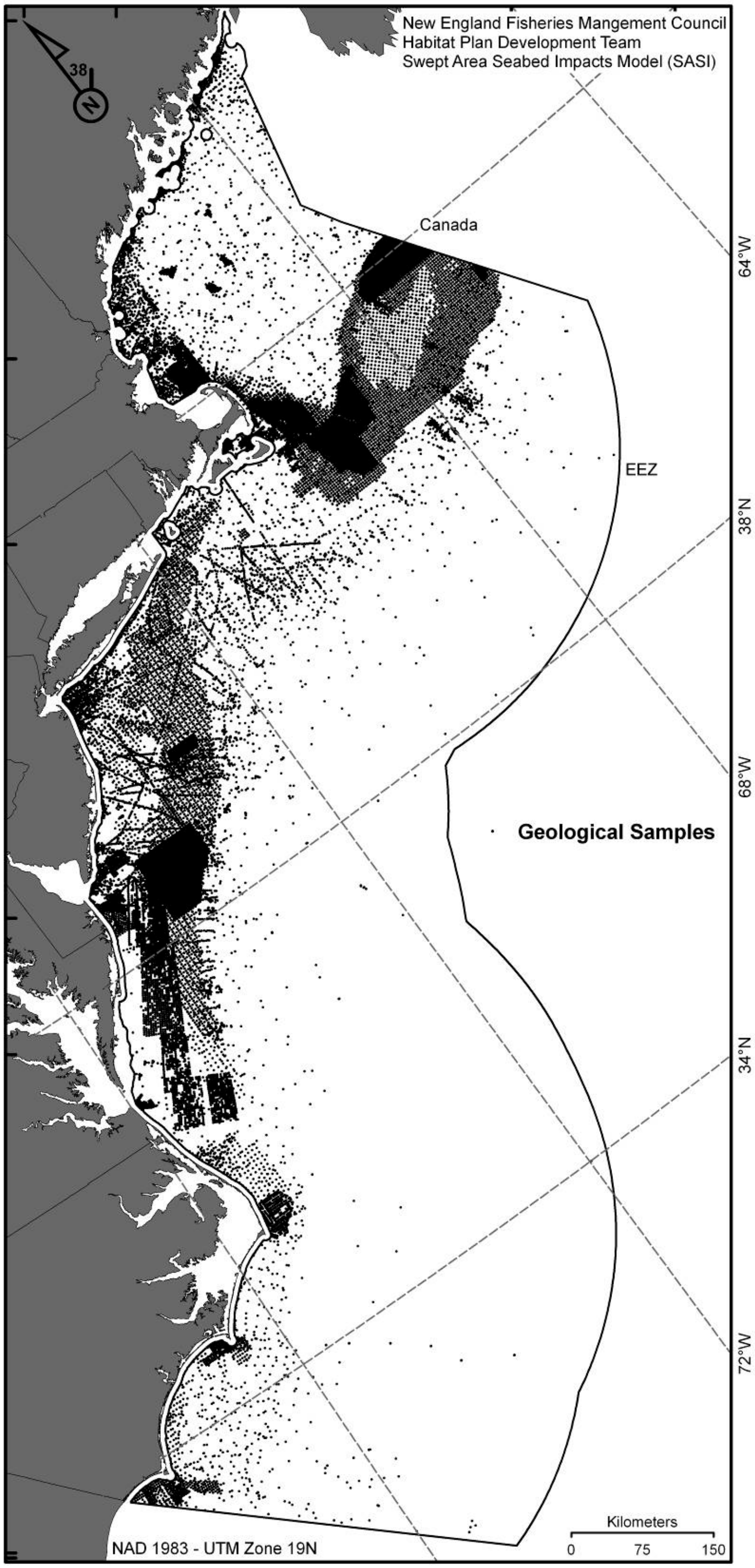
Map 1 – Construction of a Voronoi diagram, part one. This zoomed-in view of the model domain shows the individual substrate data sampling points.



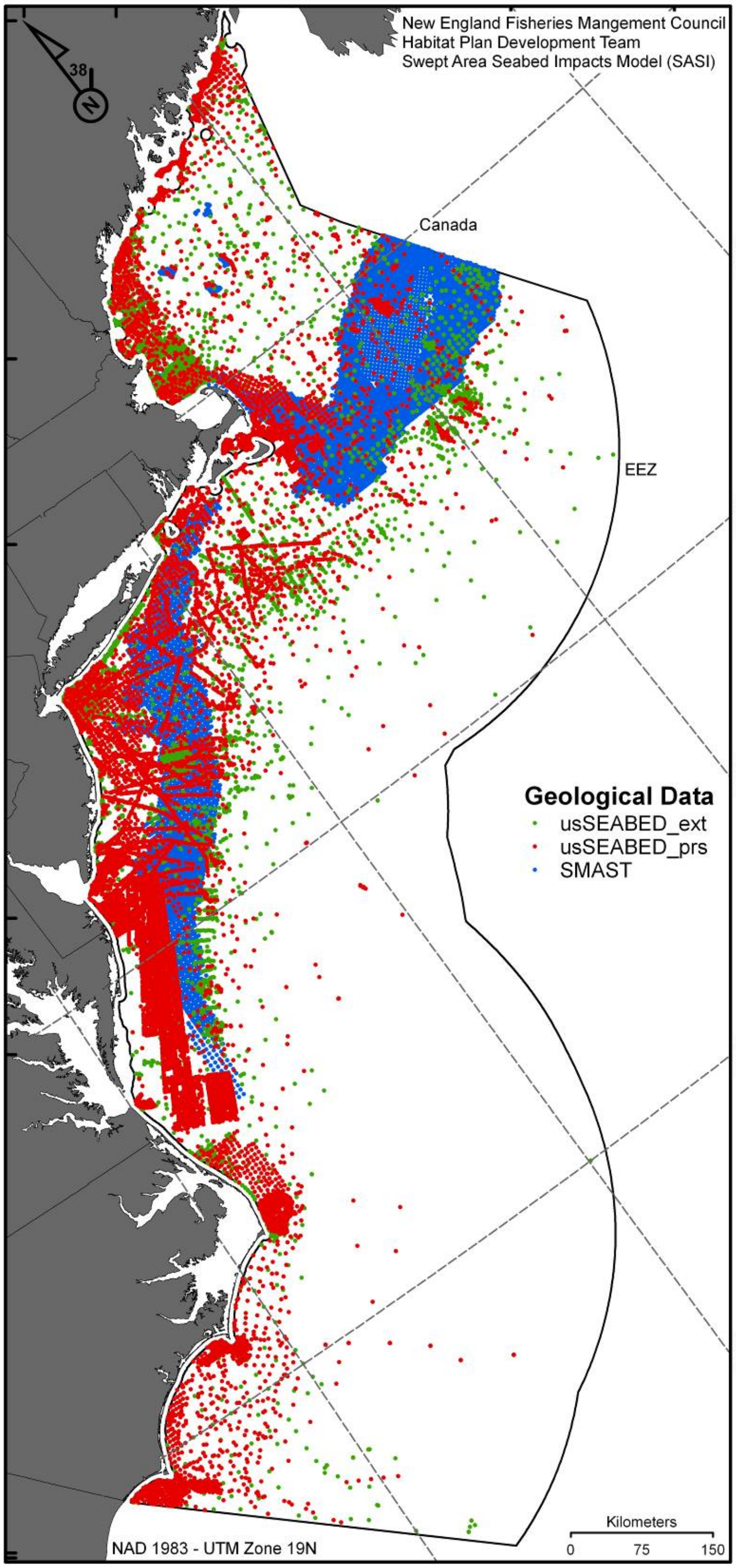
Map 2 – Construction of a Voronoi diagram, part two. This zoomed-in view of the model domain gives an example of how a Voronoi grid is drawn around individual sampling points.



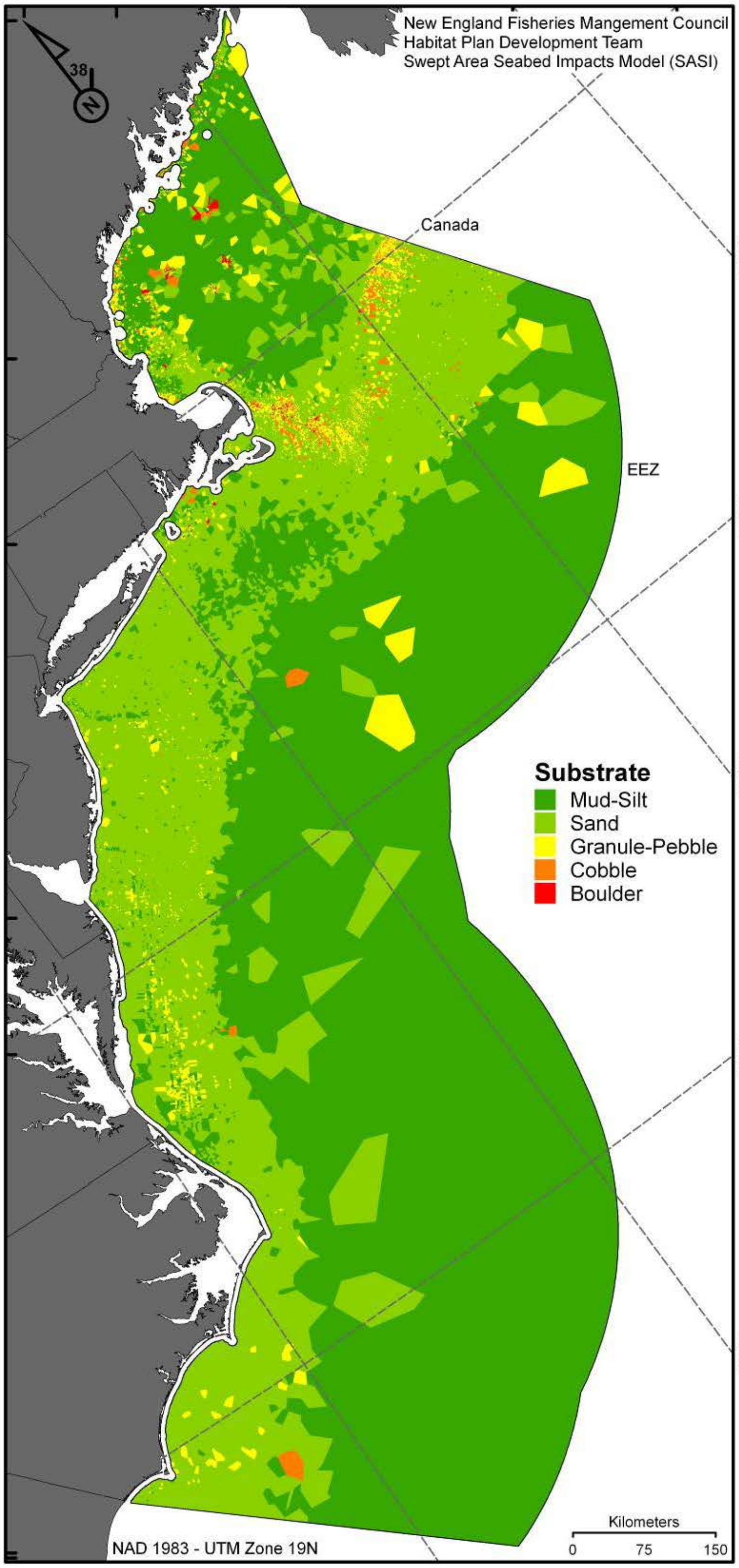
Map 3 – Geological sample locations.



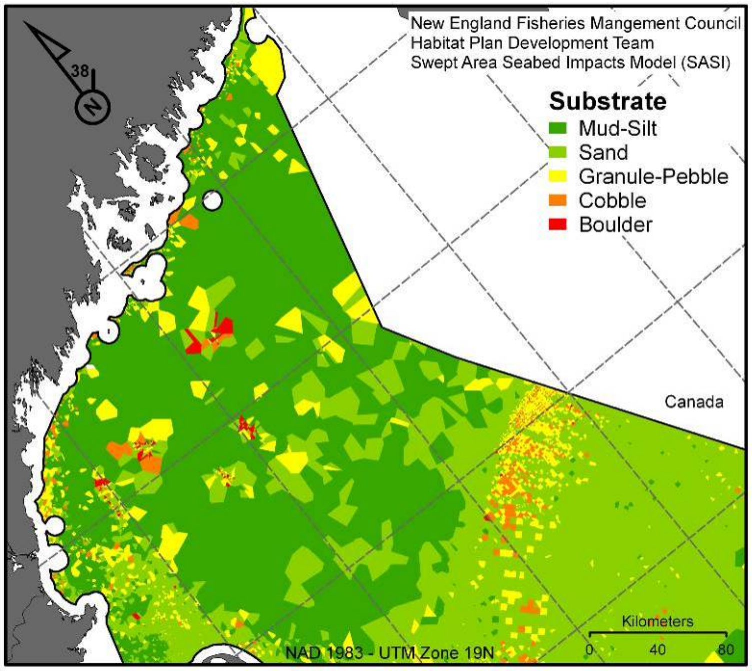
Map 4 – Geological samples by source.



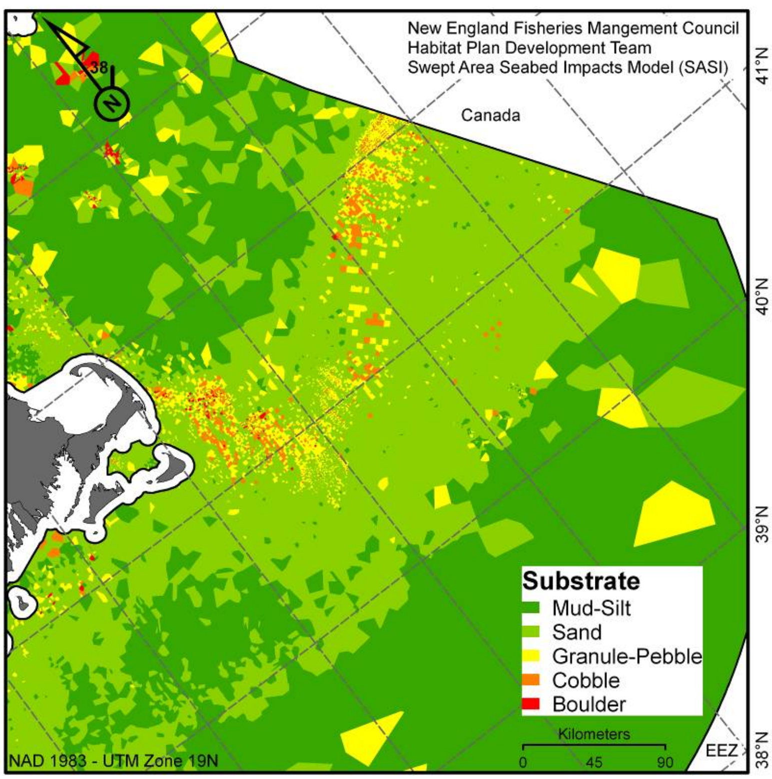
Map 5 - Dominant substrate coding for the entire model domain.



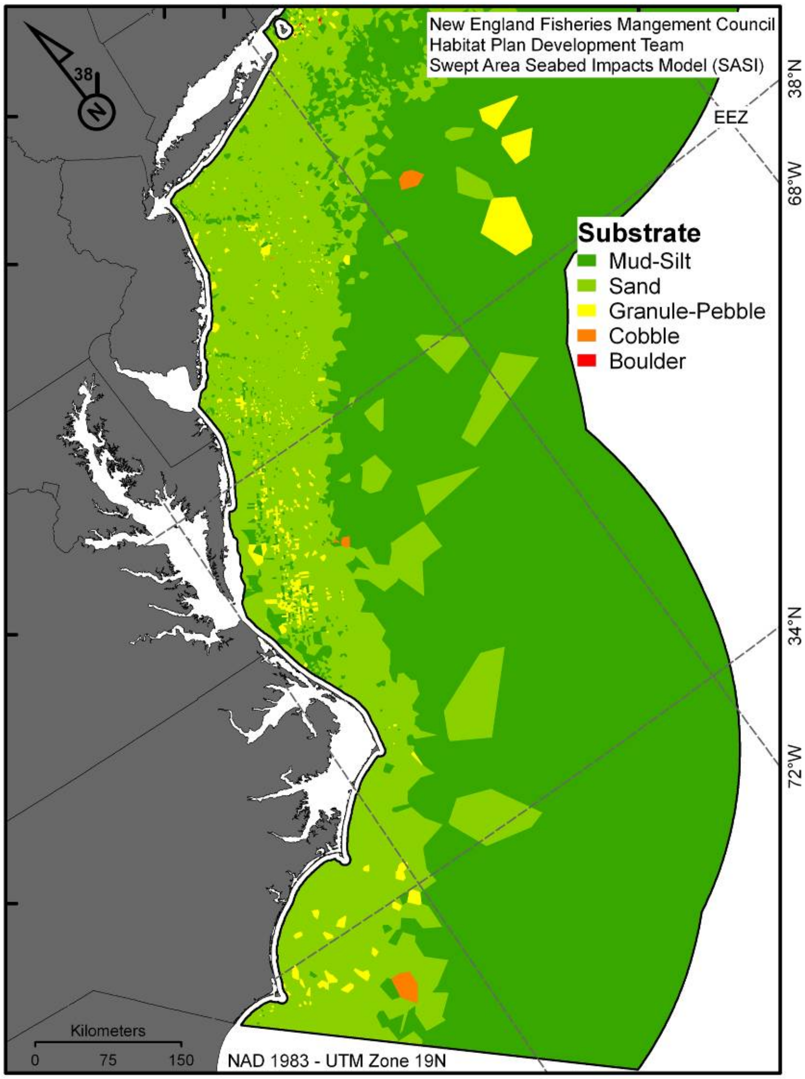
Map 6 –Dominant substrate coding for Gulf of Maine.



Map 7 – Dominant substrate coding for Georges Bank.



Map 8 – Dominant substrate coding for the Mid-Atlantic Bight.



7.2 Classifying natural disturbance using depth and shear stress

As water flow increases over the seabed, the shear stress increases and the hydrodynamic forces acting on the bottom will eventually dislodge and start to move substrate particles. The relationship between velocity and critical levels are substrate particles start to move is depicted by the Hjulstrøm Curve and the relationship between shear stress and particle movement with a the Shield's Curve. This threshold for substrate particle movement is termed critical shear stress. To allow for the use of separate habitat recovery parameters based on shear stress, each cell in the base grid is classified as either high or low energy based on model-derived maximum shear stress. Where shear stress modeling is unavailable, depth is used as shown below (Table 63). Depth is used as a proxy for wave-driven annual flow events. A depth of 60 m is selected as the boundary for high-energy levels based on the average depth where annual storm-event wave height conditions occur (Butman 1986).

Table 63 – Shear stress model components

Condition	*Data source*	*Parameterization*	
		High energy	*Low energy*
Shear stress	The max shear stress magnitude on the bottom in $N \cdot m^{-2}$ derived from the M2 and S2 tidal components only	High = shear stress ≥ 0.194 $N \cdot m^{-2}$ (critical shear stress sufficient to initiate motion in coarse sand)	Low = shear stress < 0.194 $N \cdot m^{-2}$
Depth	Coastal Relief Model depth data	High = depths ≤ 60m	Low = depths > 60m

Digital soundings data are queried from the National Geophysical Data Center of NOAA using the online National Ocean Service data portal (http://www.ngdc.noaa.gov/mgg/gdas/ims/hyd_cri.html). There are 4,000,000 records in the model domain and depth is estimated using the average value of the digital soundings data in each map cell.

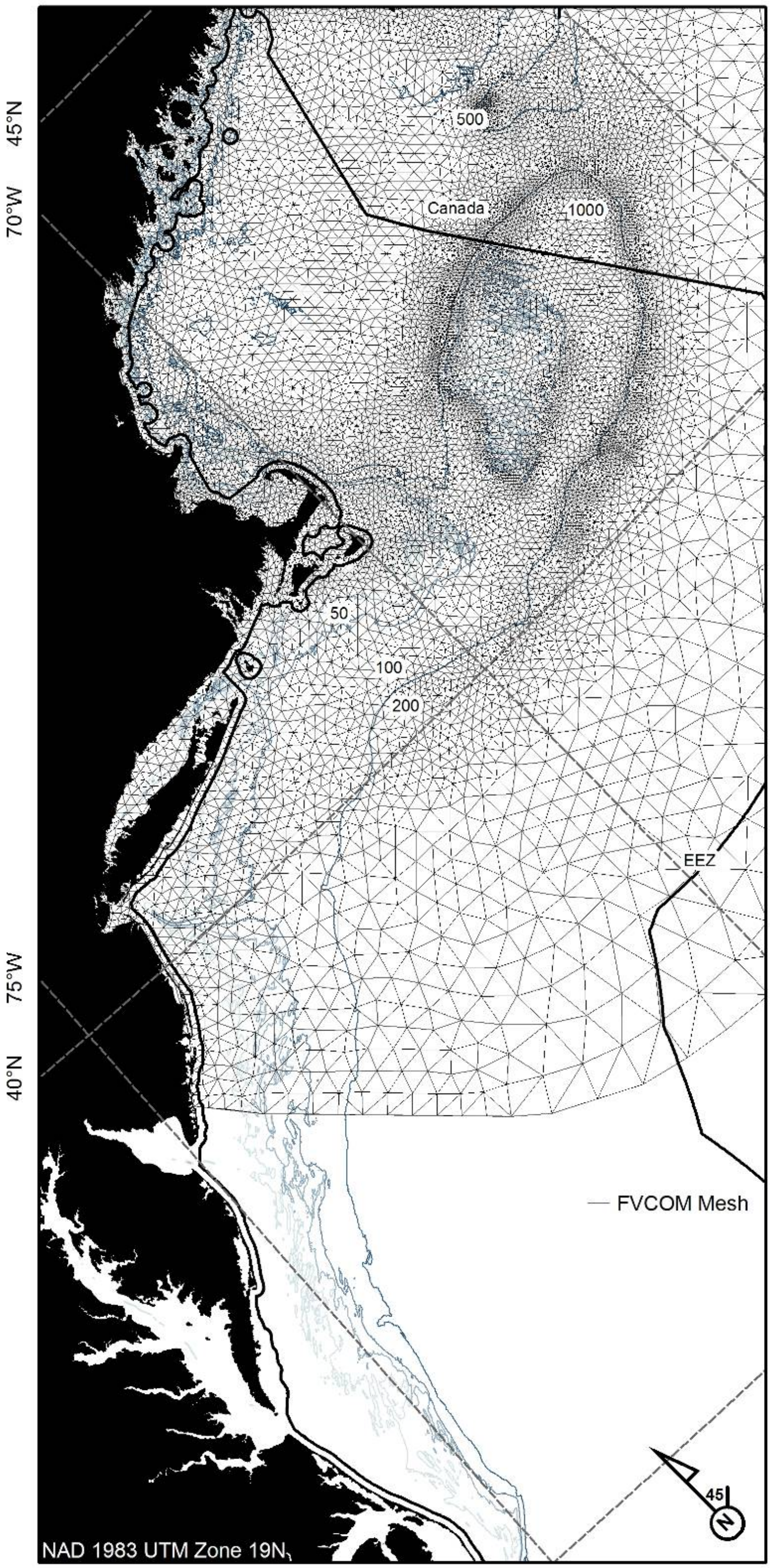
Shear stress is calculated using the Gulf of Maine module of the Finite Volume Coastal Ocean Model (FVCOM-GoM) (Chen et al., 2003, 2006, Cowles, 2008). The bottom stress in the model is calculated where the drag coefficient is depth-based and critical shear stress is $\log_{10}$ (shear). Maximum shear stress magnitudes are derived from the M_2 and S_2 tidal components; these would thus represent the mean spring tides and would not include the effects of perigee/apogee.

FVCOM is an open source Fortran90 software package for the simulation of ocean processes in coastal regions run by the Marine Ecosystem Dynamics Modeling Group at the University of Massachusetts Dartmouth, Department of Fisheries Oceanography (http://fvcom.smast.umassd.edu/FVCOM/index.html). The kernel of the code computes a solution of the hydrostatic primitive equations on unstructured grids using a finite-volume flux formulation (for details see Chen et al. 2003, 2006, Cowles, 2008). The FVCOM-Gulf of Maine (GoM) domain includes the entire Gulf of Maine, the Scotian Shelf to 45.2° N, and the New England Shelf to the northern edge of the Mid-Atlantic at 39.1° N. The model mesh contains 30,000 elements in the horizontal and 30 layers in the vertical. Resolution ranges from approximately 3km on Georges Bank to 15km near the open boundary. The model is advanced at a time step of 120s. A high performance computer cluster (32 processors) is used to run FVCOM-GoM, requiring about 8 hours of wall clock time for each month of simulated time. Boundary forcing in the FVCOM-GoM system includes prescription of the five major tidal constituents at the open boundary, freshwater input from major rivers in the Gulf of Maine, and wind stress and heat flux derived from a high resolution configuration of the MM5 meteorological model. At the open boundary, hydrography is set using monthly climatology fields derived from survey data using optimal interpolation techniques. Assimilation of daily mean satellite-derived sea surface temperature (SST) into the model SST is included to improve the model temperature state. The model has been validated using long-term observations of tidal and subtidal currents and as well as hydrography (Cowles et al. 2008).

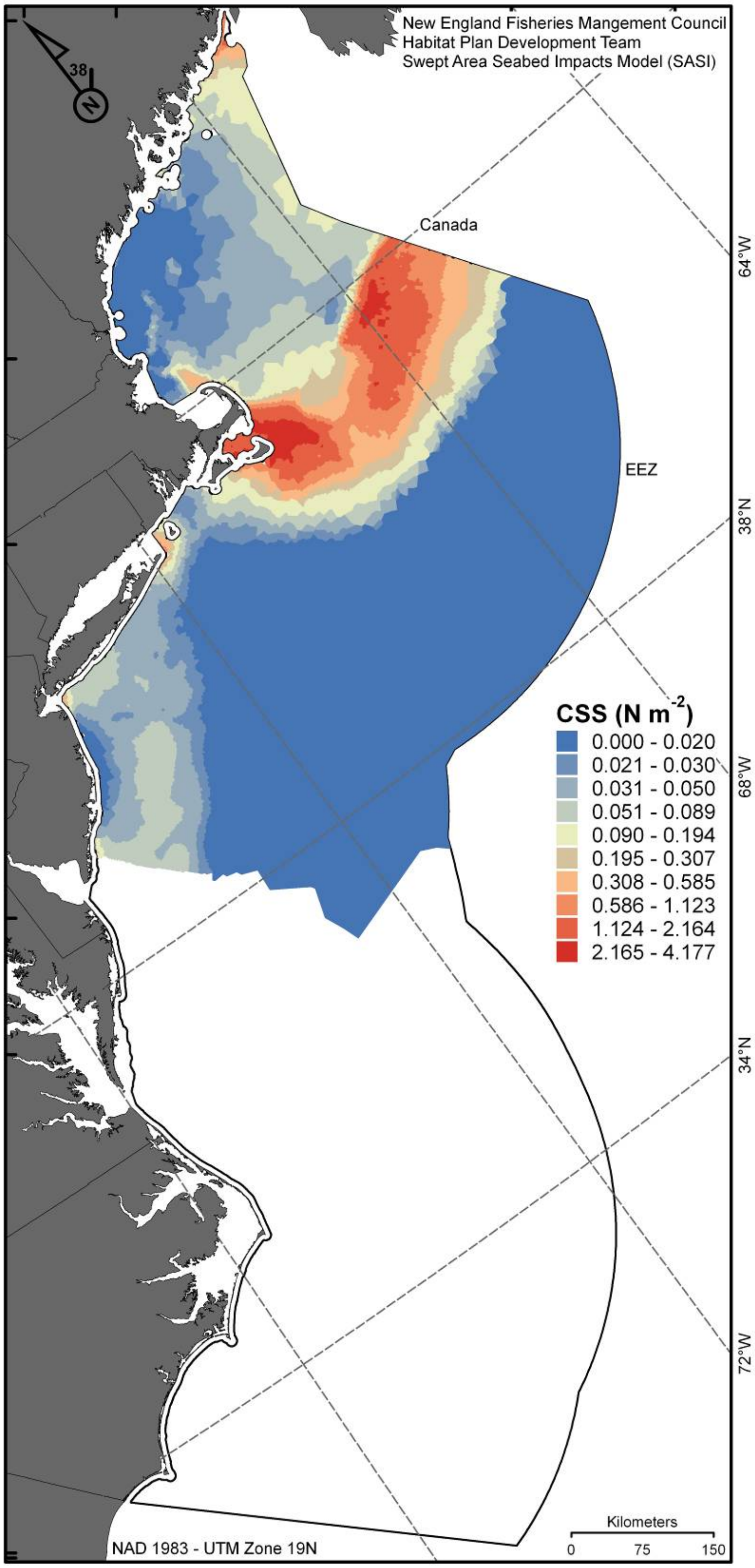
The circulation in the Gulf of Maine, Georges Bank and the New England Shelf regions is simulated from 1995-present. Hourly model hydrographic and velocity data fields are computed at each cell in the domain. Shear stress is computed from the model velocity fields using the "law of the wall" with a depth-based estimate of bottom roughness (Bradshaw and Huang 1995).

High or low energy values are inferred from the shear stress surface to the SASI model grid based on spatial overlap (Map 10). Where more than one shear stress estimate occurred per SASI model grid, the mean of the values is used. Outside the FVCOM model domain energy values are based on the 60 m depth criteria (Map 11). This is reasonable given regions outside the domain include the deep water GOM and the southern Mid-Atlantic where tidal flows are relatively low or are diminished by depth. Combining these two sources of information, Map 12 shows the basis for coding each Voronoi grid cell as high or low energy.

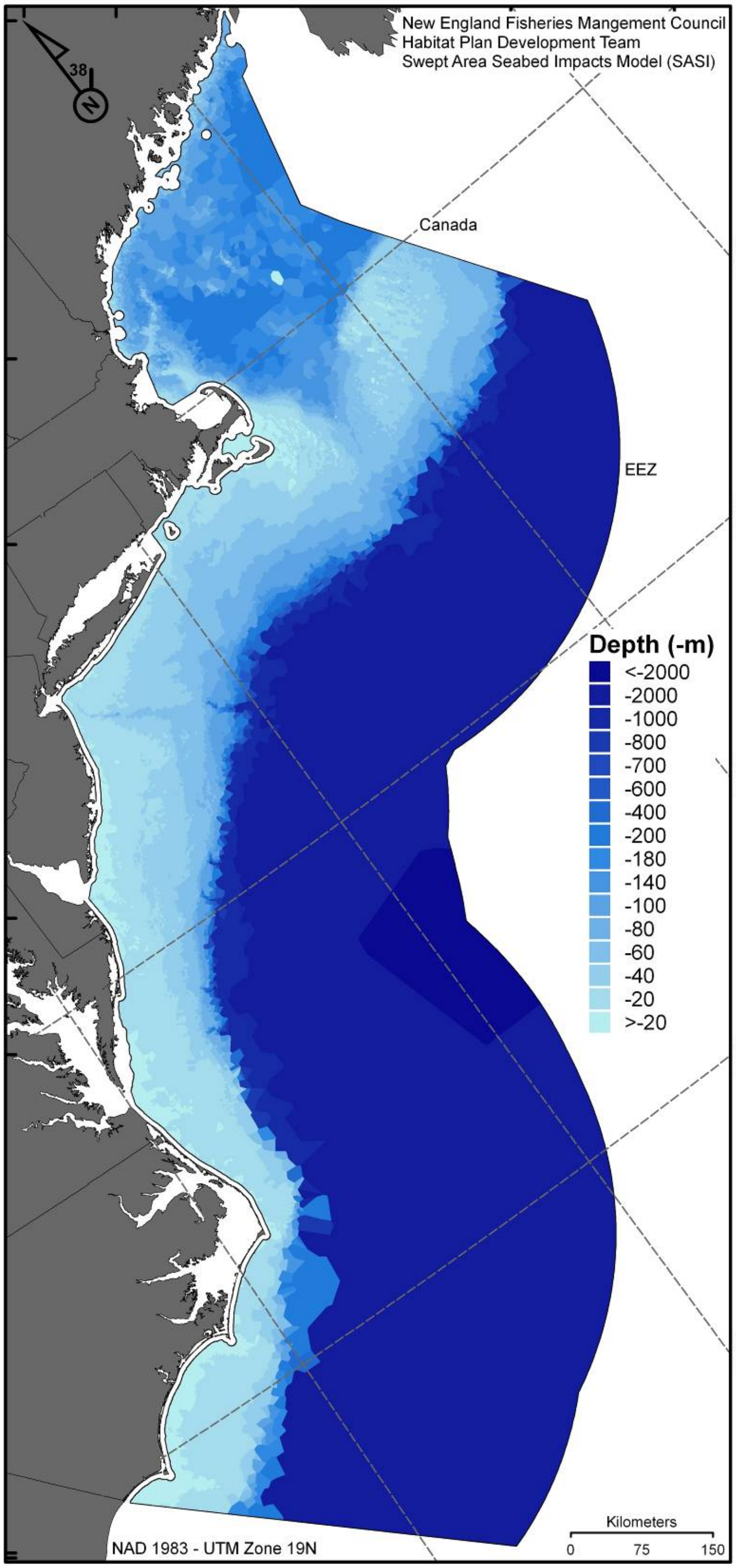
Map 9 - FVCOM domain and nodes.



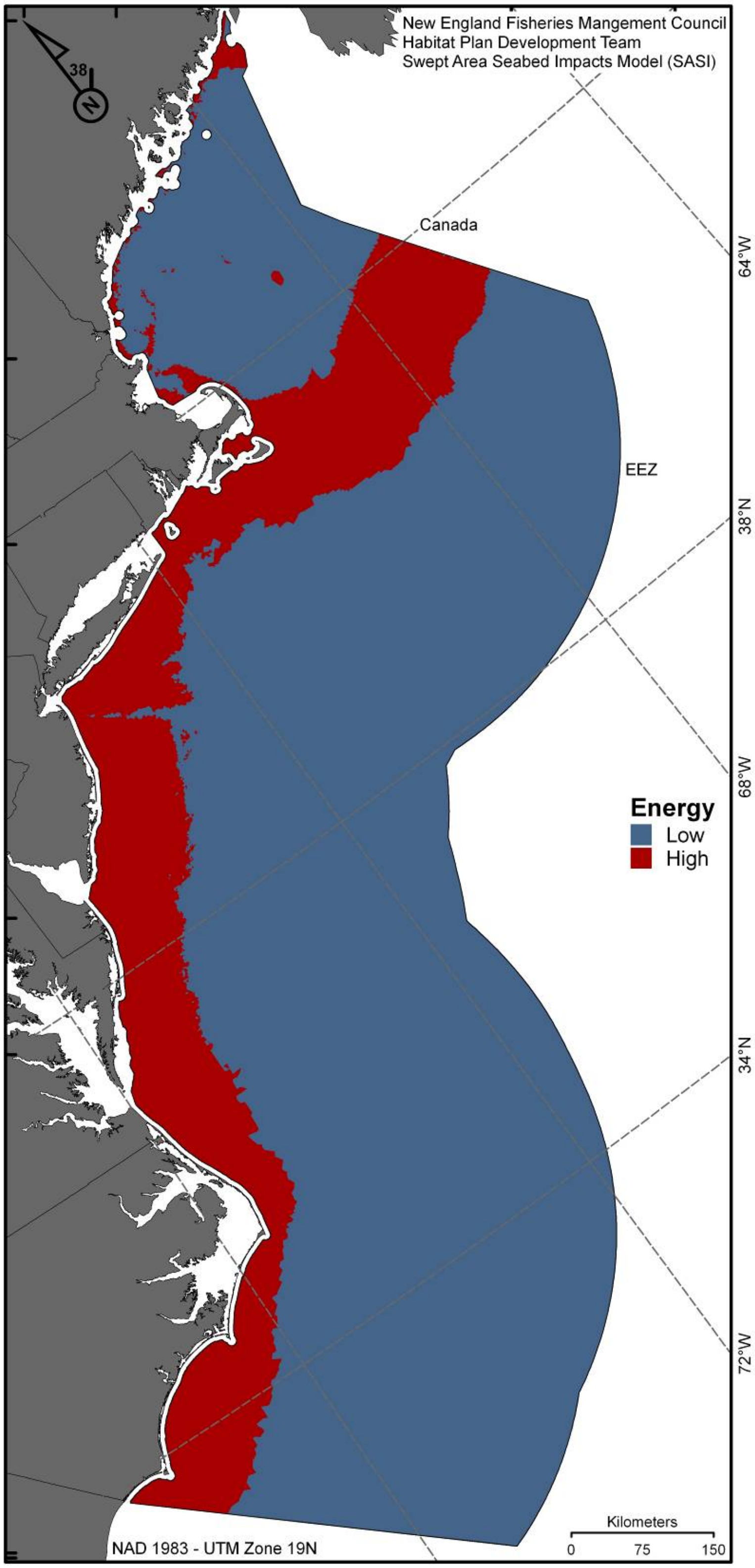
Map 10 – Base grid cell coding of energy resulting from critical shear stress model.



Map 11 – Bathymetry map based on the National Ocean Service data portal



Map 12– Base grid cell coding of energy resulting from depth and energy combined. Coastline is rotated 38°.



8.0 Spatially estimating adverse effects from fishing on fish habitats: the SASI model

This section describes how the two components of the SASI model, vulnerability and contact-adjusted area swept, are integrated with the spatial grids to produce the adverse effect estimate, Z, which is measured in km^2.

8.1 Equations

One unit of fishing effort will generate an impact on benthic habitat that is equal to the area swept by that unit of effort, A, scaled by the assessed vulnerability of the underlying habitat type to that type of fishing gear.

In the Vulnerability Assessment, the vulnerability of each habitat type to fishing is decomposed into a combination susceptibility and recovery. The susceptibility parameters are used to initially modify area swept, and the recovery parameters are used to determine the rate of decay of the adverse effect estimate in the years following impact. Incorporating this recovery vector requires a discrete difference equation. Let the basic equation be:

$$Z_{t+1} = Z_t\left[1 + \left(X_t - Y_t\right)\right], \qquad (1)$$

where Z_t is adverse effect going into that year, X_t is the positive effect of one time unit (year) of habitat recovery, and Y_t is the adverse effect of one time unit of fishing activity (i.e., A modified by the susceptibility parameters). If adverse effect in a given year (Y_t combined with Z_t) is greater than recovery, X_t, Z_{t+1} will be negative.

The positive effect term X_t is the proportion of Z_t that recovers within a given time step, and is estimated using a linear decay model as

$$X_t = \frac{\left\lfloor \lambda(\mathrm{A}\omega)_{t_0} \right\rfloor \Delta t}{Z_t} \;. \qquad (2)$$

The parameter λ represents the decay rate and is calculated as $1/\tau$ where τ is the total number of time steps (years) over which the adverse effects of fishing will decay, t_0 is the initial time unit when the effect entered the model, and Δt is the contemporary time step, such that $\Delta t = t - t_0$ where t is the year for which the calculation is being made.

A, the contact-adjusted area swept by one unit of fishing effort, can be represented as

$$A = (w\chi)d \;, \qquad (3)$$

where, w is the linear effective width of the fishing gear and χ is a constant representing the degree of bottom contact a particular fishing gear component may have. The variable d is the distance traveled in one unit of fishing effort.

The adverse effect term Y is the proportion of Z that is introduced into the model at time t,

$$Y_t = \frac{(A\omega)_t}{Z_t} \quad . \qquad (4)$$

Indexing this dynamic model across all units of fishing effort (*j*) by nine fishing gear types (*i*) and a matrix of habitat types determined by combinations of five substrates (*k*), two energy environments (*l*) and *y* individual habitat features (*m*) leaves us with

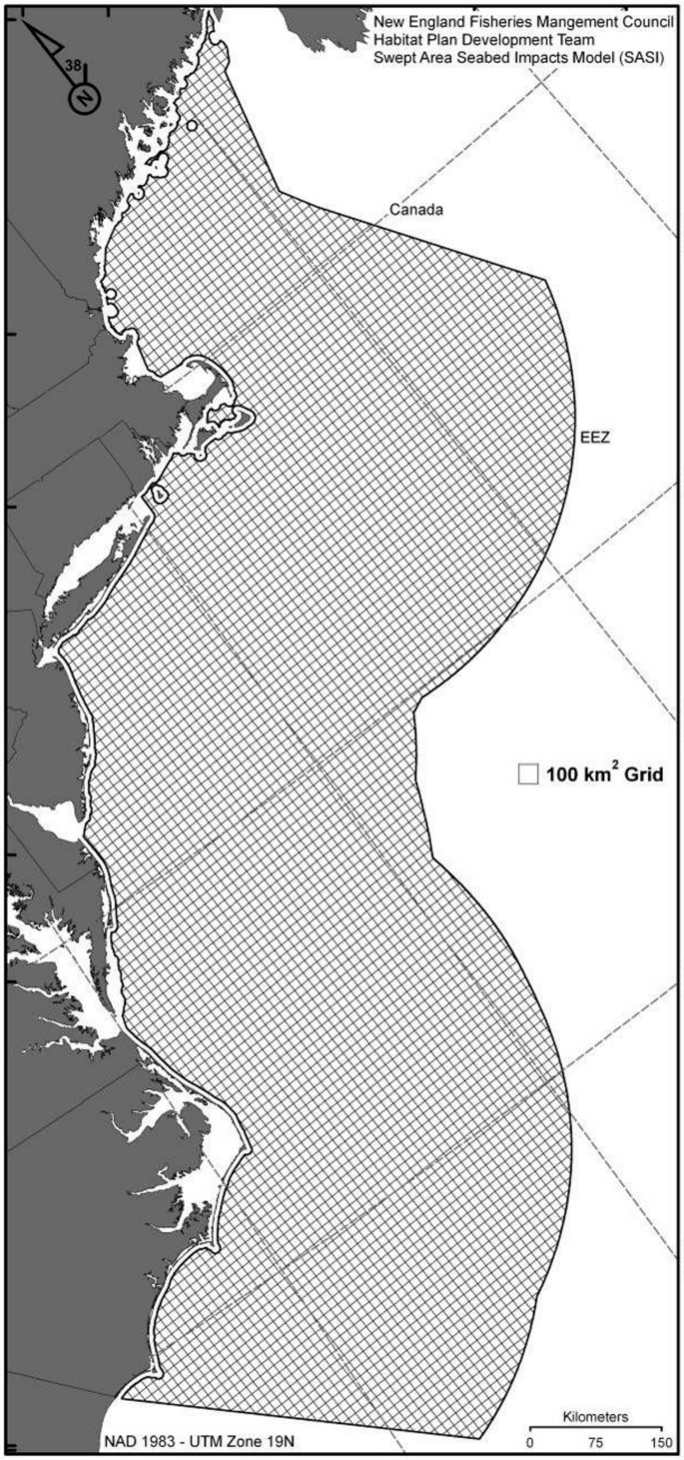
$$Z_{t+1} = Z_t + \left[\sum_{i=1}^{9} \sum_{j=1}^{n} \sum_{k=1}^{5} \sum_{l=1}^{2} \sum_{m=1}^{y} \left[\left(\lambda \left(A_{i,j} \omega_{k,l} \right)_{t_0} \Delta t \right) - \left(A_{i,j} \omega_{k,l} \right)_t \right] \right] . \qquad (5)$$

8.2 Methods

This section describes how the vulnerability parameters (S and R) are combined with area swept data to produce spatially-specific estimates of adverse effect. One issue that needed to be resolved in the model is that the spatial resolutions of substrate and fishing effort data are not the same. Many of the cells in the unstructured substrate grid are extremely small--much smaller than the resolution of trip report data. Therefore, a structured grid is created to overlay the unstructured grid (Map 13). A higher resolution map showing the overlay between the structured and unstructured grids is also shown (Map 14).

If a unit of fishing effort occurs within a 100 km^2 grid cell, it is modified according to the S and R values associated with that grid cell, in proportion to the area covered by each dominant substrate/energy combination (i.e. habitat type). Table 64 shows the ten habitat types identified in the Vulnerability Assessment, broken down into their geological and biological components. As an example, the lower part of the figure above shows the proportions of four sample 100 km^2 grid cell that are coded as sand, granule-pebble, cobble, and boulder dominated. Note that all of the grid cells shown are high energy, and do not contain any mud substrate, such that only four habitat types are represented in the highlighted cells.

Map 13 - Structured SASI grid



Map 14 – Structured and unstructured grid overlay.

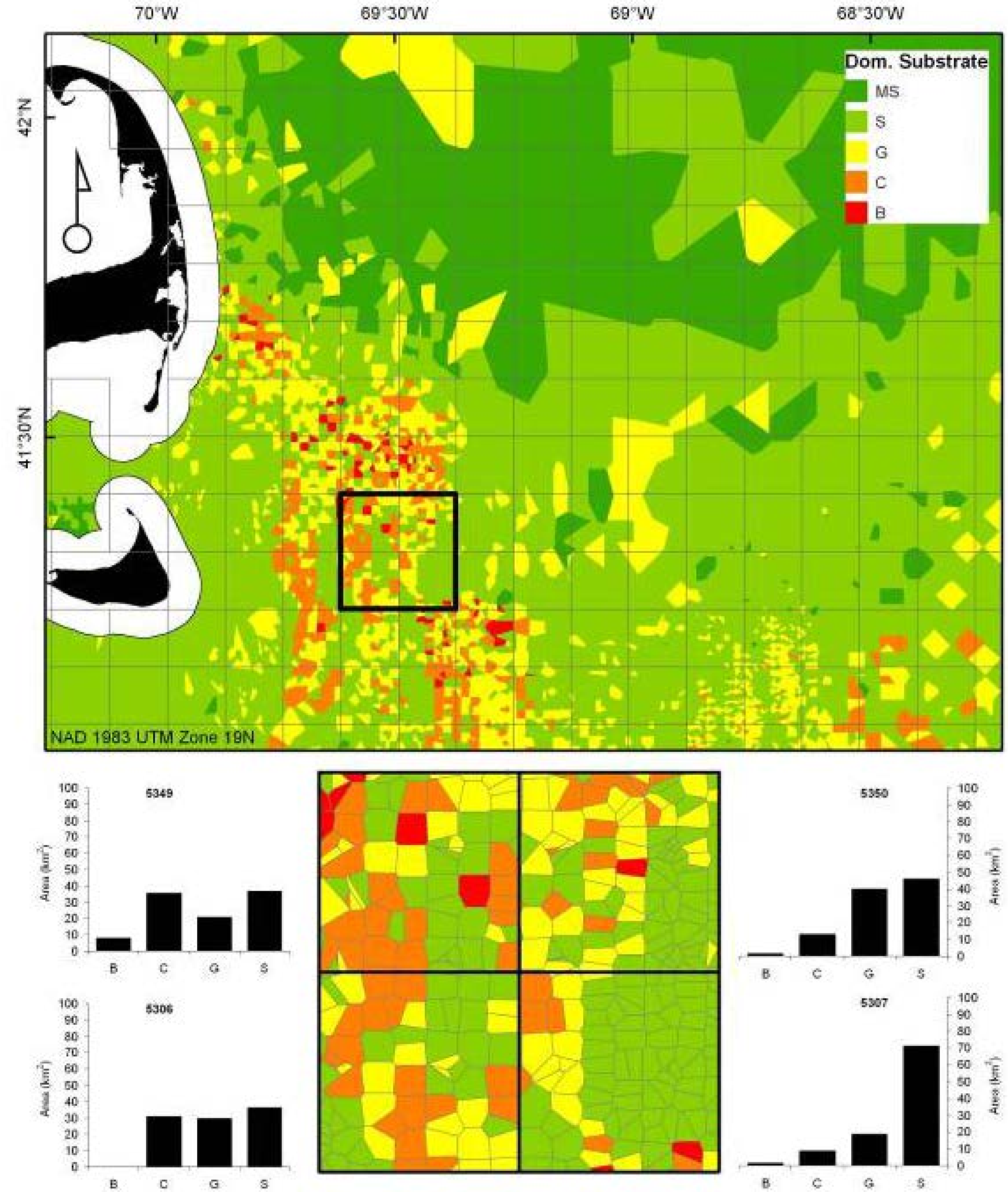


Table 64 – Ten habitat types identified in the Vulnerability Assessment.

	High Energy		***Low energy***	
	Geological features (modify 50% of A)	***Biological features (modify 50% of A)***	***Geological features (modify 50% of A)***	***Biological features (modify 50% of A)***
Mud	Biogenic burrows, biogenic depressions, sediments	Cerianthid burrowing anemones, hydroids, mussels, tube-dwelling amphipods	Biogenic burrows, biogenic depressions, sediments	Cerianthid burrowing anemones, sea pens, hydroids, mussels, tube-dwelling amphipods
Sand	Biogenic burrows, biogenic depressions, sediments, bedforms, shell deposits	Cerianthid burrowing anemones, tube-dwelling amphipods, ascidians, hydroids, *Filograna implexa*, sponges, mussels, scallops	Biogenic burrows, biogenic depressions, sediments, shell deposits	Cerianthid burrowing anemones, sea pens, tube-dwelling amphipods, ascidians, hydroids, *Filograna implexa*, sponges, mussels, scallops
Granule-pebble	Scattered granule-pebble, granule-pebble pavement, shell deposits	Actinarian anemones, cerianthid burrowing anemones, ascidians, brachiopods, bryozoans, hydroids, macroalgae, *Filograna implexa*, other tube-dwelling polychaetes, sponges, mussels, scallops	Scattered granule-pebble, shell deposits	Actinarian anemones, cerianthid burrowing anemones, ascidians, brachiopods, bryozoans, hydroids, *Filograna implexa*, other tube-dwelling polychaetes, sponges, mussels, scallops
Cobble	Scattered cobble, piled cobble, cobble pavement	Actinarian anemones, ascidians, brachiopods, bryozoans, hydroids, macroalgae, *Filograna implexa*, other tube-dwelling polychaetes, sponges, mussels	Scattered cobble, piled cobble	Actinarian anemones, ascidians, brachiopods, bryozoans, hydroids, *Filograna implexa*, other tube-dwelling polychaetes, sponges, mussels
Boulder	Scattered boulder, piled boulder	Actinarian anemones, ascidians, brachiopods, bryozoans, hydroids, macroalgae, *Filograna implexa*, other tube-dwelling polychaetes, sponges, scallops, mussels	Scattered boulder, piled boulder	Actinarian anemones, ascidians, brachiopods, bryozoans, hydroids, *Filograna implexa*, other tube-dwelling polychaetes, sponges, scallops, mussels

When applying S and R values to area swept estimates in the model, SASI draws from the appropriate distribution of gear-appropriate percent reduction (S) and recovery time (R) sciresm as indicated by the 0-3 scores from Table 22, Table 24, Table 26, Table 28, and Table 29. **Within a habitat type, the geological and biological components are weighted equally** (i.e. they contribute equally to modifying area swept). **Within each habitat type, individual features contribute equally as well**. These equal weighting assumptions are made in the absence of empirical data on either the distribution of features within substrates or the relative importance of the features to managed species.

As an example, if an entire 100 km^2 grid cell is coded as low energy mud, with susceptibility scores for three geological features of 1, 2, and 3, respectively, and susceptibility scores for three biological features of 1, 2, and 3, respectively, 1/6 of the area swept for that cell is modified by each feature's score. As area swept enters the model in year 1, for the proportion modified by S scores of 1, anywhere from 10-25% of the effort would go forward in the model, corresponding to the S definitions. For scores of 2, anywhere from 25-50% would go forward, for scores of 3, some amount >50% would go forward. No particular underlying distribution of percentages is assumed; in other words, as implemented, the SASI model has an equal probability of using 51% and 96% when applying an S score of 3 to the fraction of area swept expected to encounter features with a score of S=3.

Similarly, for the recovery scores, if R=0, that fraction of the area swept would be removed from the model in the following year. For R=1, this would take either 1 or 2 years, for R=2, 2-5 years, or for R=3, 5-10 years. The terminal year selected for R=3 is expected to have a significant effect on how much area swept accumulates under a given model run. A value of 10 years is selected according to the potential recovery times for the various features incorporated in the SASI model, acknowledging that it may be an underestimate for some features.

Assumptions are also made that limit certain gear types to certain substrates when the model is implemented spatially (Table 65). In particular, matrices for hydraulic dredges in mud, cobble, and boulder (both for high and low energy) are not evaluated because hydraulic dredges are assumed unable to fish in these substrate types and therefore matrices are not evaluated. In the case of shrimp, squid, and raised footrope trawls, trawl matrices for cobble and boulder are developed, but S/R values from these matrices are not applied to these gear types.

Table 65 – Rules for applying matrix results to a particular substrate/energy combination. Asterisk (*) indicates that if that substrate/gear type interaction occurs in 100 km^2 grid cell the model, that type of substrate would be ignored and effort would be modified according to S/R scores for the 'fishable' gear/substrate interactions, in proportion to the percent coverage of those substrates.

Gear type	*If cell is coded as mud, matrix results applied:*	*If cell is coded as sand, matrix results applied:*	*If cell is coded as g/p, matrix results applied*	*If cell is coded as cobble, matrix results applied*	*If cell is coded as boulder, matrix results applied*
Generic otter trawl	All trawls, mud	All trawls, sand	All trawls, g/p	All trawls, cobble	All trawls, boulder
Shrimp trawl	All trawls, mud	All trawls, sand	All trawls, g/p	-*	-*
Squid trawl	All trawls, mud	All trawls, sand	All trawls, g/p	-*	-*
Raised footrope trawl	All trawls, mud	All trawls, sand	All trawls, g/p	-*	-*
Scallop dredge	Scallop, mud	Scallop, sand	Scallop, g/p	Scallop, cobble	Scallop, boulder
Hydraulic dredge	-*	Hydraulic, sand	Hydraulic, g/p	-*	-*
Longline	Longline, mud	Longline, sand	Longline, g/p	Longline,	Longline,

Gear type	*If cell is coded as mud, matrix results applied:*	*If cell is coded as sand, matrix results applied:*	*If cell is coded as g/p, matrix results applied*	*If cell is coded as cobble, matrix results applied*	*If cell is coded as boulder, matrix results applied*
				cobble	boulder
Gillnet	Gillnet, mud	Gillnet, sand	Gillnet, g/p	Gillnet, cobble	Gillnet, boulder
Trap	Trap, mud	Trap, sand	Trap, g/p	Trap, cobble	Trap, boulder

These assumptions are necessary because of uncertainties associated with the substrate and fishing effort distributions, which might cause unrealistic spatial overlaps between area swept for a particular gear type and certain substrates. In cases where a fraction of the seabed within a cell is coded as an unfishable substrate for a gear type, that fraction of the cell is ignored when applying S and R scores, and only the scores associated with the fishable substrates are used.

For example, take a case where a 100 km^2 cell is all high energy, with 50% of the area sand-dominated, 40% granule-pebble-dominated, and 10% cobble-dominated, and 1000 km^2 of fishing effort area swept associated with squid trawl gear is applied to the cell. If the gear were assumed to be able to fish on cobble-dominated bottom, 500 km^2 would be modified according to the S and R scores in the generic otter trawl high energy sand matrix, 400 km^2 would be modified according to the S and R scores in the generic otter trawl high energy granule-pebble matrix, and 100 km^2 would be modified according to the S and R scores in the generic otter trawl high energy cobble matrix. Because the gear cannot fish on cobble, 566 km^2 would be modified according to the sand matrix, and 444 km^2 would be modified according to the granule-pebble matrix.

In cases where an entire 100 km^2 cell contains an unfishable dominant substrate type, any area swept that would have been applied to that cell is zeroed out and does not carry forward in the model. In practice, because the areas dominated by cobble and boulder are so small, and are surrounded by sand, granule-pebble, and/or mud, this scenario only applies to hydraulic dredge gear area swept in 100 km^2 cells coded entirely as mud.

8.3 Outputs

The vulnerability and area swept data layers are combined with the substrate/energy grids to generate impact surfaces at the 100km^2 cell level. The resulting Z (adverse effect) estimates are measured in square kilometers, and represent the nominal area swept in a cell conditioned by the susceptibility and recovery parameters assigned to the habitat features inferred to the substrates known to exist in that cell. Three classes of outputs are generated: simulated (Z_{∞}/$Z_{infinity}$), realized ($Z_{realized}$), and instantaneous (Z_{net}). Z_{∞} and $Z_{realized}$ outputs are discussed below; Znet outputs are discussed in section 10.0.

8.3.1 Simulation runs

Simulated model outputs (Z_∞/$Z_{infinity}$) are based on running the SASI model with a hypothetical, uniformly distributed amount of area swept applied to each 100 km^2.grid cell for each gear type. The model results and maps are intended to show how the SASI model combines the susceptibility and recovery parameters for a particular gear type with the underlying substrate and energy distributions. **This is intended to indicate the underlying vulnerability of a given location to a given gear type.** Because the amount of area swept is the same across gears, the locations that are more or less vulnerable to adverse effects from fishing can be compared.

The model is run continuously, with area swept added in annual time steps, and the simulated outputs for the terminal year are mapped/analyzed, once the model has reached its asymptotic equilibrium (i.e., once Z is stable). Because the maximum recovery time that may be assigned to a habitat feature is 10 years, this equilibrium is reached in year 11. This asymptotically stable equilibrium is referred to as Z_∞. Not all grid cells in the model domain are included in these model runs. For each gear type, the domain is truncated based on a maximum depth, estimated based on depths reported in the fishery observer data. Also, these simulation runs are only conducted for the six major gear types, corresponding with the six sets of vulnerability assessment matrices. Results for individual types of trawls (i.e. shrimp, squid, raised footrope) and the two permit categories of scallop dredge (i.e. limited access, general category) are decomposed in the realized runs (see next section).

According to the assumptions made in section 2.0 about which features occur in which substrate/energy-dominated environments, fishing gears can then be expected to encounter different features at different rates. Some features will be encountered more frequently because the substrate/energy environment in which they occur is more common, and/or the feature occurs in multiple substrate/energy environments. Features that are more frequently encountered will have a greater influence on the resulting area swept values from the model.

Table 66 and Table 67 show the implicit interactions of gears and features from the SASI model under a uniform area swept assumption. The total km^2 of high and low energy seabed potentially fished by each gear type given the fishing depth assumptions is shown on the last line of each subsection. Geological and biological features are shown separately because their S and R scores are applied to fishing effort in equal proportion. Within a particular substrate/energy and within the biological or geological habitat component, an equal distribution of each individual biological or geological feature is assumed. Therefore, the different percentages for each feature relate to the underlying distribution of dominant-substrates, and also to the presence of some features in multiple dominant substrates. The distributions in the tables relate also to the assumed depth-based footprint of a particular gear type.

Table 66– Distribution of geological features in high and low energy environment within the areas assumed to be fishable by particular gears. Hydraulic dredge gears are additionally assumed not to be able to fish in mud, cobble, or boulder substrates.

Distribution of geological features in low energy		Trawl	Scallop	Hydraulic	Longline	Gillnet	Trap
	Bedforms	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Biogenic burrows	24.9%	24.0%	17.6%	24.6%	24.3%	24.9%
	Biogenic depressions	24.9%	24.0%	17.6%	24.6%	24.3%	24.9%
	Boulder, piled	0.4%	0.2%	0.0%	0.5%	0.5%	0.4%
	Boulder, scattered, in sand	0.4%	0.2%	0.0%	0.5%	0.5%	0.4%
	Cobble, pavement	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Cobble, piled	1.0%	1.1%	0.0%	1.1%	1.2%	1.0%
	Cobble, scattered in sand	1.0%	1.1%	0.0%	1.1%	1.2%	1.0%
	Granule-pebble, pavement	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Granule-pebble, scattered, in sand	4.7%	4.5%	5.9%	4.8%	4.9%	4.7%
	Sediments, subsurface	0.0%	0.0%	17.6%	0.0%	0.0%	0.0%
	Sediments, unfeatured surface	24.9%	24.0%	17.6%	24.6%	24.3%	24.9%
	Shell deposits	17.9%	20.8%	23.6%	18.4%	18.8%	17.9%
	Total area, low energy (km^2)	*105,111*	*22,684*	*35,225*	*93,029*	*80,835*	*106,734*

Distribution of geological features in high energy		Trawl	Scallop	Hydraulic	Longline	Gillnet	Trap
	Bedforms	15.1%	15.1%	15.9%	15.1%	15.1%	15.1%
	Biogenic burrows	19.3%	19.4%	15.9%	19.3%	19.3%	19.3%
	Biogenic depressions	19.3%	19.4%	15.9%	19.3%	19.3%	19.3%
	Boulder, piled	0.6%	0.6%	0.0%	0.6%	0.6%	0.6%
	Boulder, scattered, in sand	0.6%	0.6%	0.0%	0.6%	0.6%	0.6%
	Cobble, pavement	2.1%	2.0%	0.0%	2.1%	2.1%	2.1%
	Cobble, piled	2.1%	2.0%	0.0%	2.1%	2.1%	2.1%
	Cobble, scattered in sand	2.1%	2.0%	0.0%	2.1%	2.1%	2.1%
	Granule-pebble, pavement	6.5%	6.5%	6.9%	6.6%	6.5%	6.5%
	Granule-pebble, scattered, in sand	6.5%	6.5%	6.9%	6.6%	6.5%	6.5%
	Sediments, subsurface	0.0%	0.0%	15.9%	0.0%	0.0%	0.0%
	Sediments, unfeatured surface	4.3%	4.3%	0.0%	4.3%	4.3%	4.3%
	Shell deposits	21.6%	21.6%	22.7%	21.6%	21.6%	21.6%
	Total area, high energy (km^2)	*125,324*	*119,982*	*116,382*	*125,261*	*125,204*	*125,324*

Table 67 – Distribution of biological features in high and low energy environment within the areas assumed to be fishable by particular gears, according to the maximum depth thresholds. Hydraulic dredge gears are additionally assumed not to be able to fish in mud, cobble, or boulder substrates.

Distribution of biological features in low energy	Trawl	Scallop	Hydraulic	Longline	Gillnet	Trap
Amphipods, tube-dwelling	10.3%	9.7%	7.9%	10.0%	9.8%	9.8%
Anemones, actinarian	2.5%	2.3%	2.7%	2.6%	2.7%	2.4%
Anemones, cerianthid burrowing	12.2%	11.5%	10.5%	12.0%	11.8%	11.7%
Ascidians	8.0%	8.9%	10.5%	8.1%	8.3%	7.6%
Brachiopods	2.5%	2.3%	2.7%	2.6%	2.7%	2.4%
Bryozoans	2.5%	2.3%	2.7%	2.6%	2.7%	2.4%
Corals, sea pens	10.3%	9.7%	7.9%	10.0%	9.8%	9.8%
Hydroids	12.8%	12.0%	10.5%	12.6%	12.5%	12.2%
Macroalgae	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Modiolus modiolus	12.8%	12.0%	10.5%	12.6%	12.5%	12.2%
Placopecten magellanicus	7.8%	8.9%	10.5%	7.9%	8.1%	7.5%
Polychaetes, *Filograna implexa*	8.0%	8.9%	10.5%	8.1%	8.3%	7.6%
Polychaetes, other tube-dwelling	2.5%	2.3%	2.7%	2.6%	2.7%	2.4%
Sponges	8.0%	8.9%	10.5%	8.1%	8.3%	12.2%
Total area, low energy (km^2)	*105,111*	*22,684*	*35,225*	*93,029*	*80,835*	*106,734*

Distribution of biological features in high energy	Trawl	Scallop	Hydraulic	Longline	Gillnet	Trap
Amphipods, tube-dwelling	7.3%	7.4%	7.1%	7.3%	7.3%	7.3%
Anemones, actinarian	3.5%	3.5%	3.0%	3.5%	3.5%	3.5%
Anemones, cerianthid burrowing	9.8%	9.8%	10.1%	9.8%	9.8%	9.8%
Ascidians	9.2%	9.2%	10.1%	9.2%	9.2%	9.2%
Brachiopods	3.5%	3.5%	3.0%	3.5%	3.5%	3.5%
Bryozoans	3.5%	3.5%	3.0%	3.5%	3.5%	3.5%
Corals, sea pens	7.3%	7.4%	7.1%	7.3%	7.3%	7.3%
Hydroids	10.8%	10.8%	10.1%	10.8%	10.8%	10.8%
Macroalgae	3.5%	3.5%	3.0%	3.5%	3.5%	3.5%
Modiolus modiolus	10.8%	10.8%	10.1%	10.8%	10.8%	10.8%
Placopecten magellanicus	9.0%	9.0%	10.1%	9.0%	9.0%	9.0%
Polychaetes, *Filograna implexa*	9.2%	9.2%	10.1%	9.2%	9.2%	9.2%
Polychaetes, other tube-dwelling	3.5%	3.5%	3.0%	3.5%	3.5%	3.5%
Sponges	9.2%	9.2%	10.1%	9.2%	9.2%	9.2%
Total area, high energy (km^2)	*125,324*	*119,982*	*116,382*	*125,261*	*125,204*	*125,324*

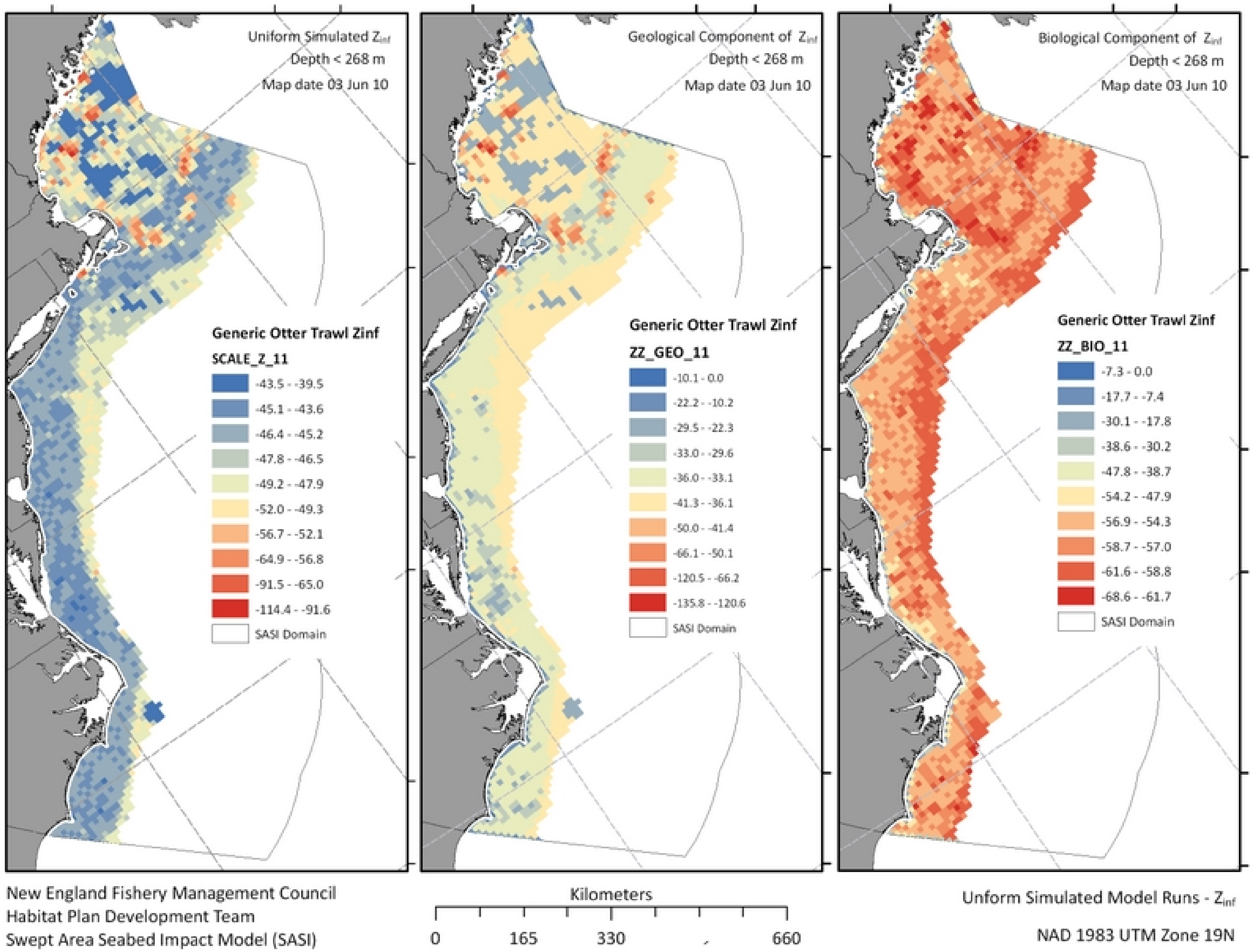
Table 68 (below) is similar to the ones above, but shows the proportions of the fishable area for each gear type dominated by each substrate class.

Table 68 – Distribution of dominant substrates, by energy environment, within the areas assumed to be fishable by particular gears, according to maximum depth thresholds. Hydraulic dredge gears are additionally assumed not to be able to fish in mud, cobble, or boulder substrates.

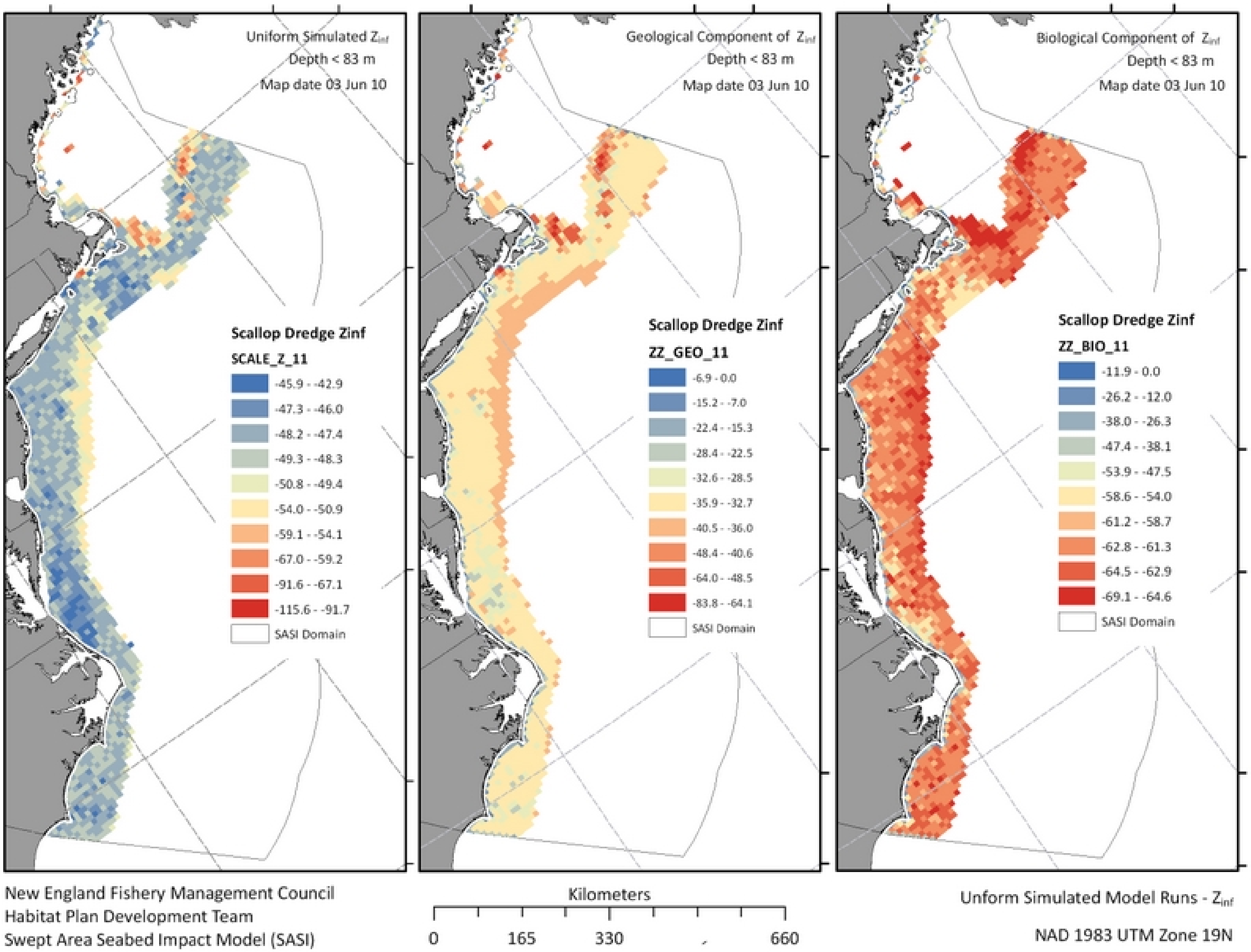
		Trawl	Scallop	Hydraulic	Longline	Gillnet	Trap
Distribution of substrates in low energy	**Mud**	37.5%	25.8%	0.0%	35.7%	33.9%	37.6%
	Sand	42.9%	54.8%	74.8%	43.8%	44.8%	42.9%
	Granule- pebble	15.1%	15.1%	25.2%	15.7%	15.9%	15.1%
	Cobble	3.2%	3.7%	0.0%	3.4%	3.8%	3.1%
	Boulder	1.4%	0.7%	0.0%	1.5%	1.6%	1.3%
	Total area, low energy (km^2)	*105,111*	*22,684*	*35,225*	*93,029*	*80,835*	*106,734*
		Trawl	**Scallop**	**Hydraulic**	**Longline**	**Gillnet**	**Trap**
Distribution of substrates in high energy	**Mud**	15.0%	15.1%	0.0%	14.9%	14.9%	15.0%
	Sand	52.9%	53.0%	69.9%	52.9%	52.9%	52.9%
	Granule- pebble	22.9%	22.9%	30.1%	23.0%	23.0%	22.9%
	Cobble	7.2%	7.0%	0.0%	7.2%	7.2%	7.2%
	Boulder	2.1%	2.1%	0.0%	2.1%	2.1%	2.1%
	Total area, high energy (km^2)	*125,324*	*119,982*	*116,382*	*125,261*	*125,204*	*125,324*

Simulated outputs for each of the six major gear types are shown in the maps below. These are presented as combined Z_∞ (left panel), geological contribution to Z_∞ (center panel), and biological contribution to Z_∞ (right panel),. Note that the scales (color ramps) vary between panels and between gear types.

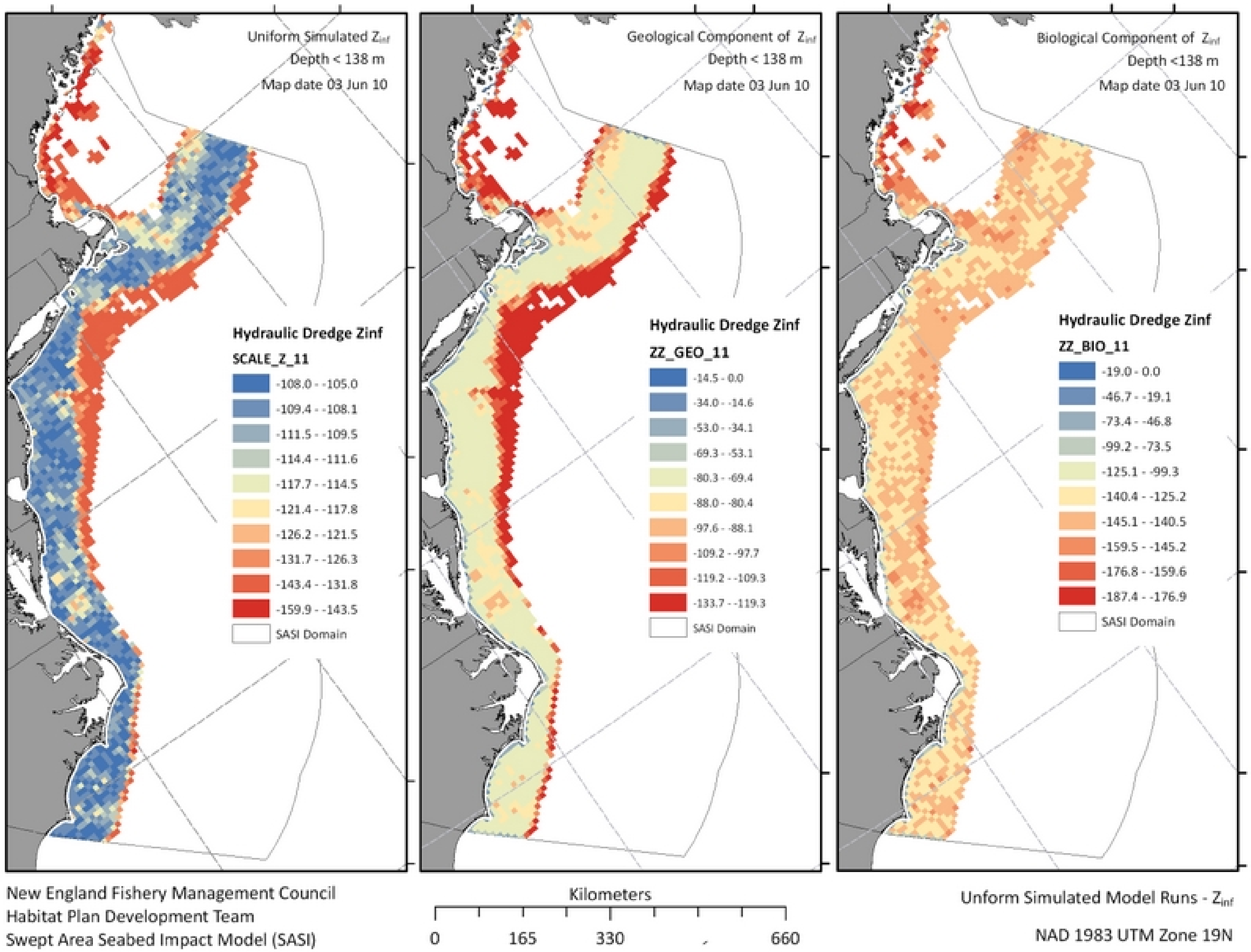
Map 15 – Simulation outputs (Z_∞) for trawl gear.



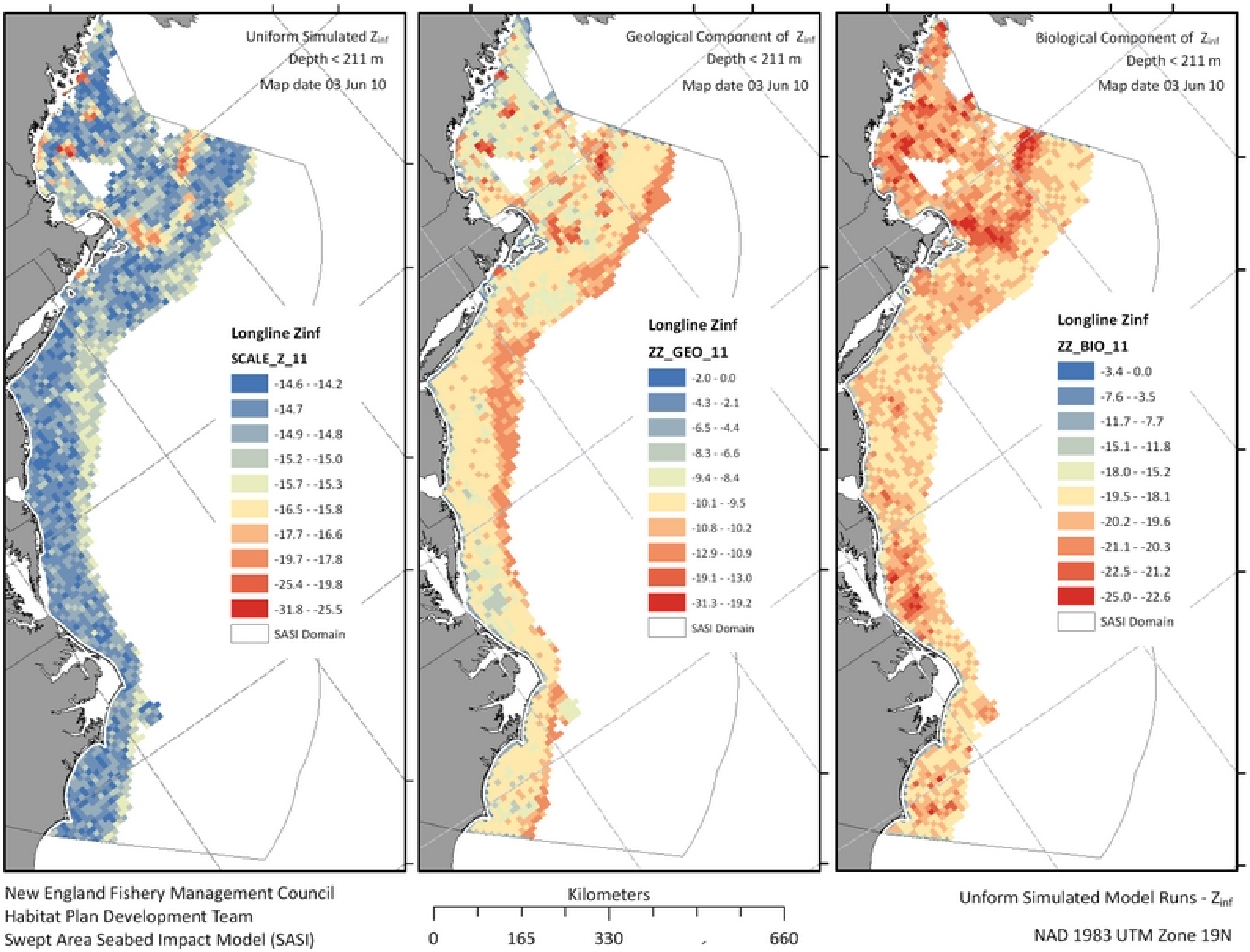
Map 16 – Simulation outputs (Z∞) for scallop dredge gear.



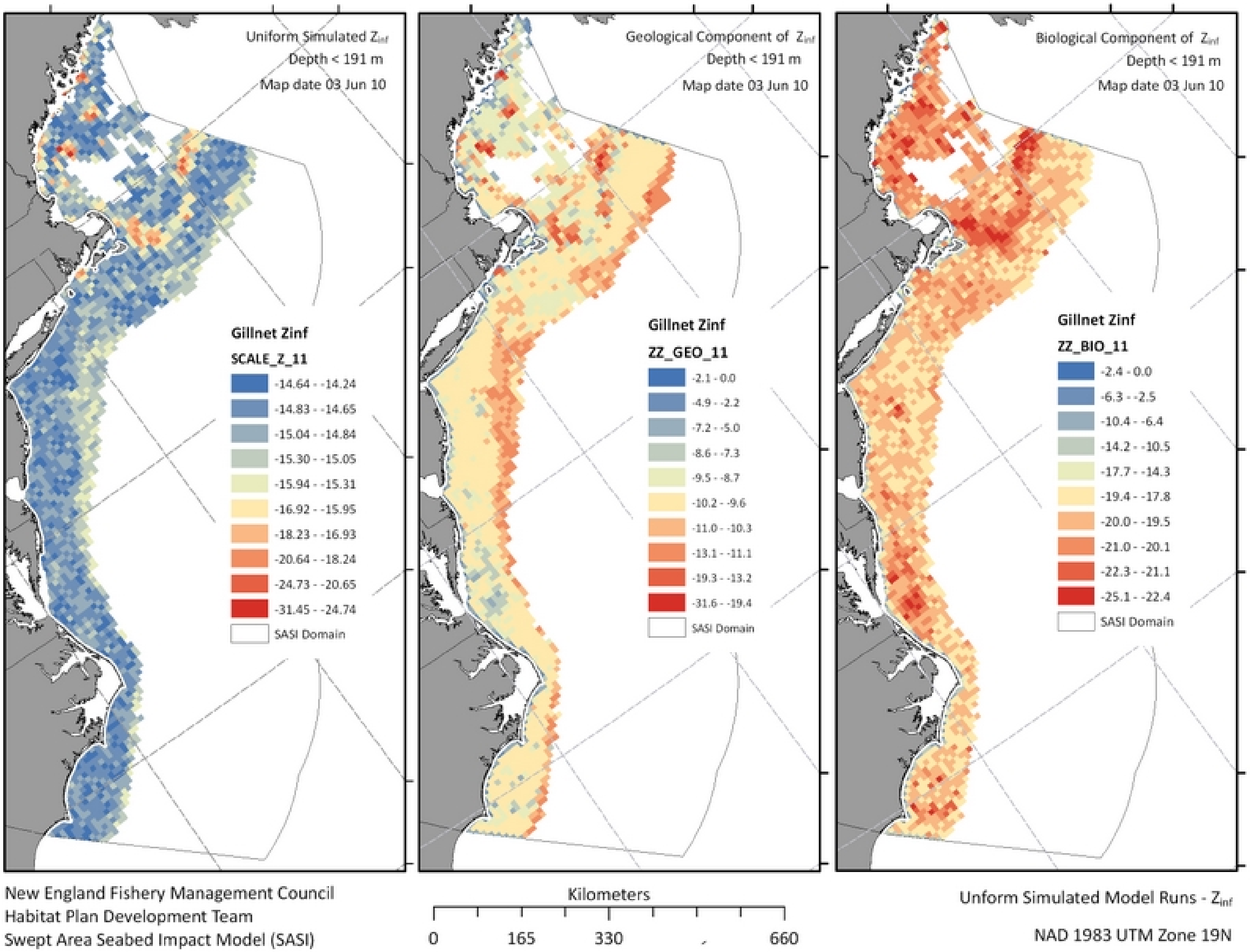
Map 17 – Simulation outputs (Z_∞) for hydraulic dredge gear.



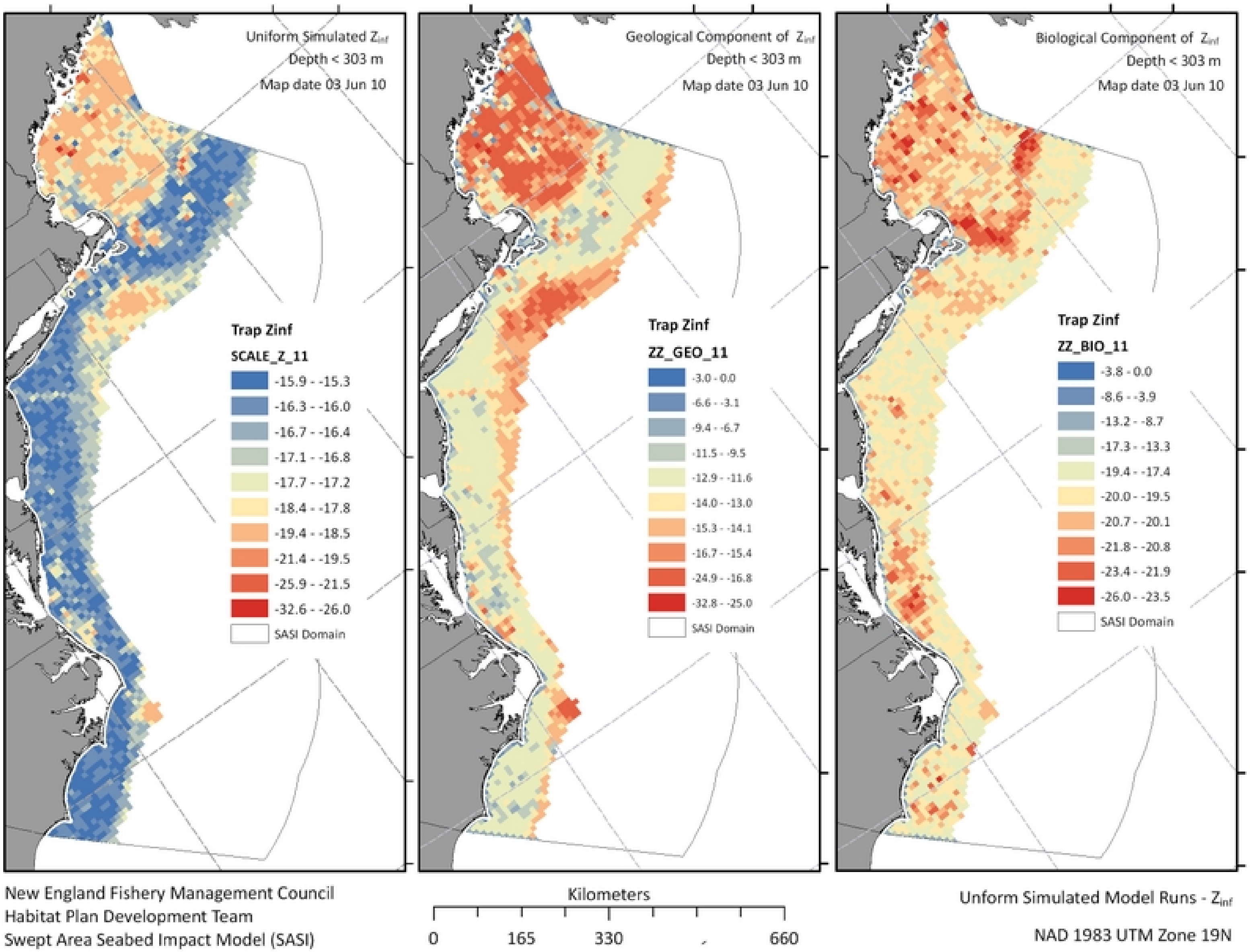
Map 18 – Simulation outputs (Z_∞) for longline gear.



Map 19 – Simulation outputs (Z_∞) for gillnet gear.



Map 20– Simulation outputs (Z_∞) for trap gear.



8.3.2 Realized effort runs

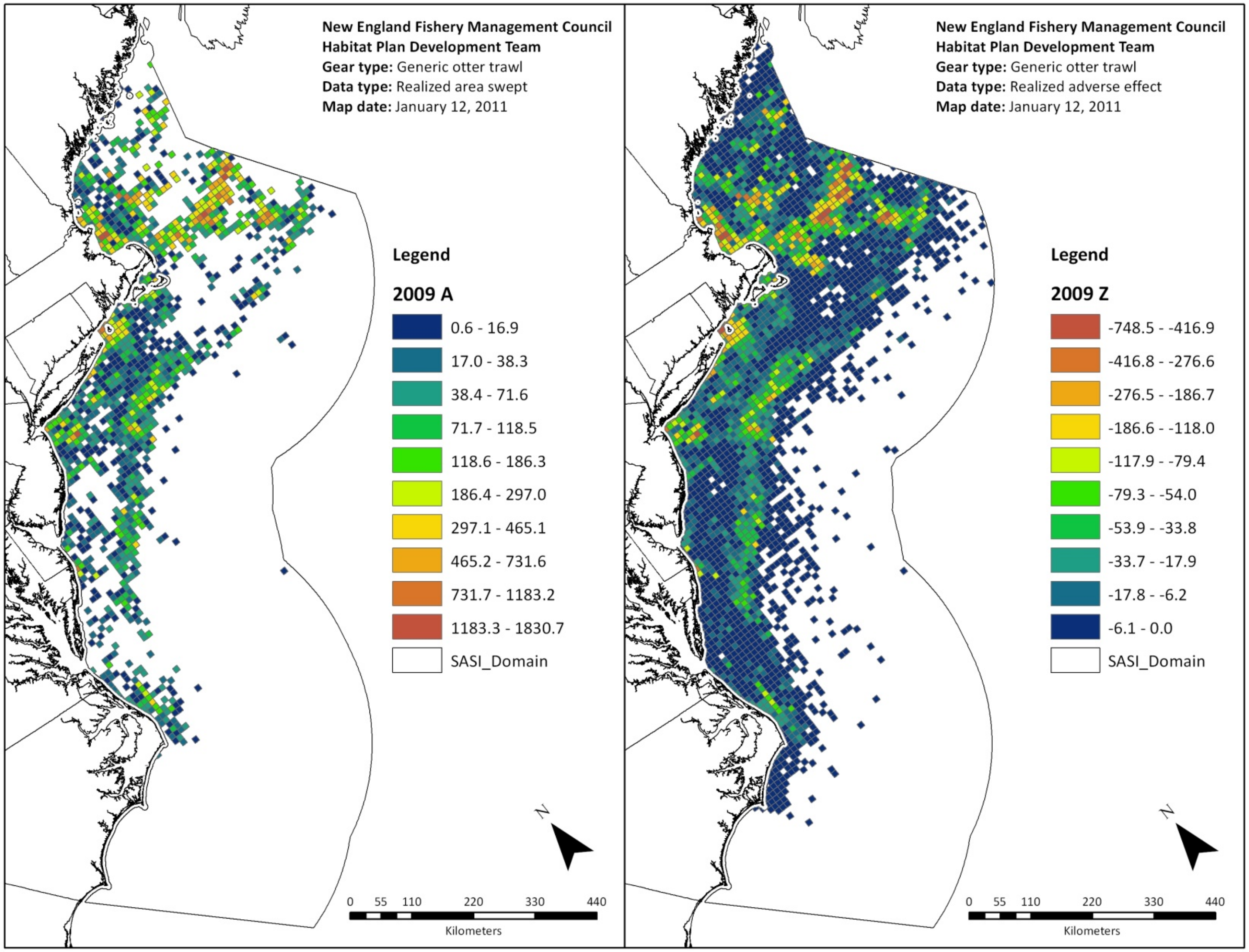
Realized model outputs use empirical estimates of contact-adjusted area swept (A) based on VTR data from 1996-2008, generated as described in section 6.0. They are intended to represent the actual impact of fishing on the seabed. The magnitude of the resulting adverse effect (Z) estimates can be compared between years and between gear types. Four trawl types and two scallop dredge types are decomposed for this analysis. The analysis is run on a calendar year basis, despite different fishing years for the various gear types/FMPs (e.g. May 1 – April 30 for Multispecies FMP, March 1 – February 28/29 for the Scallop FMP).

As with the simulation runs, the model runs continuously, with area swept added in annual time steps. However, realized outputs are mapped on an annual basis to show change over time. Unlike the simulation model, to ensure that the annual $Z_{realized}$ values in the first ten years after 1996 incorporate decaying adverse effect from each of the ten previous years, as applicable, a starting $Z_{realized}$ condition is required. In order to approximate these starting conditions, 1996 area swept data are used for each year from 1985 onward. The exception to this is the hydraulic dredge gear type, where year 2000 area swept data are used (data for this gear are only available from 2000 onward).

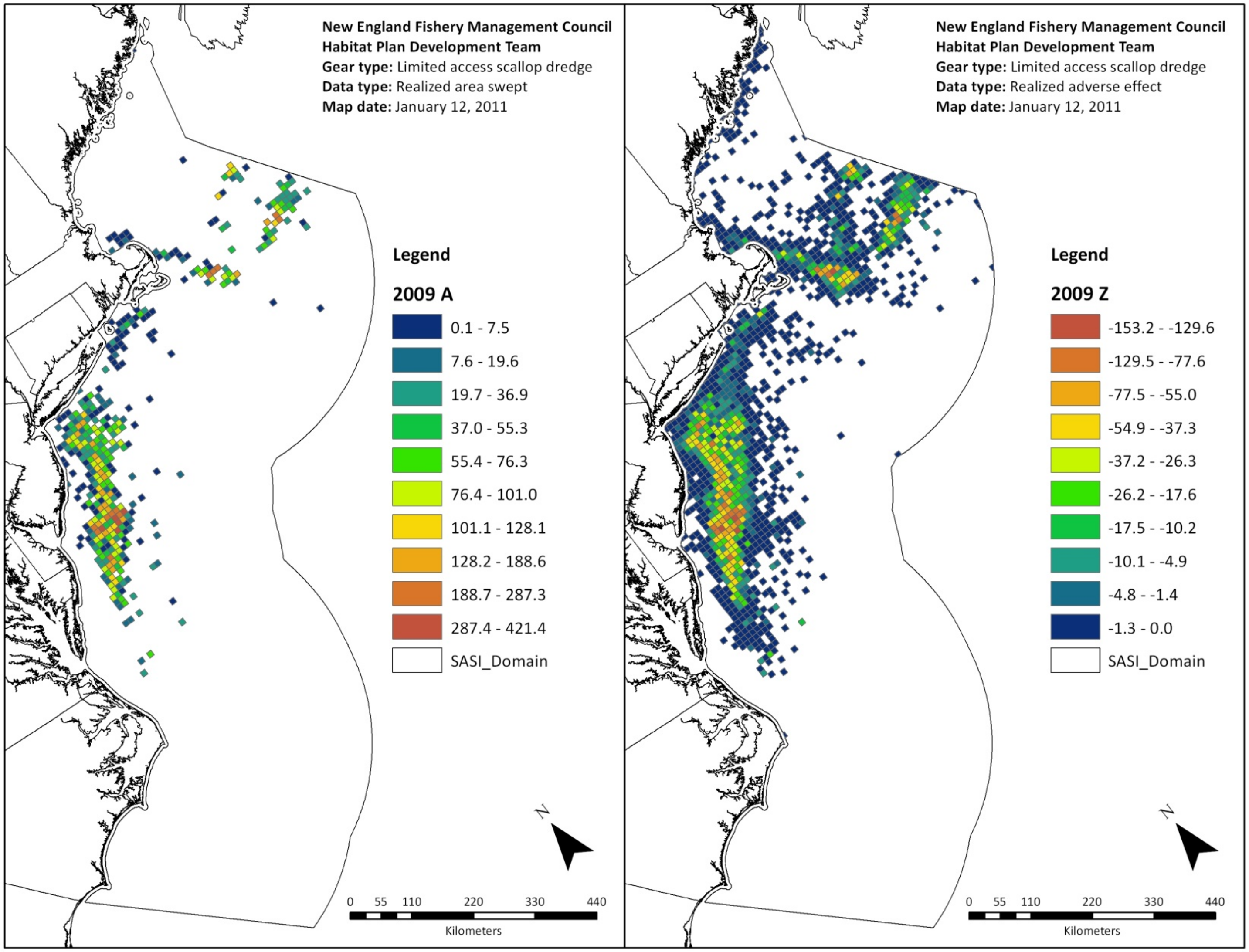
For the two gear types that account for the majority of fishing effort (generic otter trawl and limited access sea scallop), it appears likely that using 1996 data to represent the previous 10 years' adverse effect leads to underestimates of the magnitude of the starting adverse effect condition. For groundfish species, as well as for sea scallops, 1996 landings are much lower than the annual average for the previous ten years. However, this is not universally true: for some of the species that accounted for less fishing effort, including skates (harvested with generic otter trawl gear), as well as for squids, 1996 landings are higher than the previous ten years' averages. It is important to bear in mind that area swept does not have a direct relationship with landings, however: it depends partly on catch rate and partly on the magnitude of catches.

The following sample maps show realized area swept and adverse effect for selected gear types during selected years. Note that larger positive values of A indicate more fishing effort, but that because of the way the model equations are written, the more negative Z values indicate a greater magnitude of area swept.

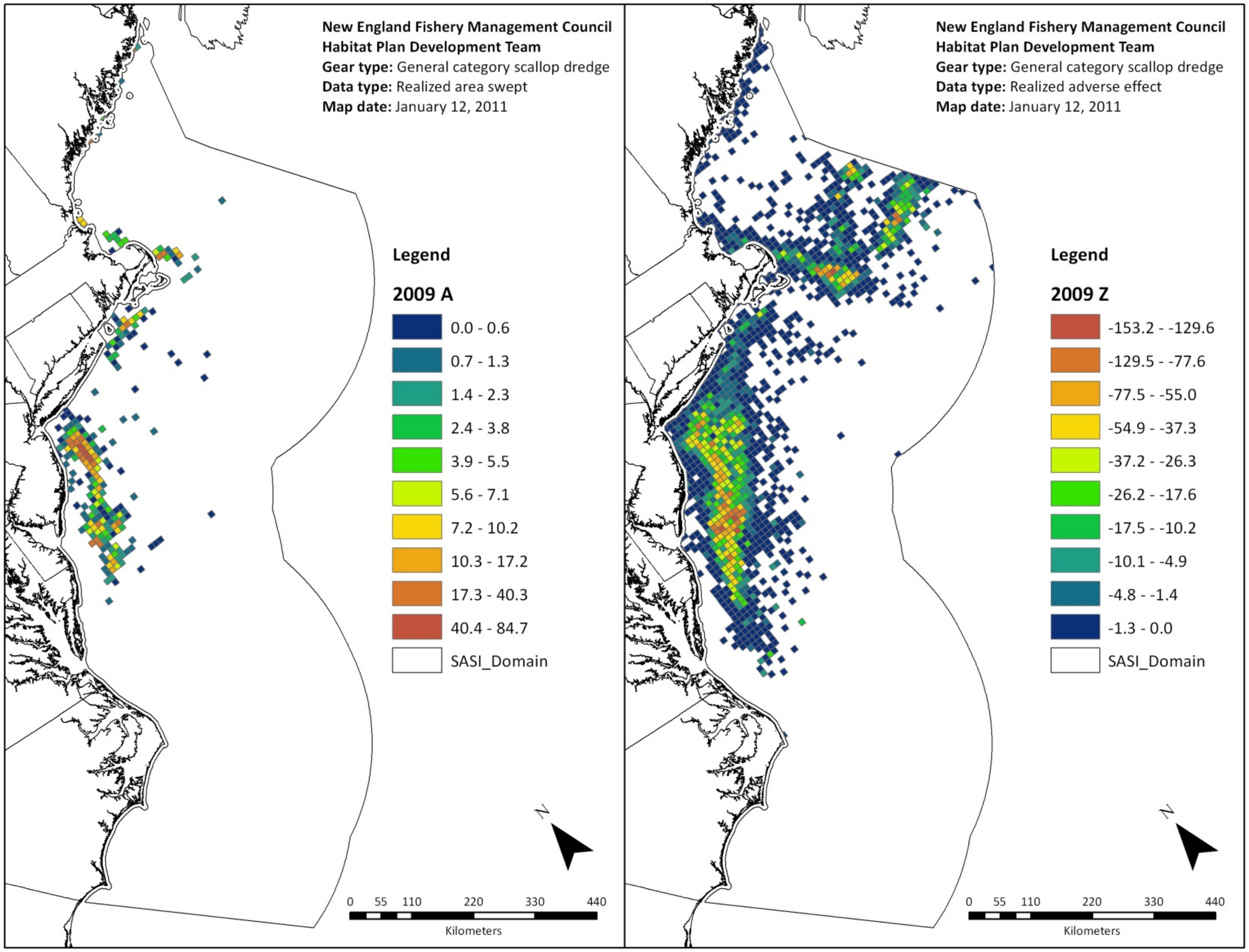
Map 21 – Generic otter trawl realized area swept and adverse effect for calendar year 2009.



Map 22 – Limited access scallop dredge realized adverse effect and area swept for calendar year 2009.



Map 23 – General category scallop dredge realized adverse effect and area swept for calendar year 2009.



8.4 Model assumptions and limitations

Any model is necessarily a simplification of reality, and should be interpreted with a full understanding of the underlying data sources and assumptions. In the absence of perfect information about fishing effort, substrate and feature distributions, and the nature of the interaction between fishing gears and seabed features, numerous simplifying assumptions are made during development of SASI. It is important to bear these assumptions in mind when using SASI for management applications.

The primary assumption of SASI is that area swept, when adjusted for gear contact with the seabed, is a proxy for seabed impact. Further, seabed impact as modified to account for the vulnerability of habitat features encountered is taken as a suitable proxy for the adverse effect of fishing on fish habitat.

This assumption relates closely to a limitation of the model, namely that **the analysis is unable to provide information about the relationship between habitat or seafloor features and fish production**. Seabed structural features, both geological and biological, are assumed to be components of the essential habitat required by various managed species. However, little information about the relationship between particular habitat features and fish or fishery productivity is available. In other words, the relative importance of these features to fish is not well known, nor is the relative abundance of structural features in the environment. Investigations of these critical relationships is suggested as a research priority.

Another assumption is that fishing does not have significant impacts on the water column. This assumption limited the scope of the SASI model. While EFH includes "both the waters and substrate necessary for spawning, breeding, feeding and growth to maturity", this analysis focuses exclusively on habitat features capable of providing shelter.

Certain assumptions relate to the area swept models. One is that, **within a tow, fishing gear impact is constant.** In particular, there is constant and unchanged impact along the entire length of a gear component and the impact of each gear component on fish habitat is cumulative. In the case of a demersal trawl, additional assumptions include, otter board angle of attack is constant, ground cables are straight along their entire length, and otter board and net spread are constant.

Other assumptions relate to the spatial data and parameter estimates. For example, we assumed **that habitats are homogeneous within unstructured grid cells, and between unstructured cells with the same substrate and energy.** This is despite the knowledge that the attributes of habitat mediating the distribution of individual fish within a habitat "type" are extremely patchy. In other words, there are fine-scale ecological interactions of species with their habitats that are not addressed in SASI. In addition, this implies a lack of regional and/or depth-based differences in the feature distributions associated with SASI habitat types, which is an obvious oversimplification of reality. Another assumption, which relates to the lack of information on the relationship between habitat features and fish production, **is that each of the geological and biological features should contribute equally to the modification of area swept and that, between them, the geological and biological components should contribute equally**.

Other assumptions relate to the way fishing effort is combined in the model. Foremost among these is the assumption that **fishing area swept is additive**. As the model runs over time, units of fishing area swept are continually added in annual time steps. This area swept decays based on the appropriate feature recovery values for that substrate and energy type.

This approach ignores two possibilities. One is that the first pass of a fishing gear in an area may have the greatest impact. A "first pass" hypothesis has been proposed but has not been verified empirically and is not universally accepted. Second, and conversely, that adverse effects from fishing may be greater once fishing effort levels reach a certain magnitude and the seabed state is altered such that later passes of the gear have a more deleterious effect—that fishing impacts have a non-linear concave effect on the functional value of habitats. Importantly, a conceptual model of fishing impacts on habitat developed by Auster (1998) illustrates a linear decline in physical attributes, consistent with SASI model assumptions, but also discusses the issues of threshold and feedback effects. He hypothesized that an alternative to the "first pass" scenario is one that approaches a linear, arithmetic decline based on increased rate of impacts with feedback loops to an earlier state due to recovery/recruitment and the physical processes that reset the clock to some earlier state. This alternative view is adopted here.

Certain limitations are the result of data availability. **A major limitation is that the spatial resolution of fishing effort data is generally poor.** For example, the primary type of fishing effort data used, vessel trip reports, have limited spatial information associated with them. The best case scenario is a trip report where the latitude/longitude coordinate given accurately corresponds to the average fishing location for the trip. Even in this instance, the locations of all tows are inferred to this single point. Using the 100 km^2 structured grid allows the SASI model to bridge between low resolution effort data and the more finely resolved unstructured substrate grid. However, in some cases, fishing effort can only reliably be inferred to statistical areas, which are much larger than the unstructured grid cells to which vulnerability estimates are inferred. If appropriate for a specific data set, larger (or smaller) structured grid cells could be used with the same unstructured substrate/energy grid. Spatial scale issues are further discussed in section 8.5.

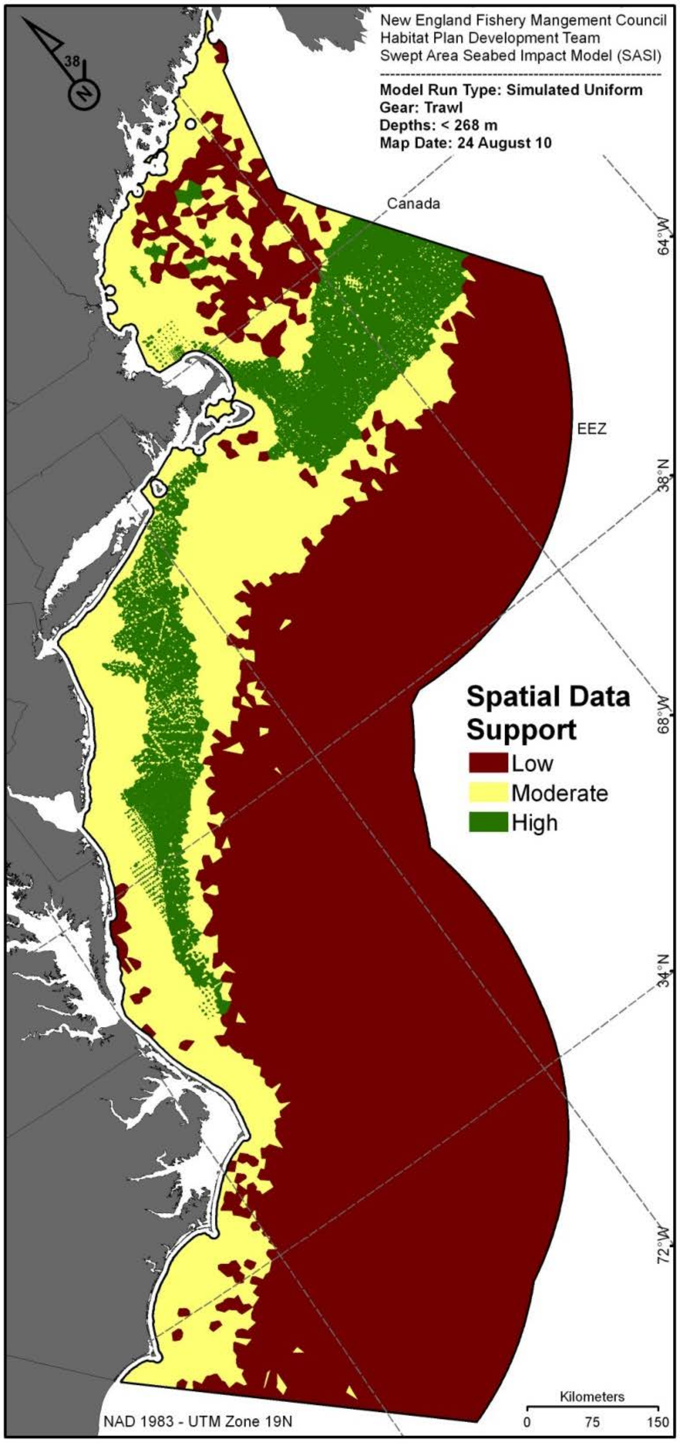
In addition, **the ability of the model to produce differential estimates of adverse effect between similar gear types is limited by the lack of information about gear configurations.** In particular, both the susceptibility values and the contact indices average between trawl tows that in reality represent a variety of sweep configurations. The configurations could range from large rockhoppers to small rollers, and it is likely that sweep configuration influences seabed impact. However, because data on sweep types are not available for all trips, and because the influence of different sweep types on susceptibility is not clearly demonstrated in the literature, the model does distinguish impacts between different types of sweeps, except to the extent that contact indices for shrimp, raised footrope, and squid trawls are specified individually. The influence of this limitation is mitigated by the fact that the sweep comprises only about 30% of the total effective linear width for most otter trawl gears. Going beyond trawl gear, there is substantial uncertainty associated with the various fixed gear model specifications, in terms of estimating both the contact patch and the movement of the gear across the seabed. Because mobile gear area swept and seabed impact dwarfs that for fixed gear, this has not been the subject of much research.

Another model limitation relates to the availability of substrate data. Fortunately, a strength of SASI is that the unstructured grid can be modified as data becomes available. **However, in the near term, information on substrate classes larger than granule-pebble is unavailable in deeper waters outside the domain of the SMAST video survey.** For example, spatial distributions of hard substrates in the canyon areas along the edge of the continental shelf are not well known, so these locations are not well resolved in the model grid. As a result, their vulnerability may not be accurately estimated. Higher resolution spatial data incorporating all five dominant substrates may exist for some deep-water areas, but they are not geographically comprehensive and would require substantial work to put in a useful format (P. Auster, pers. comm.). It might also be possible to infer presence of outcropped rocks and rafted boulders based on bathymetric data. In large part, these locations are currently coded as mud. If features in rock outcrops had higher vulnerability than features in mud, the SASI model will underestimate overall vulnerability. Map 24 is a visual representation of spatial data support.

In translating VA-derived S and R estimates into SASI, a uniform distribution of habitat features within their assigned dominate substrates is assumed. In the SASI model, individual feature S and R scores are used to modify small portions of area swept, and then the effects are summed across features, substrates, and energy regimes to generate impact estimates at the 100 km^2 grid cell level. Therefore, minimizing estimation error requires both the presence and relative abundance of features in the cell to be as reflective of actual distributions as possible. Unfortunately there is no comprehensive empirical data available to inform relative abundance estimates. An even weighting of features' scores is assumed. (An alternative approach might be to weight the relative abundance of features equal to the relative importance of those features to commercially targeted fish as habitat, but this is also, obviously, unknown.) Due to this equal weighting approach, the contribution of rare features to adverse effects are almost certainly overestimated. In addition, for those substrates that contained fewer features in a given feature class, the individual contribution of each feature is greater, and the subsequent potential for any individual feature to bias the result is higher. For example, the geological feature category for boulder substrates includes only two features - scattered boulders or piled boulders. In contrast, there are ten biological features inferred to boulder substrates, such that each feature's score has relatively less weight.

All features are assumed to have equal probabilities of encounter by fishing gears. Logically, however, some features are likely to be avoided during fishing operations, such as cobble and boulder piles that tend to snag nets. Thus, assuming that all features are equally at risk likely results in overestimating the vulnerability of these avoided features. Assigning the same biological feature scores across substrates and energies implies that the biological features consist of the same species in each substrate and energy level, even though they are, in reality, different. Research on the distribution of both biological and geological features and how the species composition and vulnerability of biological features differ as a function of these factors could be used to enhance future assessments. Since the distribution of features within a substrate and energy regime likely varies both on local and regional (as well as temporal/seasonal) scales, readers should be careful to avoid over interpreting the findings.

Map 24 - Spatial data support. High = full range of substrates detectable, high sampling frequency; Moderate = only mud- granule pebble detectable or low sampling frequency; Low = only mud- granule pebble detectable and low sampling frequency.



8.5 Spatial and temporal scale

It is critical to understand the spatial scale of the model and how this affects its application to fishery management decision making. Ecological studies should clearly define the components of sampling and analysis scales (Dungan et al., 2002). The scale of sampling includes three levels; the *grain* is the elementary sampling unit (most basic measurement scale), the *lag* is the distance or time between samples, and *extent* is the sampling domain (Dungan et al. 2002). Most importantly, no spatial or temporal structure can be detected that is smaller than the sampling grain or larger than the extent (Legendre and Legendre, 1998).

For example, the spatial sampling unit of the SMAST video survey is a 3.24 m^2 video quadrat but in this analysis quadrats are pooled by station so the spatial grain is 100 m^2, the total area in which quadrat sampling occurred at each station. The spatial lag, the average distance between stations, is 1 km, and the total spatial extent of the surveys is 70,000 km^2 (Table 69). Similarly, the temporal grain, the video recording time at each quadrat, is 0.25 – 0.5 minutes. The temporal lag, the time interval between stations, is 0.5 – 1 hours / 5 – 10 days, and the total temporal extent is 11 years (1999 - 2009). This is the only data source used in the SASI analysis which employed one sampling design throughout its temporal extent (11yrs). The usSEABED data were compiled from more than 50 different geological surveys so the temporal and spatial scales of sampling vary widely depending on the methods employed. Most samples (~80%) were collected with benthic grabs, so the sampling grain likely ranges from 0.1 to 0.5 m^2.

Table 69 – SASI inputs and output spatial scales

			Spatial Scale	
Input	**Data Source**	**Grain**	**Lag**	**Extent**
Geology	Video Survey	100 m^2	1 km	70,000 km^2
Geology	usSEABED	0.1 - 0.5 m^2	3.1 km	598,089 km^2
Geology	Combined	0.1 - 100 m^2	1.96 km	598,089 km^2
Energy	NOS Depth	1-10 m^2	0.35 km	598,089 km^2
Energy	FVCOM CSS	-	5.9 km	30,8976 km^2
Fishing	VTR, VMS	5 - 11,000 km^2	2 - 100 km	598,089 km^2
SASI output		**100 km^2**	**10 km**	**598,089 km^2**

Table 70 – SASI inputs and output temporal scales

			Temporal Scale	
Input	**Data Source**	**Grain**	**Lag**	**Extent**
Geology	Video Survey	seconds-minutes	hours -days	11 years
Geology	usSEABED	instant	hours - years	>50 years
Geology	Combined	-	hours - years	>50 years
Energy	NOS Depth	seconds-minutes	days	129 years
Energy	FVCOM CSS	seconds	minutes	10 years
Fishing	VTR, VMS	minutes - days	minutes - months	10 years

	Temporal Scale		
SASI output	**I year**	**1 year**	**25 years**

8.6 Sensitivity analyses

Given model formulation, it is not possible to construct confidence intervals or estimates of uncertainty around the adverse effects estimates generated by SASI. To evaluate the robustness of model outputs to certain assumptions/inputs, the SASI simulation model is tested for changes in the distribution of adverse effects when three model parameters are changed:

(1) the duration of recovery;
(2) the gear/substrate sensitivity and recovery values; and
(3) the contribution of geological and biological features to the total adverse effect

The methods and results for each sensitivity test are described in the following sections.

8.6.1 Model Sensitivity Test 1: Duration of Recovery

To test model sensitivity to the recovery time steps parameterized in the model, two potential sources of error are considered; specifically that the recovery durations parameterized in the model are either too short (test 1.1) or too long (test 1.2). Sensitivity is tested by changing parameters as follows:

Table 71 – Recovery sensitivity test 1.1 (extended recovery duration)

R	*Definition*	*Model Parameter*	*Sensitivity Definition*	*Sensitivity Parameter*
0	1 year	1	1 year	1
1	1-2 years	1 + round(ranuni(0))	2-3 years	2 + round(ranuni(0))
2	2-5 years	2 + round(3*(ranuni(0)))	3-20 years	3 + round(17*(ranuni(0)))
3	5-10 years	5 + round(5*(ranuni(0)))	20-50 years	20 + round(30*(ranuni(0)))

The left frame (below) shows the spatial distribution of adverse effect (Z_∞) binned by standard deviations from the mean value domain-wide for this sensitivity test. The highlighted areas represent roughly the top 3% of the distribution, or approximately 80-100 cells out of roughly 2,550 cells in the domain. The right frame (below) shows the spatial distribution of adverse effects under the base case scenario, as SASI is currently parameterized. Extending the duration of recovery time steps does not fundamentally alter the spatial distribution of modeled adverse effects. Areas accumulating adverse effects within the bin covered by Z_∞ values ranging between 1.5 and 2.5 standard deviations from the mean tended to expand around central core clusters with the longer time steps, and a few isolated grid cells are elevated, particularly in the Gulf of Maine. While trawl gear is the only model output shown here, this conclusion holds across gear types.

Map 25 – Recovery sensitivity test 1.1 (extended recovery duration)

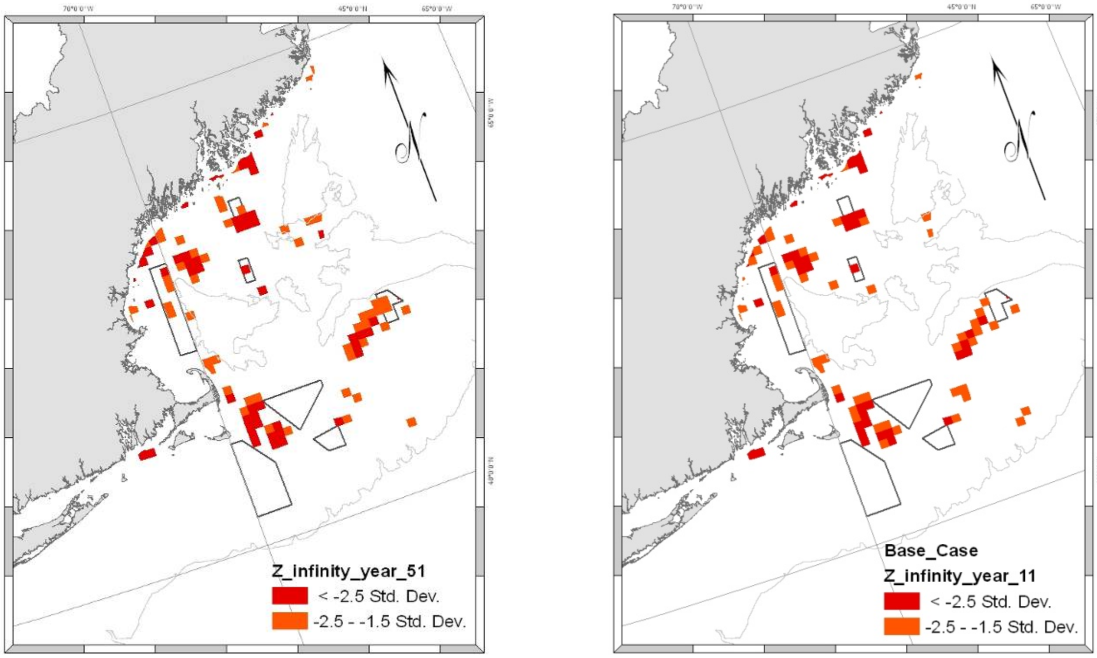


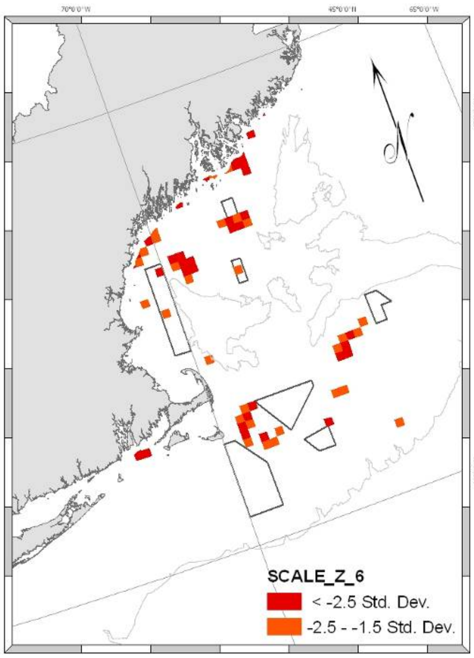
Table 72 – Recovery sensitivity test 1.2 (compressed recovery duration)

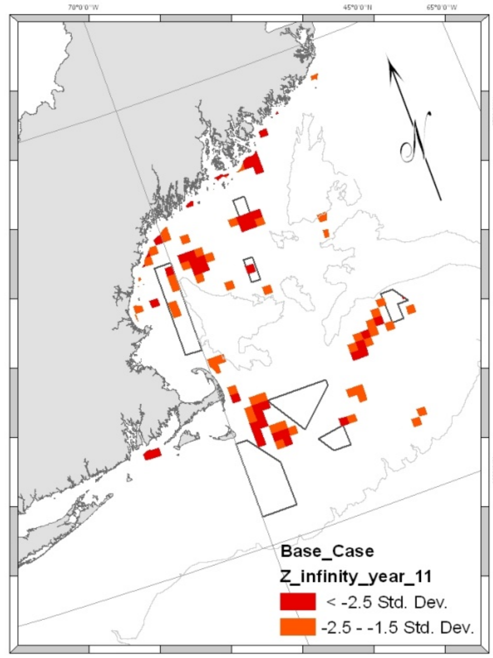
R	*Definition*	*Model Parameter*	*Sensitivity Test Definition*	*Sensitivity Test Parameter*
0	1 year	1	1 year	1
1	1-2 years	1 + round(ranuni(0))	1 year	1
2	2-5 years	2 + round(3*(ranuni(0)))	1-2 years	1 + round(1*(ranuni(0)))
3	5-10 years	5 + round(5*(ranuni(0)))	2-5 years	2 + round(3*(ranuni(0)))

The left frame (below) shows the spatial distribution of adverse effect (Z_∞) binned by standard deviations from the mean value domain-wide for this sensitivity test. The highlighted areas represent roughly the top 3% of the distribution, or approximately 80-100 cells out of roughly 2,550 cells in the domain. The right frame (below) shows the spatial distribution of adverse effects under the base case scenario, as SASI is currently parameterized.

Compressing the recovery durations does not fundamentally alter the spatial distribution of modeled adverse effects. Areas accumulating adverse effects within the bin covered by Z_∞ values ranging between 1.5 and 2.5 standard deviations from the mean tended to contract around central core clusters with the shorter time steps, and a few isolated grid cells dropped out of this bin, particularly on Georges Bank. While trawl gear is the only model output shown here, this conclusion holds across gear types.

Map 26 – Recovery sensitivity test 1.2 (compressed recovery duration)





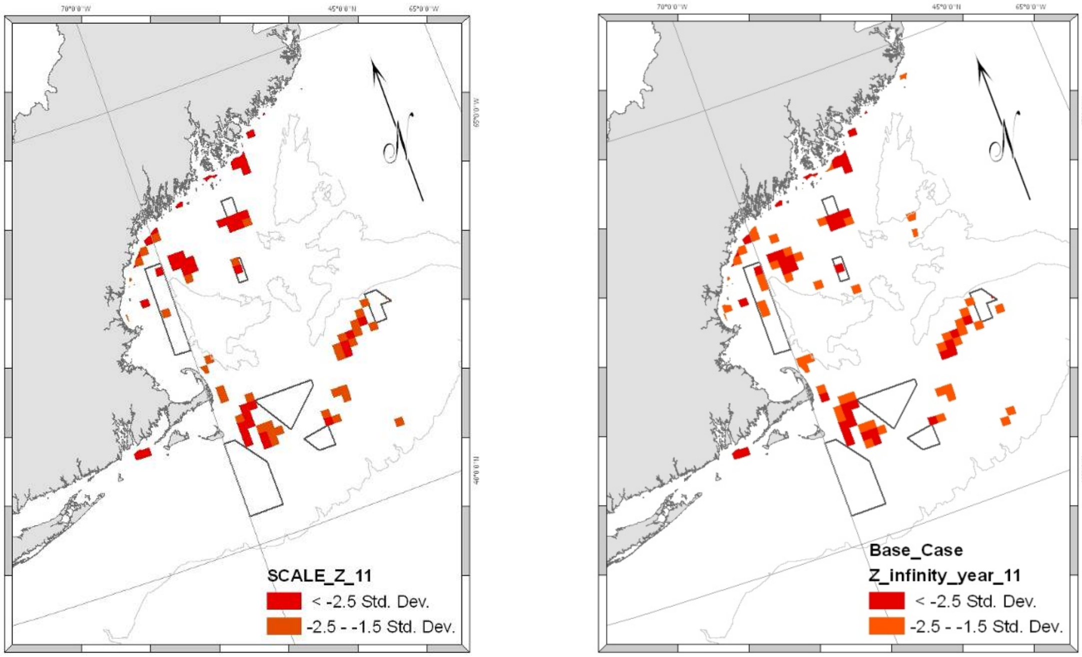
8.6.2 Model Sensitivity Test 2: Susceptibility and Recovery Scoring

The PDT notes that the most difficult interpretations of the published gear effects literature came when estimating susceptibility and recovery scores at the outer extremes of the zero, one, two and three scale. To test model sensitivity to these parameters, the team conducted model runs after converting all one (1) scores for both sensitivity and recovery to scores of zero (0) (test 2.1), and again after converting all scores of two (2) to scores of three (3) (test 2.2).

The left frame in Map 27 shows the spatial distribution of adverse effect (Z_∞) binned by standard deviations from the mean value domain-wide for the sensitivity test which set all (1) scores to (0). The highlighted areas represent roughly the top 3% of the distribution, or approximately 80-100 cells out of roughly 2,550 cells in the domain. The right frame (below) shows the spatial distribution of adverse effects under the base case scenario, as SASI is currently parameterized.

Shifting the parameter value for all features coded 1 to a code of 0 reduces slightly the number of cells that fall into the bins greater than 1.5 standard deviations from the mean adverse effect value. The fundamental distribution and clustering of areas likely to accumulate adverse effects is relatively unchanged. While trawl gear is the only model output shown here, this conclusion holds across gear types.

Map 27 – Susceptibilty and recovery sensitivity test 2.1 (under-utilization of lowest scoring category)



The top left frame in Map 28 shows the spatial distribution of adverse effect (Z_∞) for trawl gear, binned by standard deviations from the mean value domain-wide, for the sensitivity test which converted all (2) scores to (3). The highlighted areas represent roughly the top 3% of the distribution, or approximately 80-100 cells out of roughly 2,550 cells in the domain. The top right frame in Map 28 shows the spatial distribution of adverse effects under the base case scenario, as SASI is currently parameterized.

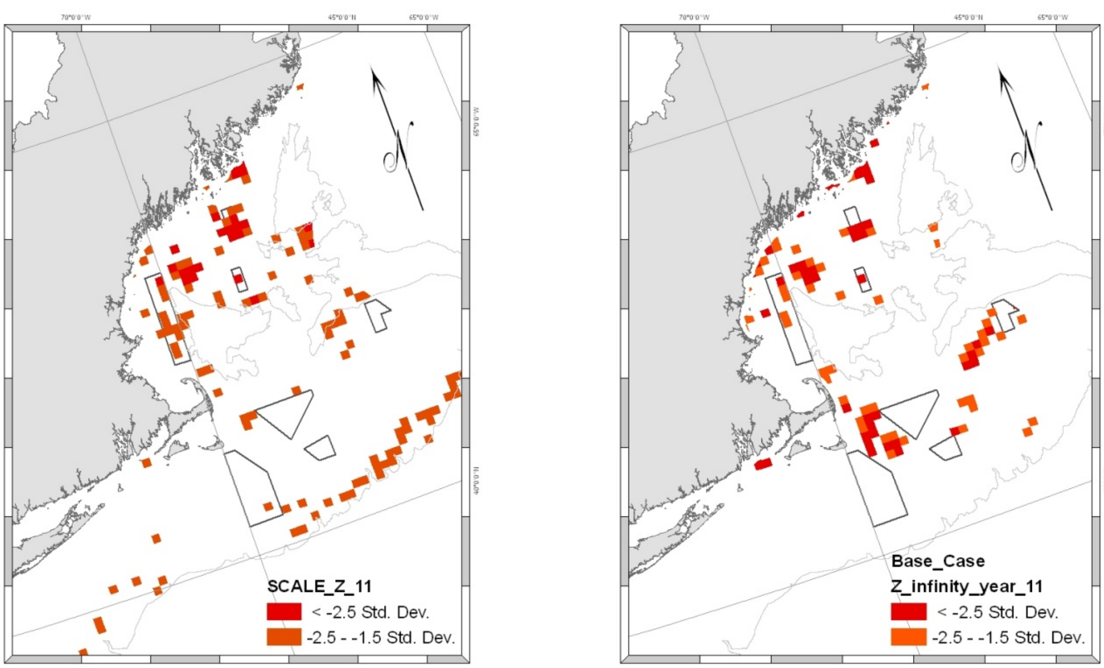
Shifting the parameter value for all features coded 2 to a code of 3 has a significant impact on the distribution of estimated adverse effects for trawl and scallop dredge gears (trawl gear shown in figure), shifting high adverse effect areas from the northern flank of Georges Bank to the edge of the continental shelf and a deepwater area just north of Georges Bank. Adverse effect accumulation in the Gulf of Maine remains similar to the base case.

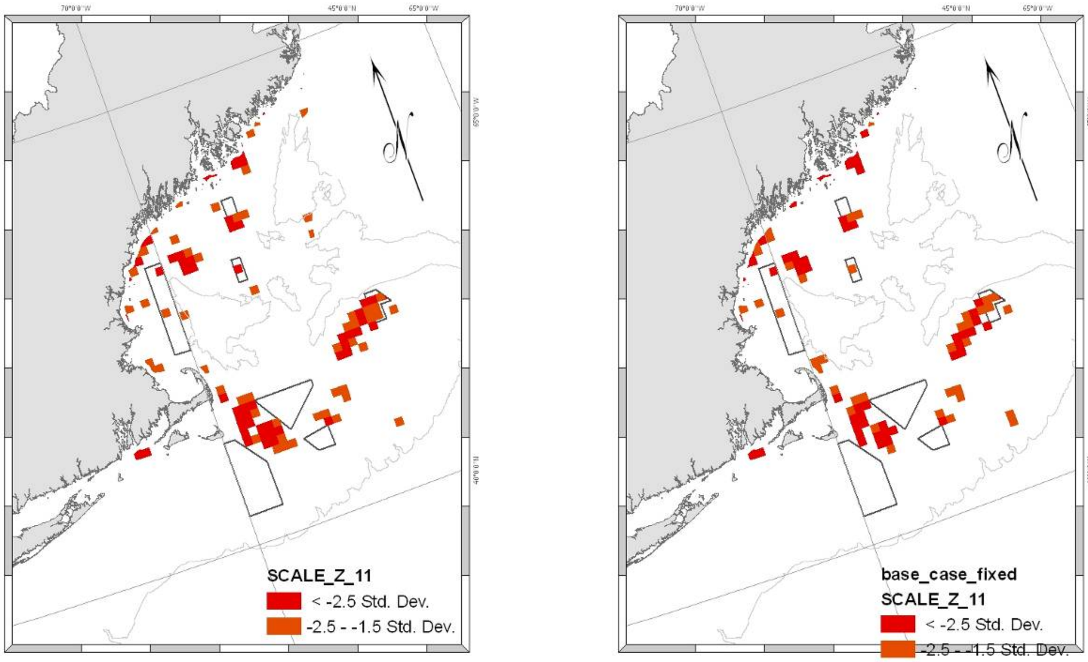
For these two gears, there are 116 individual class/feature/energy/substrate combinations evaluated in the model. Of these, only 14 are evaluated with a score of 3 for either susceptibility or recovery, while 85 are evaluated with a score of two or higher, resulting in a six-fold increase in the maximum values assigned in the matrix. The change in distribution of adverse effects that results from this six-fold increase in maximum-value scores is dominated by biological habitat components.

This sensitivity model run changes values for 71 features in total. Fifteen (15) of these are geological habitat features with high recovery rates—their mean recovery score is less than 1 (0.4). Fifty six (56) biological habitat components have their scores increased, and the mean recovery score for these features is 1.9. The features are roughly evenly distributed amongst the five dominant substrate categories, but low energy features see the greatest change in susceptibility and recovery values. All of this implies that the primary driver in the change in the distribution of areas estimated to have high adverse effects under the sensitivity model test is the relatively long recovery duration for biological features in low energy habitats.

Unlike other sensitivity model tests performed by the PDT, the SASI model is much more sensitive to extreme S and R values for trawl and scallop dredge gears than hydraulic dredge and static gears. For hydraulic clam dredge gears, this is due to the fact that very few features are evaluated with a sensitivity score of two (most features for this gear type are evaluated with either a three or zero). Twenty seven (27) features do have their recovery score increased from a two to a three under this test, but this serves only to compound the adverse effects in areas already estimated to have high values. For static gears, the lack of sensitivity to this assumption results because the static gears have zero features coded with a two or higher for susceptibility and only 26 of 102 features similarly coded for recovery. Similar to the hydraulic clam dredge case, the net effect of this is to compound the degree of adverse effect in locations already estimated to be high. The spatial distribution of high adverse effect accumulation areas therefore changes imperceptibly for these gears. The bottom left frame on Map 28shows the sensitivity model output for gillnet and longline gear, while the bottom right frame on Map 28 shows the base case model output for these gears.

Map 28 – Susceptibilty and recovery sensitivity test 2.2 (under-utilization of highest scoring category), trawl gear, top panels, gillnet and longline gear, bottom panels.



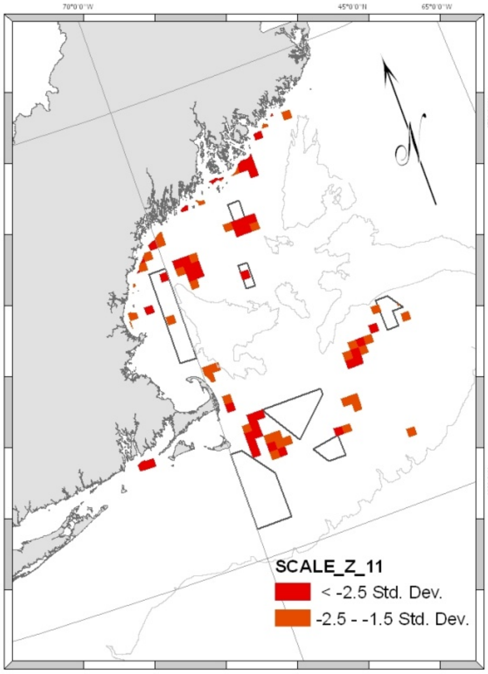


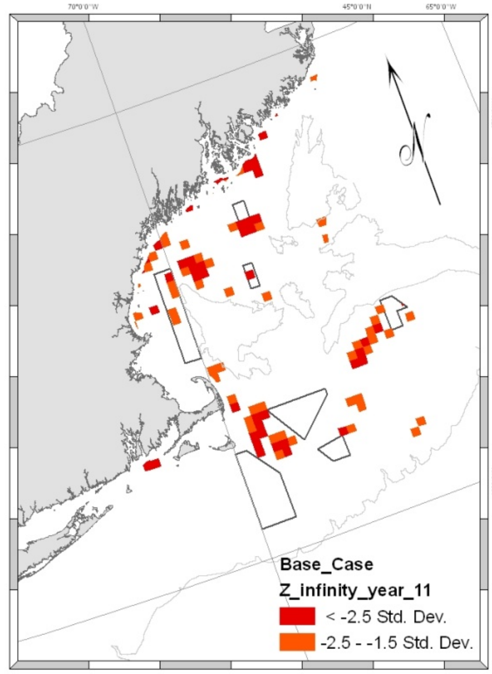
8.6.3 Model Sensitivity Test 3: Geological and Biological Feature Weighting

Absent empirical data on the relative abundance of the various features assigned sensitivity and recovery scores in the vulnerability assessment, the PDT assumed that features specific to these two components of structural habitat would be weighted equally, and therefore contribute equally to the resulting estimated adverse effect. The PDT tested the sensitivity of the model to this equal-weighting assumption by re-weighting in favor of geological habitat features and biological habitat features. Specifically, the sensitivity models altered the weighting from 50/50 (equal weighting) to 90/10 (highly skewed). Test 3.1 skewed the weighting in favor of geological habitat features, and test 3.2 skewed the weighting in favor of biological habitat features.

The left frame of Map 29 shows the spatial distribution of adverse effect (Z_{∞}) binned by standard deviations from the mean value domain-wide for this sensitivity test. The highlighted areas represent roughly the top 3% of the distribution, or approximately 80-100 cells out of roughly 2,550 cells in the domain. The right frame of Map 29 shows the spatial distribution of adverse effects under the base case scenario, as SASI is currently parameterized. Skewing the feature weighting in favor of geological habitat components reduces slightly the number of cells that fall into the bins greater than 1.5 standard deviations from the mean adverse effect value. Isolated cells in the Gulf of Maine also fall out of these bins in the distribution. The fundamental distribution and clustering of areas likely to accumulate adverse effects is relatively unchanged. While trawl gear is the only model output shown here, this conclusion holds across gear types.

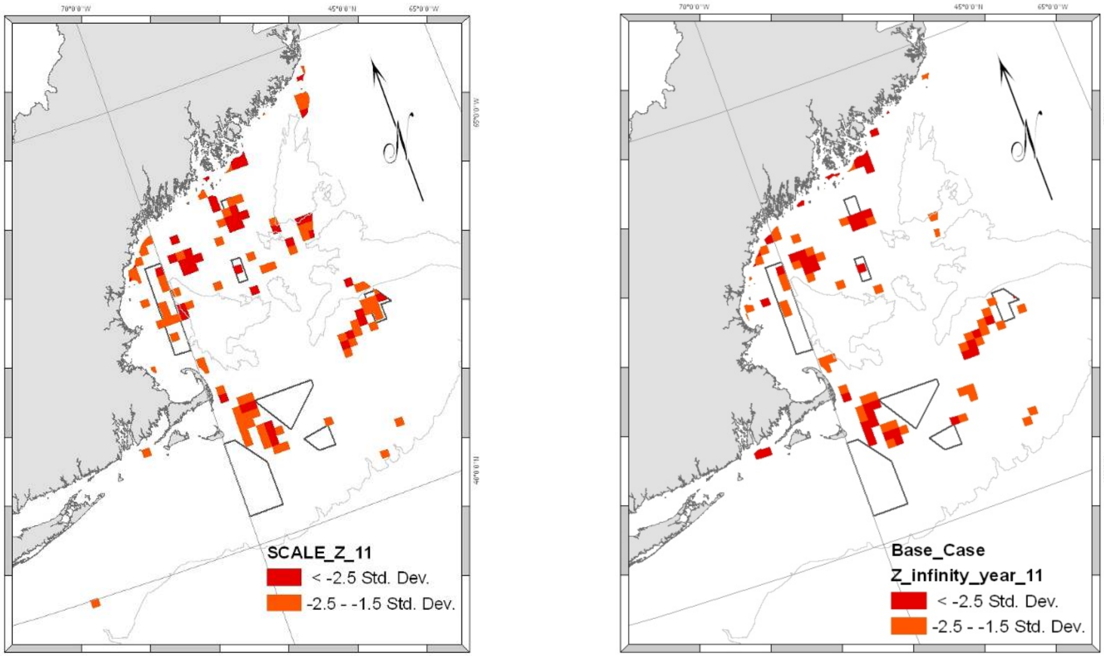
Map 29 – Feature weighting sensitivity test 3.1 results (trawl gear shown)





The left frame of Map 30 shows the spatial distribution of adverse effect (Z_∞) binned by standard deviations from the mean value domain-wide for this sensitivity test. The highlighted areas represent roughly the top 3% of the distribution, or approximately 80-100 cells out of roughly 2,550 cells in the domain. The right frame of Map 30 shows the spatial distribution of adverse effects under the base case scenario, as SASI is currently parameterized.

Map 30 – Feature weighting sensitivity test 3.2 results (trawl gear shown)



Skewing the feature weighting in favor of biological habitat components increases the number of cells that fall into the bin between 1.5 and 2.5 standard deviations from the mean adverse effect value. Spatially, many of these additional cells expand smaller clusters of high adverse effect areas in the Gulf of Maine that are not necessarily highlighted in other model runs or in the base case. This implies that, conditioned on all other assumptions in the SASI model, if biological components of structural habitat are on the order of nine times more susceptible to the adverse effects from fishing on habitat, adverse effects in a few areas in the Gulf of Maine may be underrepresented in the base case model. In particular, the center of the Western Gulf of Maine closed area and the offshore portions of the Gulf are highlighted. The PDT notes that substrate sampling in the deepwater portions of the Gulf of Maine is significantly less dense than in other areas of the domain, and that a few isolated samples of granule/pebble are likely influencing the results in these areas. The area in the center of the Western Gulf of Maine, however, is well sampled. The PDT notes that this is most likely area where the model may underestimate adverse effects if indeed the sensitivity assumption of biology-skewed feature weighting is more correct than the SASI assumption of equal weighting. While trawl gear is the only model output shown here, this conclusion holds across gear types.

8.6.4 Conclusions

The SASI model appears to be robust to all three classes of model assumption with one exception. When SASI is run with a re-coded matrix where all scores of 2 are coded as 3, areas of high adverse effects for trawl and scallop dredge gears shift somewhat from Georges Bank to the outer continental shelf. The Gulf of Maine is relatively unaffected, as are hydraulic clam dredge and static gears. Extended recovery durations for biological features in low energy areas may explain the shift. Because this sensitivity model re-codes nearly half of the features evaluated for trawl and scallop dredge gears, it is unsurprising that some change in the spatial distribution of high adverse effects results. Overall, the model appears highly robust to the primary assumptions underlying the vulnerability assessment, matrix values and the relative contribution of geological and biological habitat components to the estimated adverse effects from fishing gears on structure-forming habitat.

9.0 Spatial analyses

9.1 Objectives

The objectives of the SASI Spatial Analysis are to (1) explore the spatial structure of the asymptotic area swept (Z_∞), (2) define clusters of high and low Z_∞ for each gear type, (3) determine the levels of Z_∞ in present and candidate management areas relative to the model domain, and (4) identify the areas of equal size with Z_∞ values similar to or higher than the tested areas. Objectives 1 and 2 are addressed using Local Indicators of Spatial Association (LISA) statistics, while objectives 3 and 4 are addressed using an Equal Area Permutation (EAP) approach.

9.2 Z_∞ spatial structure and clusters (LISA)

The Local Indicators of Spatial Association (LISA) statistics developed by Anselin (1995) are designed to test individual sites for membership in clusters. These tools differ from commonly used global statistics such as Moran's *I*, Geary's *c*, and Matheron's variogram, which are designed to describe the general autocorrelation characteristics of a pattern. Cressie's (1993) "pocket plot" can identify outliers, but does not provide a formal test of significance. Variograms can dissect patterns into their directional components, but are not designed for single spatial foci as are local statistics.

9.2.1 Methods

LISA statistics including Moran Scatterplots and Local Moran's *I* are used to explore the spatial structure of Z_∞ and to determine if each SASI grid cell is a member of a high or low Z_∞ accumulation cluster. The LISA analysis for each SASI grid cell (1) indicates the extent of significant spatial clustering of similar values around that cell, and (2) the sum of LISAs for all cells is proportional to a global indictor of spatial association (Anselin 1995).

For exploratory spatial data analysis, Global Moran's *I* is used to determine the general level of spatial autocorrelation in the data. *I* is an index of linear association between a set of spatial observations x_i x_j, and a weighted average w_{ij} of their neighbors (Moran 1950):

$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j}} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j} x_i x_j}{\sum_{i=1}^{n} x_i^2} , \qquad (1)$$

where $\bar{X}$

domain are positively autocorrelated, while $I < 0$ indicates negative autocorrelation. When $I = 0$ the values are spatially random.

The spatial association of each cell with its neighbors is estimated with the Local Moran's I_i (Anselin 1995):

$$I_i = \frac{x_i}{Q_i^2} \sum_{j=1, j \neq i}^{n} w_{i,j} x_i \ , \qquad (2)$$

where

$$Q_i^2 = \frac{\sum_{j=1, j \neq i}^{n} w_{i,j}}{n-1} - \overline{X}^2 . \qquad (3)$$

When $I_i > 0$ there is positive local autocorrelation, i.e., the cell is in a neighborhood of cells with similar characteristics, but which deviate (positively or negatively) from the overall mean cell characteristics $\overline{X}^2$ (

9.2.2 Results

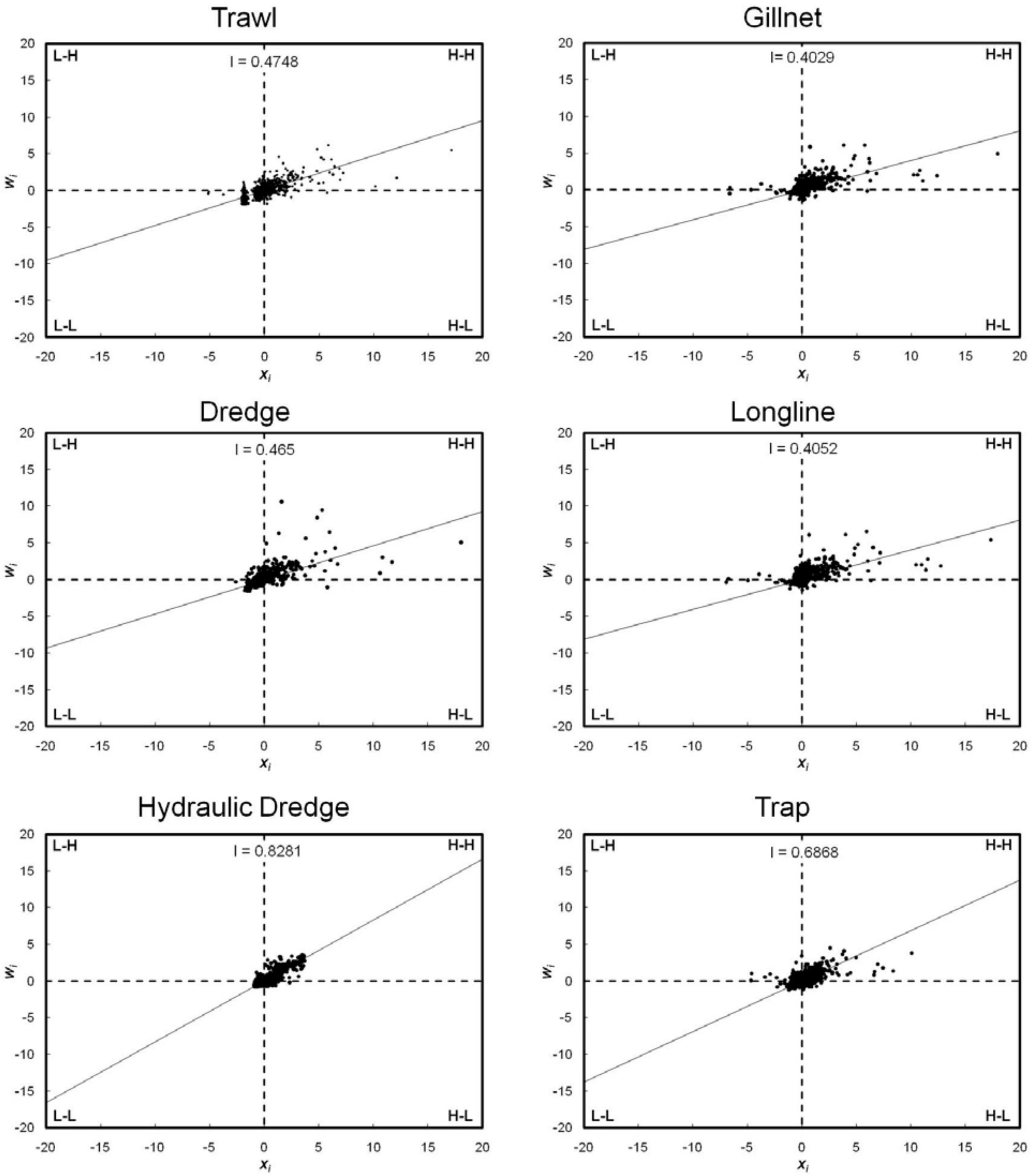
Asymptotic area swept (Z_∞) for all gear types demonstrated strong global spatial autocorrelation ($I > 0$, $p \leq 0.0001$, Table 1).

Table 73 - Global Morans *I* statistic and p-value for each gear type.

Gear	***Global Morans* I**	**p**
Trawl	0.4748	≤0.0001
Dredge	0.4650	≤0.0001
H. Dredge	0.8281	≤0.0001
Gillnet	0.4029	≤0.0001
Longline	0.4052	≤0.0001
Trap	0.6868	≤0.0001

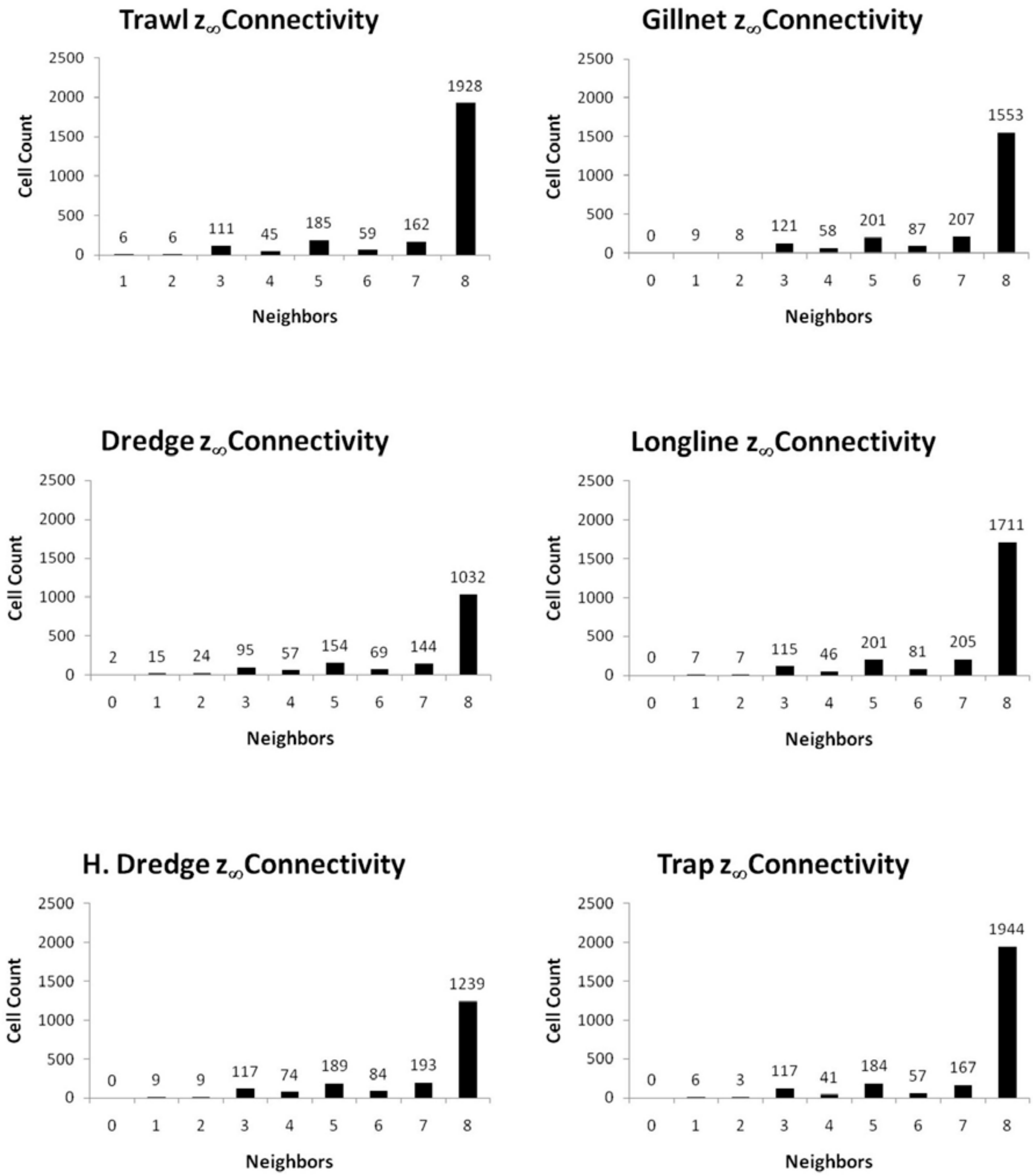
The Moran scatterplots show the degree of global spatial autocorrelation for each gear type and identify the quadrant location of every cell and neighborhood in the domain (Figure 19).

Figure 19 – Moran scatterplots for each gear type.



The different gear-specific depth limits used in SASI result in different connectivity between cells in the model (i.e. more or less edge). Reduced connectively (fewer neighbors) impacts cluster identification. The distribution of connections is similar between gear types and in all cases more than 60% of cells had 8 neighbors and 90% had at least 4 neighbors indicating that cluster identification is consistent between gear types (Figure 20).

Figure 20 – Connectivity histograms show the number of cells by number of neighbors for each gear type



The LISA analysis delimited clusters of high and low Z_∞ for all gear types at the $p \leq 0.1$, 0.05 and 0.01 levels. Using $p \leq 0.1$ criteria results in clusters which are nearly identical to $p \leq 0.05$ (11 additional cells, see Map 31) so only $p \leq 0.05$ and 0.01 results are presented in Map 32 and Map 33. Regardless of gear type, most of the cells in the model did not form significant clusters (Map 32). Where clustering occurrs, between 85 and 99% of cells are in Low-Low or High-High clusters consistent with strong spatial autocorrelation. Outliers (High-Low and Low-High) are rare. There are seven clusters identified for both trawls and scallop dredges which are larger than 300 km². These clusters correspond to named features (Table 74 and Table 75).

Table 74 – The name, mean z∞, sum z∞, and the area of each p ≤ 0.01 cluster greater than 300 km² identified for Trawl gear.

Trawl *p* ≤ 0.01

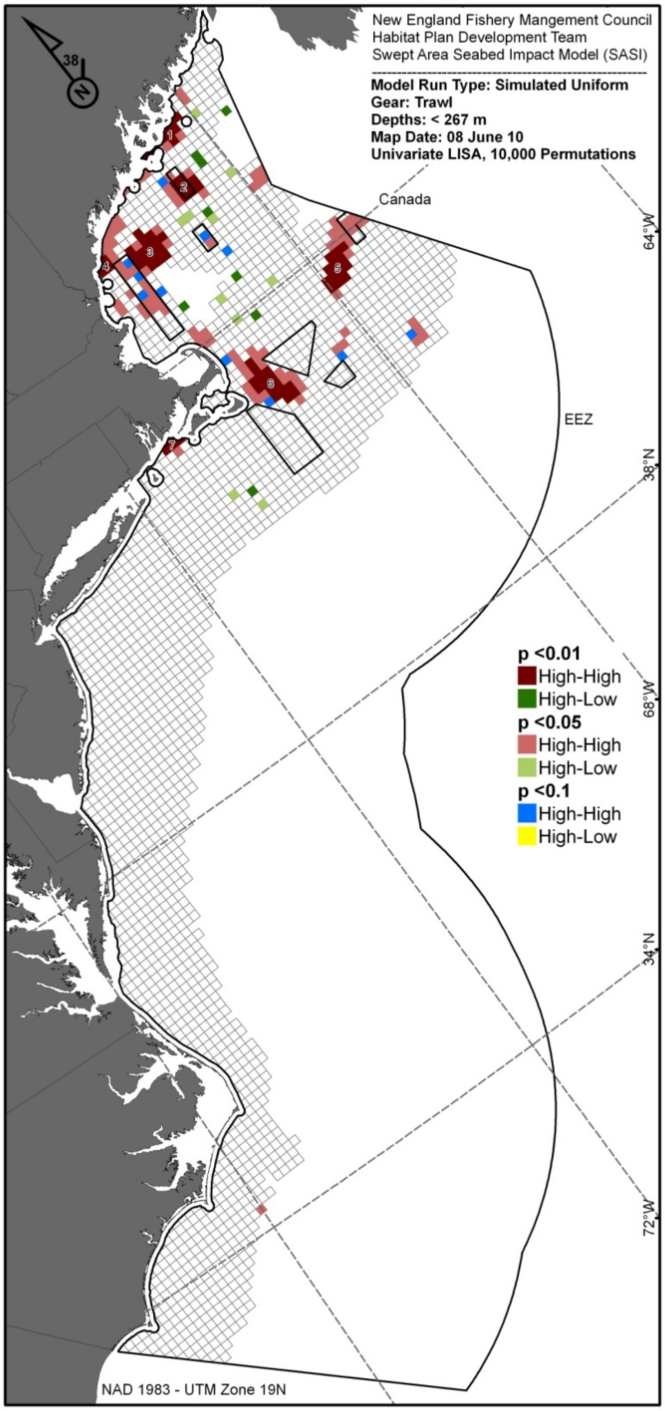
Number	Name	Mean z∞	Sum z∞	km²
1	South of Mt Desert Island Cluster	67.828	474.797	470
2	Jeffrey's Bank Cluster	60.898	487.185	800
3	Platts Bank Cluster	57.369	917.911	1600
4	Cape Neddick Cluster	51.416	154.247	283
5	Georges Shoal Cluster	57.404	746.251	1300
6	Great South Channel Cluster	55.580	833.696	1500
7	Brown's Ledge Cluster	55.785	223.138	273

Table 75 – The name, mean z∞, sum z∞, and the area of each p ≤ 0.01 cluster greater than 300 km² identified for Dredge gear.

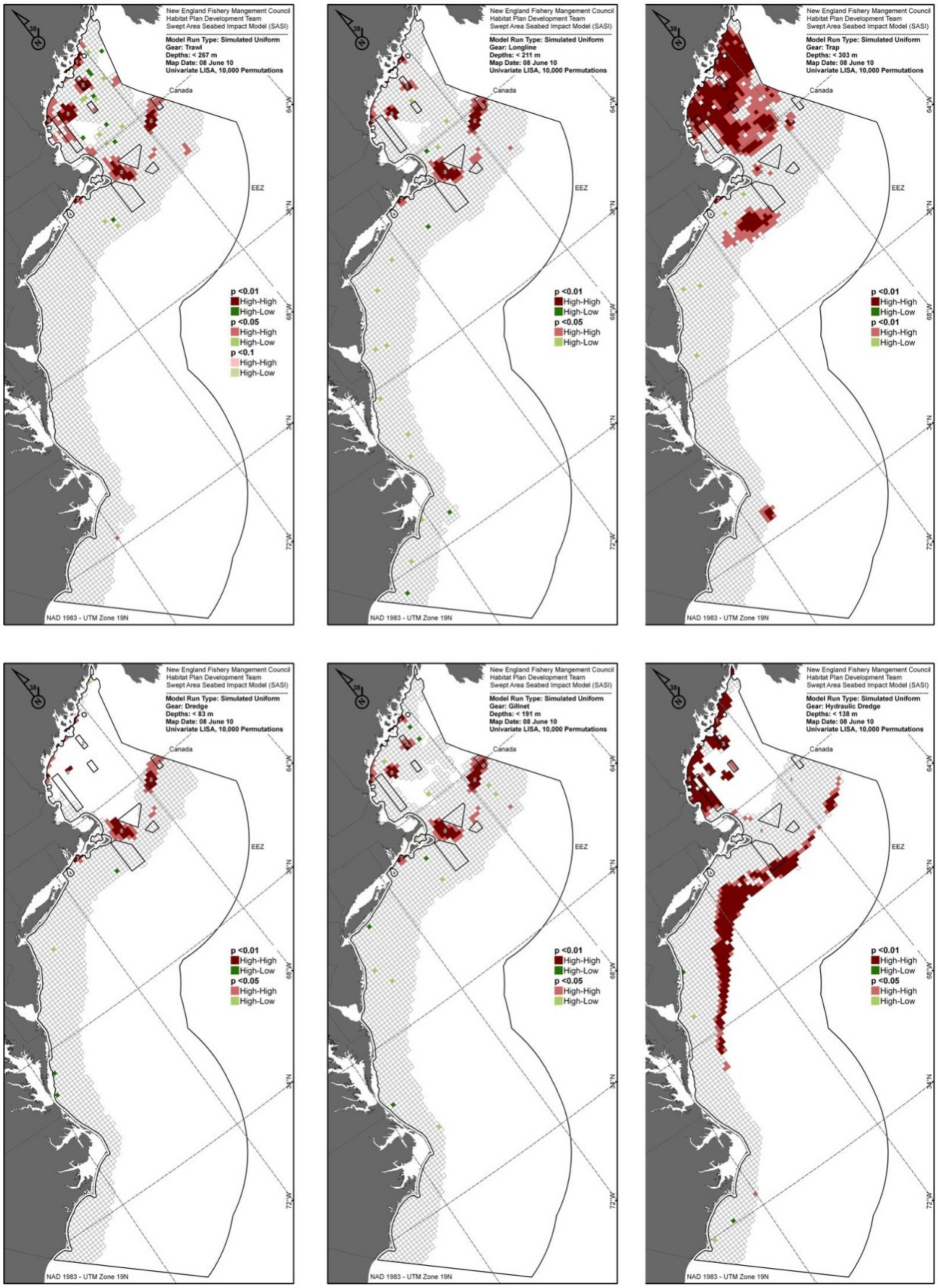
Dredge *p* ≤ 0.01

Cluster	Name	Mean z∞	Sum z∞	km²
1	South of Mt Desert Island Cluster	77.805	311.222	182
2	Jeffrey's Bank Cluster	-	-	-
3	Platts Bank Cluster	68.593	137.186	200
4	Cape Neddick Cluster	58.058	58.058	87
5	Georges Shoal Cluster	59.805	717.656	1200
6	Great South Channel Cluster	58.432	934.908	1600
7	Brown's Ledge Cluster	58.155	232.621	273

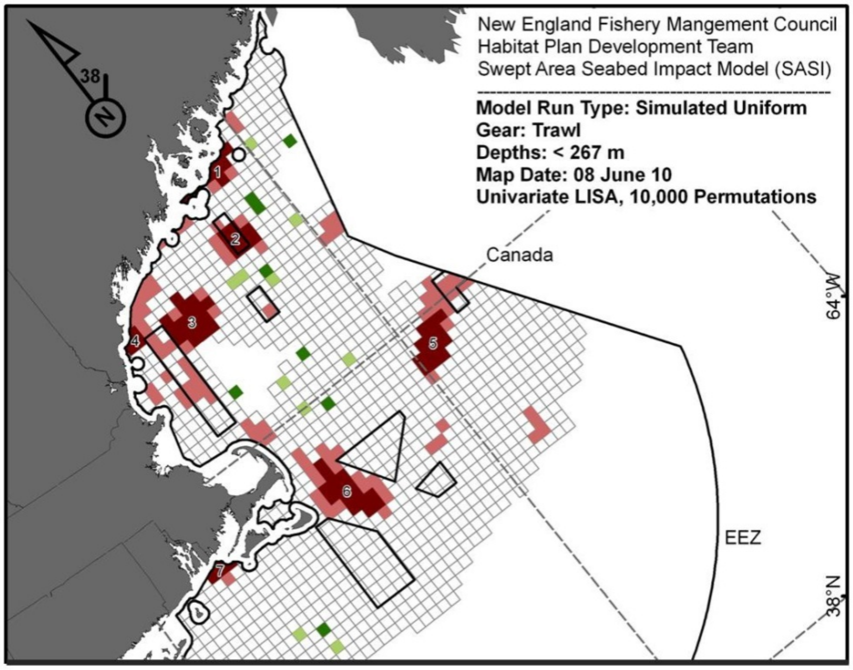
Map 31 – Maps of Z∞ H-H and H-L clusters defined by $p \leq 0.1$, 0.05 and 0.01 levels for otter trawl gear.

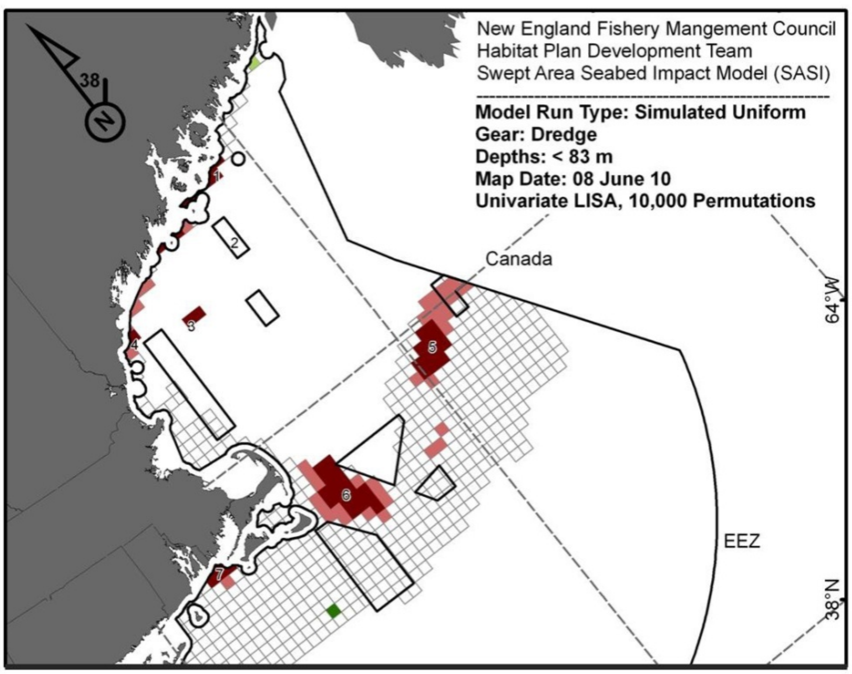


Map 32 – Maps of z_∞ HH and HL clusters defined by $p \leq 0.05$ and 0.01 levels for each gear type.



Map 33 – Maps of z_∞ HH and HL clusters defined by $p \leq 0.05$ and 0.01 levels for each trawl and scallop dredge gears.





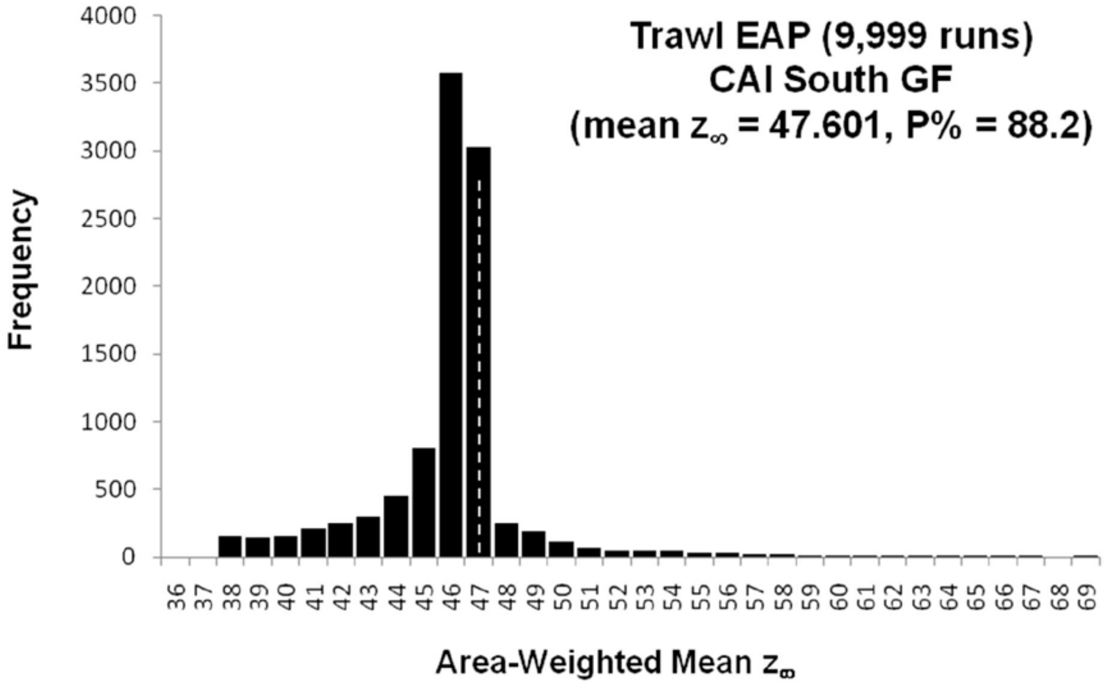
9.3 Z_∞ in present and proposed management areas (EAP)

Equal Area Permutation (EAP) tests are used to determine the levels of Z_∞ in present and proposed management areas relative to the model domain.

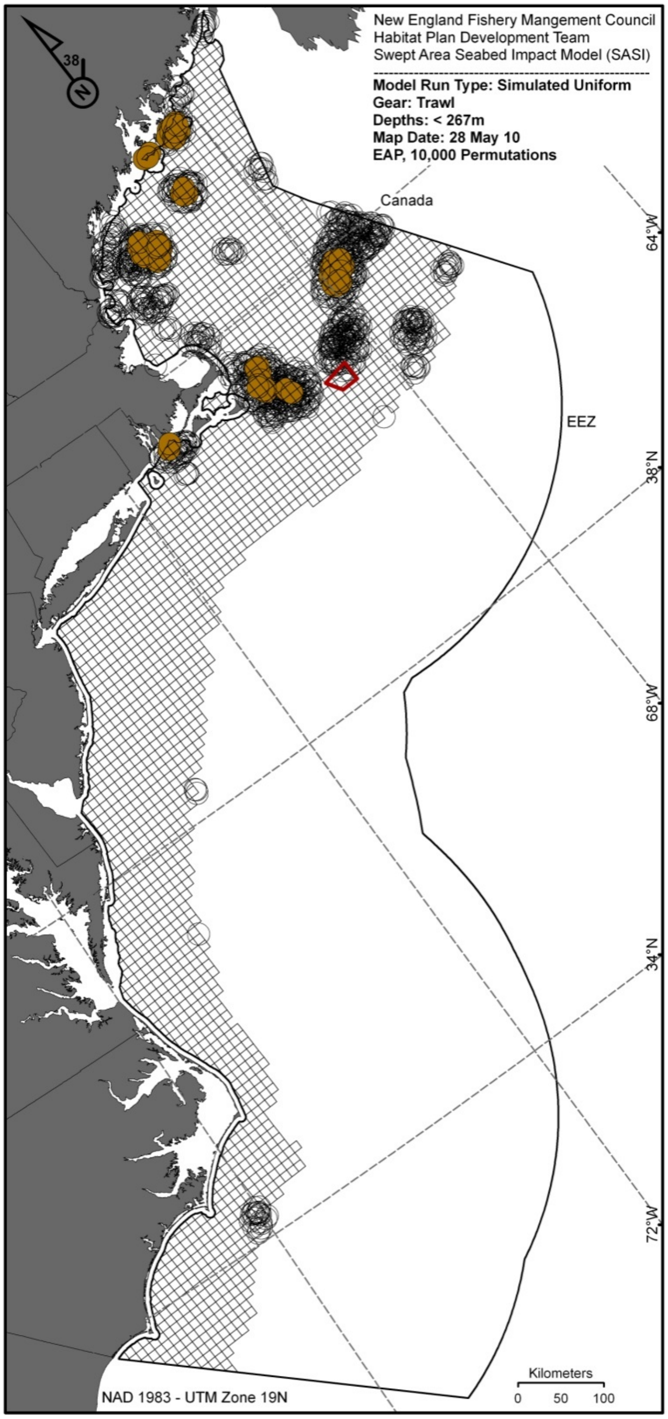
9.3.1 Methods

The area-weighted mean Z_∞ (

Figure 21 – Trawl EAP histogram for CAI South EFH Groundfish Closed Area indicating the position of the tested area in the EAP distribution (dashed line), the



Map 34 – Trawl EAP map for CAI South EFH Groundfish Closed Area. Open circles are permutation areas with



10.0 Practicability analysis

The objectives of the SASI Practicability/Opportunity Cost Analysis are to (1) understand and quantify the trade-offs inherent in the use of durable fishing gear restriction (closed) areas; and (2) define measurable thresholds for achieving the requirements to minimize adverse effects on habitat from fishing to the extent practicable, as specified in the Omnibus Amendment 2 Goals and Objectives.

10.1 Introduction

In a 2002 report entitled "Effects of Trawling and Dredging on Seafloor Habitat" (NRC 2002) the National Research Council outlined three primary tools available to fishery managers for minimizing the adverse effects from fishing on fish habitat as area closures, gear modifications and effort reductions. Large-scale, year-round area closures have been used by New England fishery managers for over fifteen years. Since 2004, these areas have also been used as a tool to minimize the adverse effects from fishing on habitat (NEFMC 2003a, 2003b). It is well recognized that both temporary and year-round fishing area closures result in effort displacement if they are not accompanied by commensurate catch or effort controls (Rijnsdorp et al. 2001, Dinmore et al. 2003). However, few studies have addressed the trade-off between habitat recovery in areas closed to fishing and the additional adverse effects of fishing in open areas. In the most pertinent and thorough such analysis, Hiddink et. al. (2006) looked specifically at the effects of area closure and effort control tools on the biomass, production, and species richness of benthic communities in the North Sea and concluded:

> *"If the areas closed to fishing have low levels of production because of high natural disturbance, and/or recover quickly after disturbance, then closure tends to have a negative effect, because trawling effort may redistribute to more productive habitats with longer recovery times. If the closed areas have high production in the absence of disturbance, and effort is displaced to areas where production is low, then closure is more beneficial."*

This section proposes a method for assessing the trade-off between recovery in areas closed to fishing and additional adverse effects resulting from fishing in the open areas. It also proposes a novel method for addressing the opposite: the potential change in aggreagate adverse effects from opening currently closed areas.

10.2 Methods

we simply construct a ratio estimator using the adverse effects from fishing (Z) and the profits derived from fishing (X). We call this the environmental impact coefficient, or *E.*

$$E = \frac{Z}{X} \ . \qquad (1)$$

Here *E* represents the domain-wide ratio of adverse effect to fishing vessel profits. Because of the granularity of the SASI model, however, it can be scaled down to the individual gear type (*i*) and parcel (p) level. Further, because Z is a time-dependant variable, a true estimate of the adverse effect of fishing requires summing all of the adverse effects from each individual fishing event across all years in which they are felt. This lifecycle estimate of adverse effect, its net stock (Z^{net}), is defined as

$$z^{net}{}_{ip} = \sum_{t=1}^{n} z_{ip} \ , \qquad (2)$$

where t is the duration, in years, of the adverse effect for each unit of fishing activity. The length of the adverse effect lifecycle for a given fishing event is directly related to the recovery times of the structural habitat features inferred to the substrate(s) found within the parcel being fished. Incorporating Z_{net} into equation (1) and indexing across gear types and parcels gives us

$$e_{ip} = \left(\frac{z^{net}}{x} \right)_{ip} \ , \qquad (3)$$

where x_{ip} is the profit ($) derived as a result of fishing by gear type i at parcel p. Profit (x) is calculated as the product of all revenues r and variable trip-level costs c across gear types i and parcels p as

$$x_{ip} = (r - c)_{ip} \ . \qquad (4)$$

Note that crew remuneration is not included in c, nor is the price of leasing either DAS or ACE in fisheries where such leases are available. Profit is not discounted over the duration of the adverse effect, as the monetary benefits of fishing are instantaneous.

Data

Z^{net} is parameterized using VTR data for actual fishing trips made by vessels fishing with any of the ten gear types used in the SASI model during the 1996-2009 timeframe. Table 1 shows the mean Z^{net} and trip length by gear type and year.

The x variable is composed of r, trip-level revenue, and c, trip-level costs. Trip-level revenues are generated using a combination of dealer reported-landings and, when dealer-level data are not available or incomplete, self-reported VTR data. Observer data are used to estimate two trip-level cost models, and these models are applied to the VTR in-domain point data used in the SASI model. The time frame for observer data collection is 2003-2009, whereas the time series for the SASI model is 1996-2009. This inconsistency is likely to induce bias, as trip-level costs (particularly fuel costs) may not be representative at the earlier years. VTR trips with no valid location data are deleted. All values are converted to 2007 dollars using the Bureau of Labor Statistics producer price index for unprocessed and packaged fish, series WPU0223.

Trip costs are sensitive to trip duration, and therefore separate cost models are estimated for trips less than 24 hours and for trips equal to or greater than 24 hours. Trip cost, the dependant variable, are the sum of the following costs: ice, food, fuel, intra-trip vessel or gear damage, miscellaneous supplies, water, oil and bait. Several model specifications and combinations of explanatory variables are explored. The final model specifications are presented in Table 2 and Table 3. Gillnet and longline are categorical variables representing the presence of that gear used on a trip; crew is a continuous variable representing the number of crew plus captain; ln_dur is the natural log of the total trip duration measured in hours; vhp2 is the vessel horsepower squared. Table 3 presents the annual sum of trip revenues, trip costs and profits by gear type.

Hydraulic clam dredge gear is, unfortunately, excluded from this analysis due to difficulties in computing trip-level revenue and insufficient observer data for generating a meaningful trip cost model.

Table 77 – Trip cost model with natural log of trip cost as dependant variable for trips less than 24 hours, Adj R^2 = 0.525 (OLS). Gillnet and longline are categorical variables representing the presence of that gear used on a trip; crew size is a continuous variable representing the number of crew plus captain; LN(duration) is the natural log of the total trip duration measured in hours.

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	2.90496	0.06213	46.75	<.0001
Gillnet	-0.57755	0.02764	-20.9	<.0001
Longline	0.24488	0.06531	3.75	0.0002
Crew size	0.32479	0.01631	19.92	<.0001
LN(duration)	0.86415	0.02679	32.26	<.0001

Table 78 – Trip cost model with natural log of trip cost as dependant variable for trips greater than or equal to 24 hours, Adj R^2 = 0.807 (OLS). Gillnet is a categorical variable representing the presence of that gear used on a trip; crew size is a continuous variable representing the number of crew plus captain; LN(duration) is the natural log of the total trip duration measured in hours; horsepower^2 is the vessel horsepower squared.

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1.8691	0.09207	20.3	<.0001
Horsepower2	1.81E-07	3.35E-08	5.41	<.0001
Gillnet	-0.76861	0.04381	-17.54	<.0001
Crew size	0.14529	0.01171	12.41	<.0001
LN(duration)	1.2594	0.02187	57.58	<.0001

Table 79 – Mean Z_{net} and trip length (days) by year and gear type. Short (< 24h) and long (≥ 24 hr) trips were combined to produce these averages.

	Generic otter trawl		Shrimp trawl		Squid trawl		Raised trawl	
Year	Z_{net}	**Trip length**	Z_{net}	**Trip length**	Z_{net}	**Trip length**	Z_{net}	**Trip length**
1996	-5.54	1.9	-1.34	0.55	-4.85	2.36	.	.
1997	-5	1.71	-1.41	0.6	-3.74	2.12	.	.
1998	-4.79	1.64	-1.35	0.55	-4.92	2.5	.	.
1999	-4.81	1.68	-1.3	0.57	-3.33	2.09	.	.
2000	-4.14	1.55	-1.32	0.51	-2.59	1.39	.	.
2001	-3.85	1.64	-1.16	0.5	-3.37	1.85	.	.
2002	-3.16	1.46	-1.25	0.61	-3.34	1.84	.	.
2003	-3.32	1.51	-1.09	0.47	-4.73	2.51	-1.03	0.96
2004	-3.18	1.45	-1.11	0.48	-3.84	2.07	-1.04	0.61
2005	-3.08	1.41	-1.07	0.49	-4.88	2.71	-0.78	0.56
2006	-3.13	1.43	-1.01	0.46	-4.11	2.18	-0.75	0.81
2007	-3.27	1.43	-1.12	0.5	-3.61	2.05	-0.76	0.54
2008	-3.09	1.36	-1.16	0.5	-3.79	2.02	-0.7	0.44
2009	-3.44	1.28	-1.13	0.45	-4.58	2.39	-0.87	0.46

	Limited access scallop dr		General category scallop dr		Longline		Gillnet	
Year	Z_{net}	**Trip length**	Z_{net}	**Trip length**	Z_{net}	**Trip length**	Z_{net}	**Trip length**
1996	-3.83	7.06	-0.1	0.44	-0.04	0.73	0	0.79
1997	-3.08	6.36	-0.12	0.45	-0.03	0.75	0	0.64
1998	-3.28	6.02	-0.13	0.46	-0.03	0.76	0	0.63
1999	-2.92	5.73	-0.13	0.46	-0.28	0.63	0	0.72
2000	-2.73	5.92	-0.17	0.53	-0.02	0.69	0	0.72
2001	-2.82	6.09	-0.18	0.55	-0.05	0.68	0	0.73
2002	-2.59	7.08	-0.18	0.54	-0.03	0.86	0	0.67
2003	-2.4	6.61	-0.16	0.56	-0.02	0.82	0	0.64
2004	-2.15	5.84	-0.15	0.59	-0.02	0.72	0	0.61
2005	-1.3	3.27	-0.16	0.61	-0.03	0.74	0	0.61
2006	-1.15	2.6	-0.19	0.67	-0.03	0.71	0	0.58
2007	-1.44	2.78	-0.18	0.67	-0.03	0.72	0	0.51
2008	-1.72	2.95	-0.17	0.64	-0.04	0.8	0	0.53
2009	-2.35	3.53	-0.16	0.59	-0.03	0.86	0	0.48

	Pots and traps	
Year	Z_{net}	**Trip length**
1996	-0.01	0.58
1997	-0.01	0.58
1998	-0.01	0.57
1999	-0.01	0.58
2000	-0.01	0.54
2001	-0.01	0.54
2002	-0.01	0.53
2003	-0.01	0.55
2004	-0.01	0.54
2005	-0.01	0.52
2006	-0.01	0.53
2007	-0.01	0.53
2008	-0.01	0.55
2009	-0.01	0.56

Table 80 – Average value, cost, and profit for all trips, and average trip duration (days) by year and gear type.

	Generic otter trawl				Shrimp trawl				Squid trawl			
Year	Trip value	Trip cost	Profit	Trip duration	Trip value	Trip cost	Profit	Trip duration	Trip value	Trip cost	Profit	Trip duration
1996	7,434	1,787	5,648	1.9	2,032	357	1,675	0.55	11,696	2,199	9,497	2.36
1997	6,951	1,569	5,381	1.71	1,687	387	1,300	0.6	9,048	1,874	7,174	2.12
1998	6,559	1,479	5,080	1.64	1,598	346	1,252	0.55	12,414	2,495	9,919	2.5
1999	6,757	1,533	5,225	1.68	1,246	347	899	0.57	8,815	2,026	6,789	2.09
2000	6,667	1,395	5,272	1.55	1,664	315	1,349	0.51	6,157	1,232	4,925	1.39
2001	7,104	1,485	5,619	1.64	943	309	634	0.5	7,726	1,704	6,021	1.85
2002	6,559	1,317	5,242	1.46	1,318	404	914	0.61	8,139	1,674	6,466	1.84
2003	6,935	1,365	5,570	1.51	1,296	289	1,006	0.47	12,132	2,394	9,738	2.51
2004	7,252	1,311	5,941	1.45	1,299	290	1,009	0.48	11,742	1,923	9,819	2.07
2005	6,297	1,266	5,031	1.41	1,153	291	862	0.49	17,315	2,722	14,594	2.71
2006	6,665	1,288	5,376	1.43	1,420	283	1,137	0.46	11,469	2,115	9,354	2.18
2007	6,358	1,306	5,053	1.43	1,447	322	1,125	0.5	10,069	2,084	7,985	2.05
2008	6,639	1,231	5,408	1.36	1,302	316	986	0.5	9,474	1,966	7,507	2.02
2009	6,388	1,155	5,234	1.28	1,231	290	940	0.45	14,255	2,310	11,946	2.39

	Raised footrope trawl				Limited Access scallop dredge				General Category scallop dredge			
Year	Trip value	Trip cost	Profit	Trip duration	Trip value	Trip cost	Profit	Trip duration	Trip value	Trip cost	Profit	Trip duration
1996	.	.	.	.	44,695	10,804	33,891	7.06	972	294	678	0.44
1997	.	.	.	.	38,452	9,399	29,053	6.36	1,074	281	793	0.45
1998	.	.	.	.	29,936	8,666	21,270	6.02	976	288	688	0.46
1999	.	.	.	.	47,359	8,265	39,095	5.73	1,231	294	936	0.46
2000	.	.	.	.	57,423	8,725	48,698	5.92	1,643	454	1,189	0.53
2001	.	.	.	.	56,322	8,989	47,333	6.09	1,712	438	1,274	0.55
2002	.	.	.	.	62,417	10,546	51,872	7.08	1,753	392	1,361	0.54
2003	3,139	791	2,349	0.96	61,867	9,617	52,250	6.61	1,884	390	1,494	0.56
2004	2,253	383	1,870	0.61	67,458	8,153	59,305	5.84	2,337	441	1,897	0.59
2005	2,112	454	1,658	0.56	42,911	4,129	38,782	3.27	3,008	479	2,529	0.61
2006	2,932	661	2,270	0.81	24,753	3,043	21,710	2.6	2,343	493	1,850	0.67
2007	2,123	381	1,742	0.54	26,566	3,338	23,228	2.78	2,343	497	1,846	0.67
2008	1,979	343	1,636	0.44	32,499	3,729	28,770	2.95	2,444	471	1,973	0.64
2009	2,072	358	1,714	0.46	41,260	4,695	36,565	3.53	2,636	458	2,178	0.59

	Longline				Gillnet				Pots and traps			
Year	**Trip value**	**Trip cost**	**Profit**	**Trip duration**	**Trip value**	**Trip cost**	**Profit**	**Trip duration**	**Trip value**	**Trip cost**	**Profit**	**Trip duration**
1996	2,725	592	2,133	0.73	2,792	320	2,473	0.79	2,342	432	1,911	0.58
1997	2,641	640	2,001	0.75	2,609	263	2,346	0.64	2,086	418	1,668	0.58
1998	2,711	645	2,065	0.76	2,670	253	2,417	0.63	1,865	409	1,456	0.57
1999	2,737	463	2,274	0.63	3,293	282	3,010	0.72	2,232	416	1,816	0.58
2000	2,452	517	1,935	0.69	3,068	265	2,803	0.72	2,189	372	1,817	0.54
2001	2,719	484	2,235	0.68	2,937	265	2,672	0.73	1,948	376	1,572	0.54
2002	3,057	625	2,432	0.86	3,015	244	2,771	0.67	2,008	372	1,636	0.53
2003	2,885	621	2,265	0.82	2,813	239	2,575	0.64	2,112	390	1,722	0.55
2004	4,061	584	3,477	0.72	2,558	228	2,331	0.61	1,982	381	1,601	0.54
2005	3,884	564	3,320	0.74	2,791	221	2,570	0.61	2,086	371	1,715	0.52
2006	2,985	546	2,440	0.71	2,545	216	2,328	0.58	1,971	362	1,608	0.53
2007	3,057	627	2,430	0.72	2,408	196	2,213	0.51	1,813	366	1,447	0.53
2008	2,787	654	2,133	0.8	2,343	201	2,142	0.53	1,834	381	1,453	0.55
2009	3,006	684	2,322	0.86	1,963	185	1,779	0.48	1,812	395	1,417	0.56

10.3 Results

To summarize the relationship between costs and benefits for each gear type, *e* is calculated as the unweighted mean value across all years and all parcels (grid cells, Table 5). This estimate includes only parcels with three or more trips per year and with three or more years of data. The reported standard deviation applies to *e* at the parcel level across time—relatively lower standard deviations (such as the raised footrope, squid and shrimp trawls) indicate fisheries with similar *e* coefficients within the same parcel across time, and higher standard deviations (such as gillnets and longlines) represent higher inter-annual variability.

In Table 5, the *e* coefficient may accurately be interpreted as the quality-adjusted area swept, in square kilometers, that results from the generation of $1,000 of gross profit at the individual trip level. The number of grid cells meeting the requirement of three or more trips in a year and three or more years in the dataset are noted.

The rank order and magnitude of the adverse effect generated per dollar provide a useful approach to understanding the impacts of various fishing gears on structural habitat. Here we can see that fixed gears are much more efficient, in terms of adverse effect, at generating fishing profits than mobile gears. Even within those classes there is variation—trawls generate an order of magnitude greater adverse effect per unit of fishing profit than scallop dredges; gillnets and pots and traps similarly generate less adverse effect per unit profit than longlines.

Table 81 – Unweighted mean *e* across all included grid cells and years, by gear type

Gear	*# grid cells*	*Mean e*	*Stddev e*
Generic otter trawl	1271	5.00	8.30
Shrimp trawl	96	8.10	11.73
Squid trawl	195	2.82	3.69
Raised footrope trawl	5	1.48	1.71
Limited Access scallop dredge	446	0.64	1.05
General Category scallop dredge	215	0.68	1.09
Demersal longline	110	0.11	0.26
Sink gillnet	688	0.03	0.08
Trap gear	601	0.04	0.07

Impacts analysis methods for closure removal options

It must be noted from the beginning that attempts to assess changes in the spatial distribution of fishing due to area-based regulatory change is extremely difficult. In the Northeast region we have used two models with relative success—the Closed Area model (CAM) for assessing impacts in the groundfish fishery and the SAMS model in the scallop fishery. Unfortunately, the large size and high level of granularity found in the SASI model does not present an easy path for the integration of those two models, though we believe that with some work the SAMS model would be an ideal basis for predicting changes in adverse effect that may result from changes in spatial management.

Site choice models, which predict where fishing vessels will re-distribute their fishing effort after closures or openings based on expected profits, are commonly used for these types of analyses. Unfortunately, they have only been successfully utilized to predict effort redistribution across much lower levels of granularity—on the order of 10 to 50 sites, rather than the 200-1,000 sites with active fishing in the SASI model. They are also extremely complicated models that take years to develop. A fully parameterized and operational site choice model covering all areas and gear types assessed within the SASI framework would certainly be valuable at this phase of analysis, but such a model is unavailable.

To allow the Council and public adequate consideration of the potential impacts of changes in spatial management regulations, we utilize the basic mechanics of SASI to demonstrate whether the proposed spatial regulation will result in GREATER or LESSER adverse effects, holding other inputs constant.

The problems basic questions to be addressed in modeling these effects are:
(1) How much different will adverse effects be in the areas potentially being opened?
(2) How much different will catch rates be?
(3) How much effort will flow into these areas?

We have little empirical data (SAPs and rotational management areas) upon which to base cost (adverse effects) and benefit (profits) estimates on. As a first approximation, we base our estimates on the potential profits and adverse effects from parcels that are proximate to and potentially representative of the profits and adverse effects likely to be observed within the opened area if fishing were allowed. These estimates are then propagated to the newly fishable areas. Eleven separate regions are selected as sub-sets of existing habitat and year-round management closures: Closed Area 1 east, north and west; Closed Area 2 south, central and north; Nantucket Lightship east and west; Cashes; Jeffries; and the Western Gulf of Maine. The figures below show which cells are used in our fished and unfished scheme. Note that individual grid cells may be coded as both fished and unfished, and unfished cells overlay the fished. Therefore, not all unfished cells are visible in these figures.

To answer question (1) above, we compare Z_{inf} estimates from the fishable areas with estimates from their matched unfished areas. Table 82 provides the difference between similar fished and unfished areas in percentage terms. These percentages are then used to scale up or down the Z^{net} estimates for the unfished areas found inside current closures.

For question (2), we begin with the assumption that catch rates and therefore profits for all fisheries will be higher than they are in the proximate similar areas, though we are unsure of how much higher they may be. To model this, we apply a factor ranging from 1 to 1.5 times observed proximate profits and iterate the model stochastically. For scallop dredge gears, where catch rates inside area closures are known to be significantly higher than 1.5 times proximate outside areas, we apply a factor that ranges from 1 to 4 times observed proximate profits.

Because we have no economic or behavioral model upon which to base the *amount* of effort likely to flow into a newly opened area, we use a similar stochastic estimation method. Effort flowing into newly opened areas is likely to be similar in distribution to the observed effort in proximate currently opened areas, and linearly related in magnitude. We therefore use observed profits in these areas as a basis for estimating profits derived from newly opened areas. To do this, we apply a range of between 1 and 5 times the observed proximate open-area profits to the newly opened areas. All profits flowing into these newly open areas are subtracted uniformly from the observed profits over the entire domain; profits are then held constant, and changes in resulting Z^{net} are reported.

Data from all years 1996-2009 are averaged to construct the profit and Z^{net} estimates for each parcel. Each of the eleven potential open areas is assess individually. Due to computing power limitations at the NEFSC, only 15 iterations of the stochastic model are performed.

Figure 22 – Closed Area 1 fished and unfished parcels

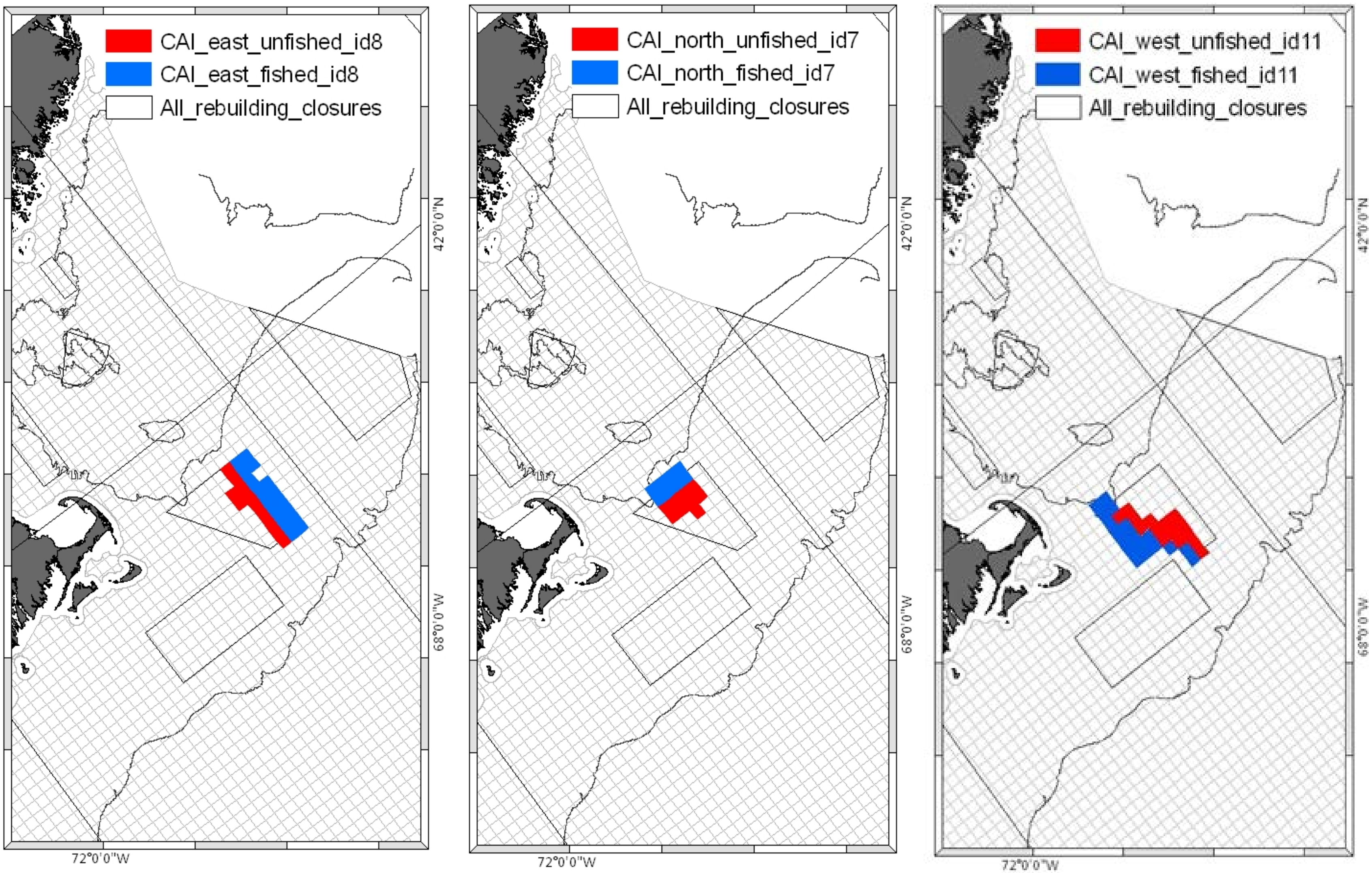


Figure 23 – Closed Area 2 fished and unfished parcels

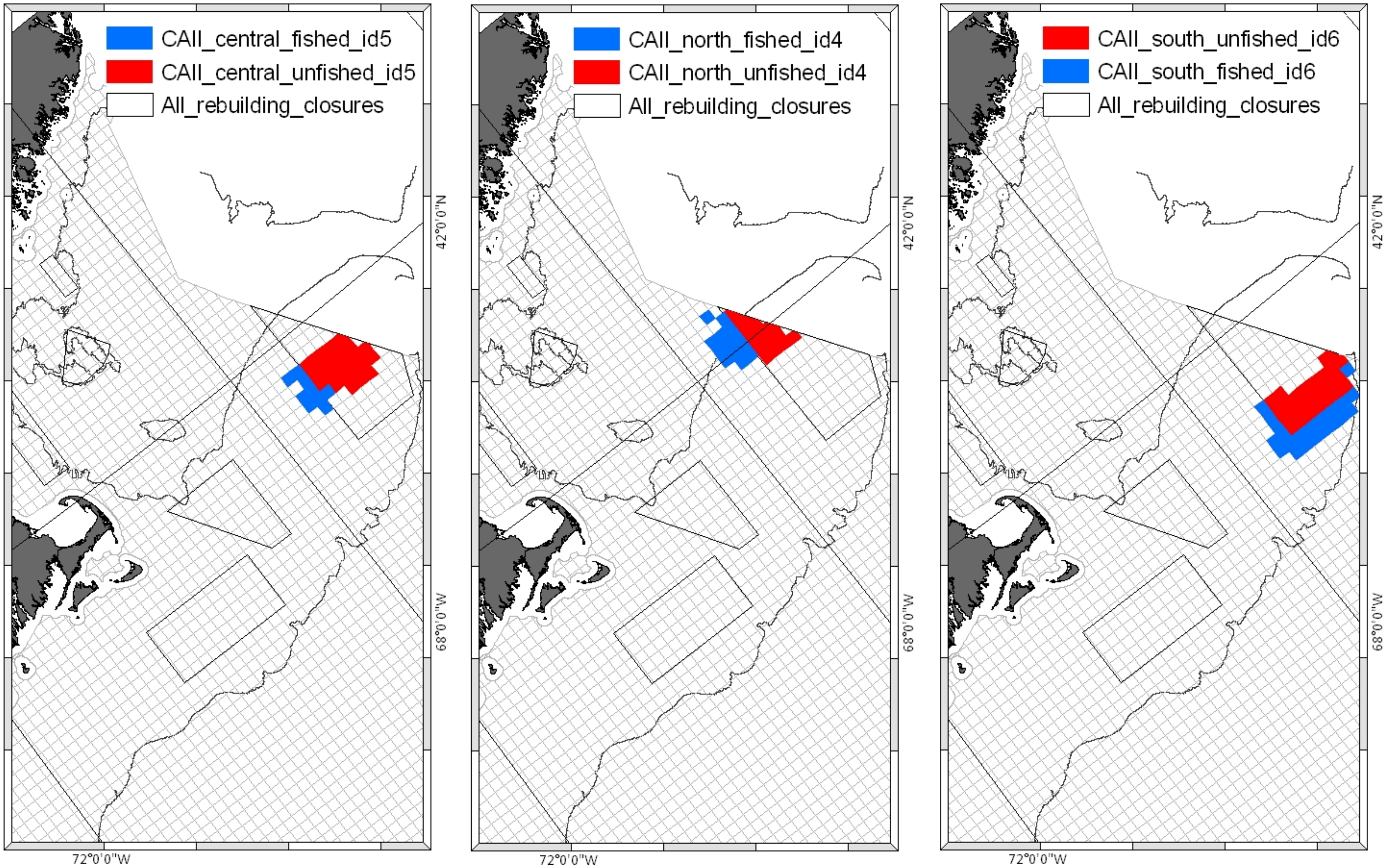


Figure 24 – Nantucket Lightship Closed Area fished and unfished parcels

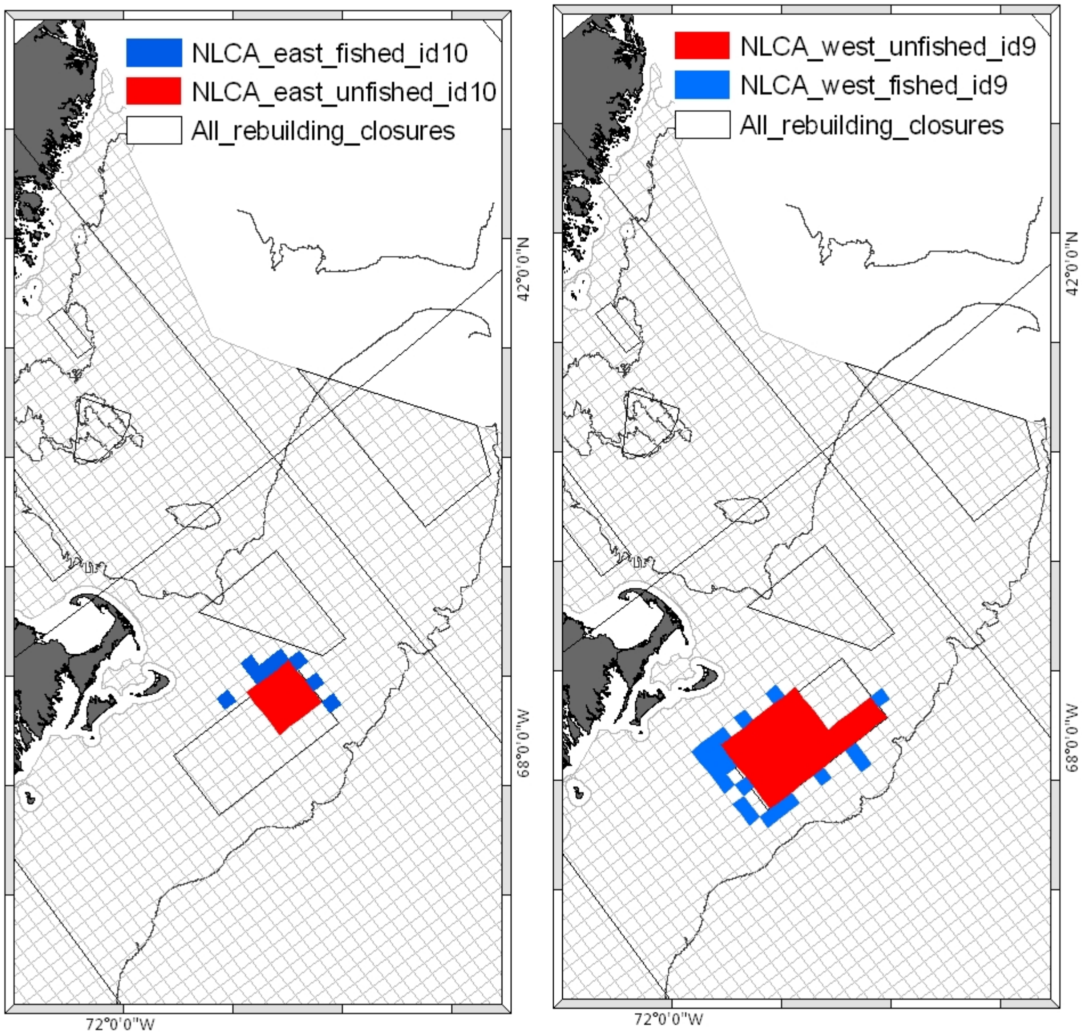


Figure 25 – Western Gulf of Maine Closed Area, Cashes Closed Area and Jeffries Bank Closed Area

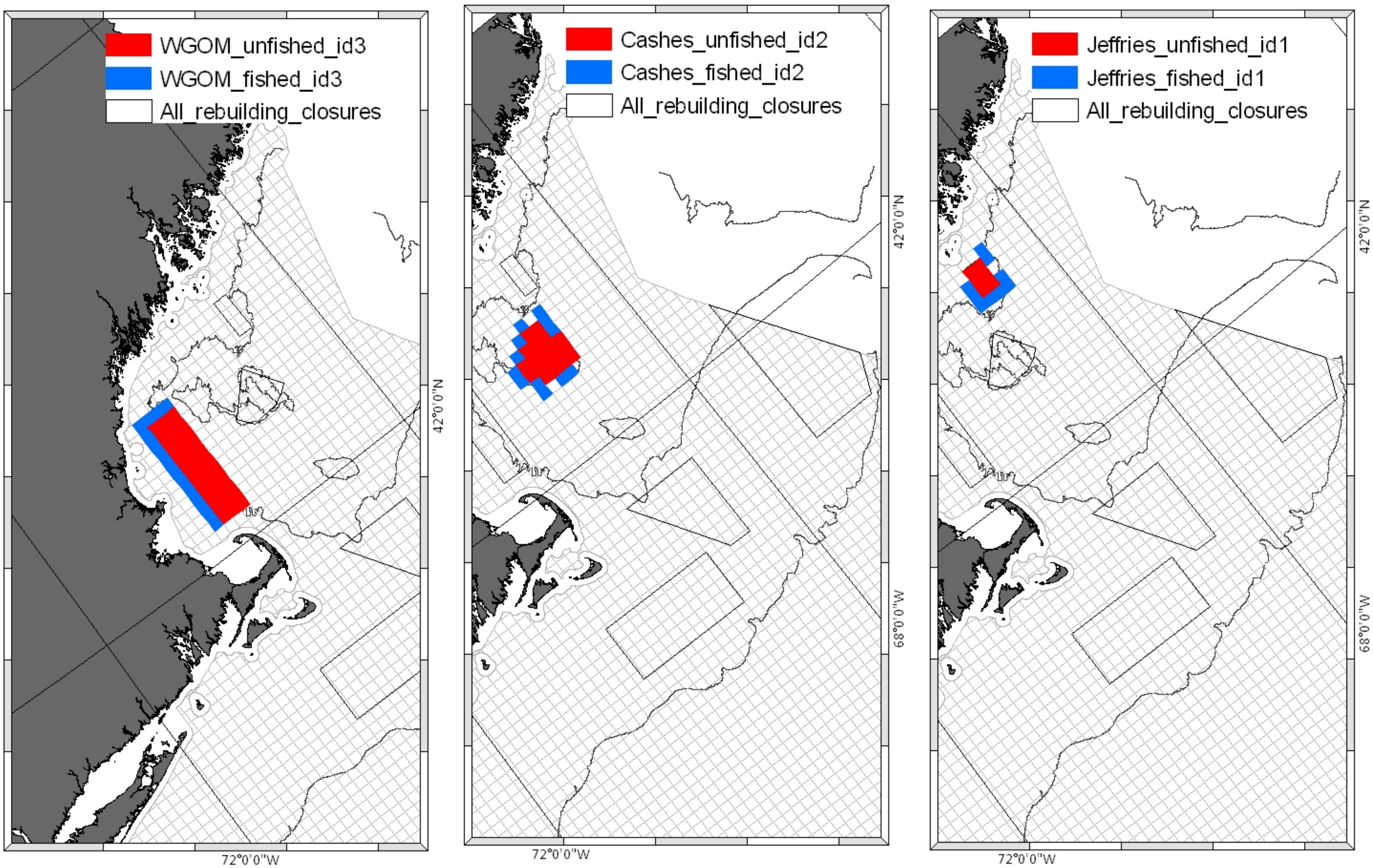


Table 82 – Z_inf, percent difference between fished and unfished parcels, by gear type

Average pct_z_inf_difference										
Row Labels	**GC Scal Dr**	**Gillnet**	**Hydaulic Dr**	**LA Scal Dr**	**Longline**	**Otter trawl**	**Pot/Trap**	**Raised trawl**	**Shrimp trawl**	**Squid trawl**
Cashes	-1.62%	-1.01%	0.93%	-1.62%	-0.83%	-3.56%	0.25%	-3.56%	-3.56%	-3.56%
Closed Area 1 East	-2.94%	-3.76%	-2.25%	-2.94%	-4.68%	0.16%	-2.99%	0.16%	0.16%	0.16%
Closed Area 1 North	3.17%	0.96%	9.68%	3.17%	1.15%	4.83%	2.82%	4.83%	4.83%	4.83%
Closed Area 1 West	4.48%	3.84%	1.63%	4.48%	3.97%	5.35%	3.28%	5.35%	5.35%	5.35%
Closed Area 2 Central	-0.87%	0.59%	1.38%	-0.87%	-0.02%	-0.67%	-0.60%	-0.67%	-0.67%	-0.67%
Closed Area 2 North	3.77%	1.56%	7.28%	3.77%	1.44%	4.65%	3.75%	4.65%	4.65%	4.65%
Closed Area 2 South	1.96%	1.12%	7.22%	1.96%	1.53%	2.05%	1.28%	2.05%	2.05%	2.05%
Jeffries	2.85%	5.05%	-6.81%	2.85%	4.98%	3.25%	7.29%	3.25%	3.25%	3.25%
NLCA East	4.21%	3.47%	1.87%	4.21%	3.93%	11.80%	3.18%	11.80%	11.80%	11.80%
NLCA West	-3.26%	0.11%	0.03%	-3.26%	-0.17%	-2.01%	5.14%	-2.01%	-2.01%	-2.01%
WGOM	-3.97%	-1.39%	-2.59%	-3.97%	-1.27%	-2.30%	0.11%	-2.30%	-2.30%	-2.30%

Summary results for closure removal options

This model estimates the potential change in adverse effects from fishing on fish habitat after a regulatory fishing area opening. The point of the analysis is to demonstrate whether or not aggregate adverse effects would increase or decrease after an area opening, given existing profit-to-adverse effect relationships in the vicinity of the potential opening and reasonable assumptions about how those relationships would translate onto newly opened fishing grounds.

We find that for nearly all area and gear type combinations, opening existing closed areas to fishing is predicted to decrease aggregate adverse effects. For mobile bottom tending gears, which comprise nearly 99% of all adverse effects in our region, allowing fishing in almost any portion of the area closures on Georges Bank is estimated to substantially decrease total adverse effects from fishing. Closures in the Gulf of Maine appear to also decrease aggregate adverse effects, but the magnitude of these reductions is substantially smaller.

The parameters used to estimate both catch rate and total effort increases for potential fishing inside closed areas may easily be adjusted either up or down based on feedback from the Committee and public, and additional time may allow for calibration of these parameters based on empirical data from special access programs, etc. So long as there is agreement that, if areas are opened, catch rates and effort levels for most fisheries are likely to be higher inside these areas than outside, the direction of change in aggregate adverse effect for these various opening scenarios will not change. Summary results presented below rely on two sets of assumptions for a HIGH and LOW estimate:

High:

- Catch rates increase btwn 0 and 50%
- Effort inside is multiple of btwn 1 and 5 of the proximate outside effort

Low:

- Catch rates increase btwn 0 and 25%
- Effort inside is multiple of btwn 1 and 2 of the proximate outside effort

Table 83 – Percent change in total Z_net after independent opening of each closure

Unfished area	Total Z_net = 158,882	*High estimate* Change in total after single-area opening	*% change*	*Low estimate* Change in total after single-area opening	*% change*
Cashes		**(5,183)**	***-8.8%***	**(420)**	***-2.2%***
Closed Area 1 East		**(5,510)**	***-4.1%***	**(1,315)**	***-1.6%***
Closed Area 1 North		**(3,000)**	***-2.3%***	**(245)**	***-1.5%***
Closed Area 1 West		**(6,248)**	***-7.0%***	**(1,303)**	***-2.3%***
Closed Area 2 Central		**(7,734)**	***-2.2%***	**(907)**	***-0.7%***
Closed Area 2 North		**(4,247)**	***-11.3%***	**319**	***-3.7%***
Closed Area 2 South		**(6,530)**	***-1.6%***	**(2,091)**	***-0.8%***
Jeffries		**(278)**	***-0.5%***	**129**	***0.1%***
NLCA East		**(4,265)**	***-5.6%***	**(1,030)**	***-2.2%***
NLCA West		**(3,902)**	***-5.4%***	**1,311**	***-1.6%***
WGOM		**(1,446)**	***-6.6%***	**599**	***-0.2%***

Impacts analysis methods for additional closure options

Similar to the methods used for estimating the potential impacts of regulatory openings of fishing areas, we use Z^{net} and e to estimate the potential changes in adverse effects resulting from closing additional areas to fishing.

To more accurately reflect current fishing practices we use parcel level mean profit and Z^{net} data from 2007 – 2009 only. For each closure scenario, we simply sum the amount of profit and Z^{net} that is found inside the proposed closure area, redistribute the 'missing' profits proportional to the observed spatial distribution of fishing effort, assign the corresponding Z^{net} estimate to the profits now generated outside the proposed area closure, and calculate the change in aggregate Z^{net}. Unlike the area opening analysis, no assumptions are made here regarding catch rates and profits for the redistributed fishing effort post-closure. Redistributed fishing effort will almost always result in lower profits and proportionally higher Z^{net}, and for this reason the estimates provided in this analysis are highly likely to overstate reductions in aggregate Z^{net}.

Data for only the George's Bank and Gulf of Maine regions are used to better reflect where displaced effort will likely fish. We focused our efforts for these analyses on the two most affected gear types – generic otter trawl and limited access scallop dredge.

Summary results for additional closure options

Area closure options for Cluster's 5 and 6 appear to potentially affect between $5-7.5 million of profits for these two gear types, representing less than 5% of their total aggregate profits from the Georges Bank and Gulf of Maine regions (see "profit at risk" in the tables below). However, the redistribution of these profits is estimated to have relatively minimal effects on aggregate Z^{net}. As with all adverse effects options, the largest net gains are to be had by regulating the otter trawl gear type, with Z^{net} reductions on the order of 1,000 km² for Cluster's 5 and 6. Closure of Cluster 5 is estimated to slightly increase adverse effects for the limited entry scallop dredge fishery. Cluster 7 is estimated to have the smallest impact, both on industry profits and adverse effects minimization.

Table 84 – Closure option for Cluster 5 (Georges Shoal), change in Z^{net} (2007-2009 VTR, profits in 1,000 dollars)

	pre_closure_ profit	profit_at_ risk	pre_closure_ z_net	closure_ z_net	*% reduction z_net*
Otter trawl	$ 57,076	$ 2,921	37,816	36,946	*2.3%*
LA Scal dr	$ 105,998	$ 4,483	6,526	6,592	*-1.0%*

Table 85 – Closure option for Cluster 6 (Great South Channel), change in Z^{net} (2007-2009 VTR, profits in 1,000 dollars)

	pre_closure_ profit	profit_at_ risk	pre_closure_ z_net	closure_ z_net	*% reduction z_net*
Otter trawl	$ 57,076	$ 1,996	37,816	36,695	*3.0%*
LA Scal dr	$ 105,998	$ 3,048	6,526	6,071	*7.0%*

Table 86 – Closure option for Cluster 7 (Brown's Ledge), change in Z^{net} (2007-2009 VTR, profits in 1,000 dollars)

	pre_closure_ profit	profit_at_ risk	pre_closure_ z_net	closure_ z_net	*% reduction z_net*
Otter trawl	$ 57,076	$ 310	37,816	37,862	*-0.1%*
LA Scal dr	$ 105,998	$ -	6,526	6,526	*0.0%*

11.0 Application of SASI results to fishery management decision making

The SASI model is intended to provide an objective and data-driven framework for evaluating fishery management decisions designed to minimize, to the extent practicable, the adverse effects of fishing on fish habitat.

The Council is required to minimize the adverse effects of fishing on EFH to the extent practicable. The MSA defines adverse effects as

"…any impact that reduces quality and/or quantity of EFH. Adverse effects may include direct or indirect physical, chemical, or biological alterations of the waters or substrate and loss of, or injury to, benthic organisms, prey species and their habitat, and other ecosystem components, if such modifications reduce the quality and/or quantity of EFH. Adverse effects to EFH may result from actions occurring within EFH or outside of EFH and may include site-specific or habitat-wide impacts, including individual, cumulative, or synergistic consequences of actions."

According to the EFH final rule, the threshold to determine whether effects are adverse is if the impact is "more than minimal and not temporary in nature". Specifically:

"Temporary impacts are those that are limited in duration and that allow the particular environment to recover without measurable impact. Minimal impacts are those that may result in relatively small changes in the affected environment and insignificant changes in ecological functions (EFH Final Rule)."

In order to minimize adverse effects, Councils must evaluate the potential adverse effects of current and proposed fishery management measures on EFH, considering.

"…the effects of each fishing activity on each type of habitat found within EFH. FMPs must describe each fishing activity, review and discuss all available relevant information (such as information regarding the intensity, extent, and frequency of any adverse effect on EFH; the type of habitat within EFH that may be affected adversely; and the habitat functions that may be disturbed), and provide conclusions regarding whether and how each fishing activity adversely affects EFH. The evaluation should also consider the cumulative effects of multiple fishing activities on EFH (EFH Final Rule)."

The EFH final rule outlines the types of management measures that might be proposed (see also NRC 2002):

- "Fishing equipment restrictions. These options may include, but are not limited to: seasonal and areal restrictions on the use of specified equipment, equipment modifications to allow escapement of particular species or particular life stages (e.g., juveniles), prohibitions on the use of explosives and chemicals, prohibitions on anchoring or setting equipment in sensitive areas, and prohibitions on fishing activities that cause significant damage to EFH.

- Time/area closures. These actions may include, but are not limited to: closing areas to all fishing or specific equipment types during spawning, migration, foraging, and nursery activities and designating zones for use as marine protected areas to limit adverse effects of fishing practices on certain vulnerable or rare areas/species/ life stages, such as those areas designated as habitat areas of particular concern.
- Harvest limits. These actions may include, but are not limited to, limits on the take of species that provide structural habitat for other species assemblages or communities and limits on the take of prey species."

Measures adopted to date by NEFMC are consistent with this guidance, and include:

- gear restrictions, including the inshore Gulf of Maine roller gear restriction;
- establishment of habitat closed areas in the multispecies and scallop FMPs;
- establishment of groundfish mortality closed areas (with associated gear restrictions), which are assumed to provide incidental benefits to EFH; and
- reductions in area swept over time (via reductions in effort and/or increased use of rotational management that provides for the same or greater harvest with less area swept).

Note that the Vulnerability Assessment estimates the susceptibility of habitats (at the feature level) to fishing gears, and the duration of the recovery period following impact. Impacts to both geological and biological structure-forming seabed features are considered. Thus, the Vulnerability Assessment, independent of the SASI model, can aid the Council in identifying habitat/gear combinations that are more susceptible and/or recover more slowly.

By combining vulnerability information with either realized or simulated fishing area swept, spatial overlap between vulnerable habitats and gear types may be assessed. Although SASI outputs are on a gear-by-gear basis, they can be evaluated synergistically for all bottom tending gear types if desired because seabed impact is expressed in like terms (i.e. km^2 area swept) for all gears.

Two fishing effort surfaces are modeled using SASI – simulated fishing effort, in which area swept for each gear type is applied evenly across grid cells, and realized fishing effort, which represents the past distribution and magnitude of area swept for the gear types across the model domain. For analyzing the impacts of management alternatives, a projected fishing effort surface could be applied to the model, allowing for comparisons between a no action alternative and any alternatives included for analysis. Such an effort surface could be thought of as a hybrid of the realized and simulated effort surfaces.

Evenly distributed simulated area swept model runs are useful for identifying areas within the domain that are likely to be vulnerable to adverse effects from particular gear types. Vulnerable areas are those in which the adverse effects of fishing gear area swept are likely to accumulate over time, due to a combination of higher susceptibility of present features to gears, slower recovery of the functional value of those features.

SASI results for different gear types can be compared in order to evaluate the benefits and costs of restricting fishing in particular areas for one or more gear types. Because SASI is based on an annual time step, model outputs are not useful for considering seasonal closures. Status quo habitat closed areas can be evaluated by considering whether adverse effects accumulate in those areas to a greater degree than across the portions of the model domain as a whole.

Additional information including the realized distribution of adverse effects, the magnitude of catches/revenues, bycatch considerations, presence of spawing areas, etc., may be incorporated to assess the practicability of existing or proposed management alternatives.

Another way in which SASI can be used is to model the difference in contact-adjusted (A) and vulnerability-adjusted (Z) area swept given a change in the assumptions about gear contact with the seabed. For example, if a new type of otter trawl with reduced bottom contact is developed, the model can estimate the resulting difference in Z by specifying a new contact index appropriate trawl component. Similarly, analyzing a roller gear restriction is possible by making the assumption that such a restriction would result in vessels no longer being able to fish in a particular substrate-dominated habitat (such as boulder-dominated), and calculating the resulting Z estimate after excluding that habitat from the model.

12.0 Estimating the vulnerability of features not in the SASI model

Ideally, the SASI model would spatially resolve fishing effects (and perhaps even non-fishing impacts) across all habitat components. Data limitations preclude such a comprehensive approach. In particular, coldwater deep sea corals and the prey of managed fish species, while important components of fish habitat that are potentially affected by fishing gears, have too little empircaly data to be considered within the SASI framework. Specifically, spatial data sufficient for the assignment of deep-sea coral and prey features to each combination of substrate and energy regime do not exist at sufficient resolution throughout the model domain.

After evaluating available data, the PDT selected a model framework (i.e. the matrix-driven geo-referenced model) which is easily adapted to new spatial information, and constructed a working model grid using geological samples—the only data source available throughout the assessment domain. This grid is refined using depth and model derived benthic boundary stress to distinguish between high and low energy environments, consistent with ecological theory and regional field studies.

Geological structure is reasonably inferred to substrate and energy-based grid cells because various features can only be formed from substrates of particular grain sizes (e.g., bedforms can be created from sand, but not from boulders). However, limiting the vulnerability assessment to the impacts of fishing on geological structures alone is acknowledged to be incomplete. Therefore, structural biological features are inferred to substrate and energy environments, and their susceptibilities to and recovery rates from fishing gear impacts are estimated. While including biological features improves the global model results by accounting for impacts to known habitat factors, local model results become less meaningful because the assumed biological features may or may not exist in a particular area. Errors resulting from the assumed distribution of biological features could become larger for smaller and smaller subareas within the model domain. (It is important to point out that it is not possible to fully evaluate the relative abundance and importance [to managed species] of the geological features, either.)

The PDT recognizes the importance of incorporating prey and coral vulnerability into the assessment of the impacts of fishing on EFH, but including soft and hard deep-sea corals in the list of structural biological features, and including prey as another habitat component, would have further decoupled the model results from local spatial empirics. When the spatial distributions of all feature classes (geological, biological, corals, and prey) are better known, the model can be made regionally specific and errors at the local level reduced. At that time, it might make sense to estimate suceptiblity and recovery scores for prey and/or coral features and use them to modify area swept values. With corals in particular, an additional concern is that the substrates on which the corals are found (i.e. rock outcrops/boulders) are not well represented in the unstructured model grid in the locations known for high coral density (i.e. canyons and seamounts).

Despite the decision not to incorporate susceptibility and recovery scores for these features into the spatial SASI model, their vulnerability, combined with information about their spatial distribution (relative to substrate and energy, when known), may help the Council to better evaluate alternatives to minimize the impacts of fishing on EFH. Prey and coral features and their vulnerability are described below in qualitative terms.

12.1 Prey features

Important benthic invertebrate prey features for regional managed species include the following groups: amphipods, decapod shrimp and crabs, echinoderms, polychaetes, infaunal bivalve mollusks. Many managed species of fish also feed on benthic and pelagic fish and invertebrates such as krill and squid that are not included in the habitat vulnerability analysis.

For the purposes of this assessment, prey features are defined as benthic, infaunal or epifaunal invertebrate organisms that are common food items for species managed by the NEFMC. Similar to the biological features, prey features are grouped taxonomically. While recognizing the importance of both fish (e.g. herring, sandlance) and pelagic invertebrates (e.g. krill, squid) as prey items, the analysis of prey features is restricted to benthic invertebrates (see explanation for the exclusion of benthic fish in Section 12.1.1.6). The exclusion of pelagic prey from the gear impact evaluation is consistent with the general exclusion of water column effects from the analysis. Further, most of the habitat impacts literature is focused on benthic invertebrates as opposed to pelagic species or fish. See Table 88 for a complete summary of the major prey categories identified in the stomachs of all the species (except Atlantic salmon) managed by the NEFMC.

Six prey features are identified using data provided by the Northeast Fisheries Science Center food web dynamics program. The dataset contains gut content information for various fish species collected during the NEFSC trawl surveys. Sampling protocols, summarized in Link and Almeida 2000, have changed slightly over time, and stomach contents of some managed species have been better sampled. Despite these limitations, the data set is believed to be more than adequate for identifying broadly important prey types across the range of species managed by the NEFMC.

These steps are taken to construct the prey features list. First, for each managed species, the average percentage by weight of each prey items is estimated from the stomach contents data for the years 1973-2005. Prey species are identified at the COLLCAT level (Table 87). Next, this is narrowed down to the subset of prey items that are benthic invertebrates. Some of these individual (i.e. COLLCAT) invertebrate prey types from the food habits database are grouped as shown in Table 87. For example, the categories CANFAM (cancer crabs) and DECCRA (other decapod crabs) are combined into decapod crabs. There is a close but not one-to-one relationship between the food habits database and the feature descriptions that follow Table 88.

Features selected are assumed to have roughly similar levels of importance to managed species. For example, four types of echinoderms, sea stars, brittle stars, sand dollars, and sea urchins, are grouped as one prey feature so as not to overweight echinoderms in the assessment as compared to other prey features, despite life history differences between the four types of echinoderms. If all four has been included as separate features, echinoderm types would have comprised four of nine prey features, which is disproportionate to their importance in managed species diets.

Table 87 – Relationship between food habits database prey categories and vulnerability assessment prey features.

COLLCAT field	*Common name*	*Feature category assigned for purpose of calculating 5% threshold*
DECCRA	Other decapod crabs	Decapod crabs
CANFAM	Cancer crabs	Decapod crabs
PANFAM	Pandalid shrimp	Decapod shrimp
CRAFAM	Crangon shirmp	Decapod shrimp
CRUSHR	Other crustacean shrimp	Decapod shrimp
POLYCH	Polychaetes	Polychaetes
AMPHIP	Amphipods	Amphipods
GAMMAR	Gammarid amphipods	Amphipods
BIVALV	Bivalves	Bivalves
MOLLUS	Molluscs	Bivalves
OPHIU1	Brittle stars	Echinoderms
ECHIN1	Sea urchins and sand dollars	Echinoderms
ASTERO	Asteroidea	Echinoderms

Table 88 – Contribution in average percentage total weight of prey items to the diets of managed species (juveniles and adults – based on stomach contents), with totals for all benthic invertebrates, all benthic prey, all pelagic prey, and all prey. Unidentified prey items, and prey items that made up less than 1% of the diet of any individual fish species, were included when calculating percentages, but are not shown in the table. Prey features that were evaluated for susceptibility and recovery are shaded. Benthic plus pelagic totals do not add up to 100 because of 'other' category in food habits database. Prey information for Atlantic sea scallop, deep-sea red crab, and Atlantic salmon are not shown.

Managed species	*Amphipods*	*Decapod crabs*	*Decapod shrimp*	*Bivalves*	*Polychaetes*	*Echinoderms*	*Total benthic inverts*	*Fish*	*Total Benthic*	*Total pelagic*	*Total*
Acadian redfish	1	0	45	0	0	0	46	0	46	38	84
American plaice	0	0	3	3	4	70	80	0	80	1	81
Atlantic cod	0	14	5	7	1	1	28	6	34	25	59
Atlantic halibut	0	15	8	0	0	0	23	40	63	21	84
Atlantic herring	14	0	13	0	0	0	27	0	27	20	47

Managed species	*Amphipods*	*Decapod crabs*	*Decapod shrimp*	*Bivalves*	*Polychaetes*	*Echinoderms*	*Total benthic inverts*	*Fish*	*Total Benthic*	*Total pelagic*	*Total*
Barndoor skate	0	41	12	0	0	0	53	13	66	16	82
Clearnose skate	0	33	2	1	1	0	37	20	57	16	73
Haddock	13	2	3	2	9	23	52	1	53	4	57
Little skate	19	24	10	8	12	0	73	1	74	2	76
Monkfish	0	0	0	0	0	0	0	19	19	30	49
Ocean pout	4	12	0	8	3	67	94	0	94	0	94
Offshore hake	0	2	3	0	0	0	5	0	5	71	76
Pollock	1	0	21	0	0	0	22	9	31	47	78
Red hake	4	7	24	1	2	0	38	2	40	23	63
Rosette skate	7	25	17	0	14	0	63	3	66	4	70
Silver hake	1	0	15	0	0	0	16	5	21	50	71
Smooth skate	1	7	45	0	1	0	54	2	56	19	75
Thorny skate	1	7	8	0	24	0	40	11	51	16	67
White hake	0	0	8	0	0	0	8	3	11	44	55
Windowpane flounder	15	14	27	0	0	0	56	12	68	6	74
Winter flounder	8	0	0	3	40	0	51	0	51	0	51
Winter skate	8	6	3	15	12	0	44	20	64	7	71
Witch flounder	2	0	0	1	71	0	74	0	74	1	75
Yellowtail flounder	25	1	0	3	38	0	69	0	69	0	69

12.1.1 Description of prey features

Six types of benthic invertebrate prey are described below. Table 89 shows the general distribution of these features by substrate and energy. Benthic fish as prey are addressed briefly at the conclusion of the section.

Table 89 – Prey habitat features and their distribution by substrate and energy.

	Mud		*Sand*		*Granule-pebble*		*Cobble*		*Boulder*	
Feature	***High***	***Low***	***High***	***Low***	***High***	***Low***	***High***	***Low***	***High***	***Low***
Amphipods	x	x	x	x	x	x	x	x	x	x
Decapod crabs	x	x	x	x	x	x	x	x	x	x
Decapod shrimp	x	x	x	x						

Echinoderms	x	x	x	x	x	x	x	x	x	x
Infaunal bivalve mollusks	x	x	x	x						
Polychaetes	x	x	x	x	x	x	x	x	x	x

12.1.1.1Amphipods

Amphipods, an order of crustaceans, make up greater than 10% by weight of the diets of Atlantic herring, haddock, little skate, windowpane flounder, and yellowtail flounder (Table 88). There are four suborders, but the primary one is the Gammaridea. Most gammarids are marine and benthic, and some are commensal with other invertebrates (e.g. *Dulichia* on the sea scallop) (Gosner 1971). The suborder Caprellidea has fewer species, and contains amphipods that are modified for attachment to other benthos, such as hydroids or algae. Generally, amphipods are found on all substrates and at all depths (Gosner 1971). Some species inhabit tubes while others are free-living. In the northeast region, amphipods range in length from 2-40 mm in (Gosner 1971). A few species commonly identified in the food habits data include *Ericthonius rubricornis*, *Leptocheirus pinguis*, *Gammarus* spp., *Monoculodes* spp., *Unciola* spp., and *Ampelisca* spp. Species like *Ampelisca* spp. also create dense "mats" of short tubes in sand and mud habitats that provide some cover for juvenile fish. Amphipods have a short life cycle: *L. pinguis*, for example, has a spring and fall cohort each year in the near shore Gulf of Maine, both of which die out by the following summer (Theil 1997).

12.1.1.2Decapod crabs and shrimp

Decapods are another order of crustaceans that includes the shrimps, crabs, lobsters, and crayfish. Decapods are found at a range of depths and salinities, and many species are benthic. Crabs and shrimp are distinguished in the vulnerability assessment based on differences in size and substrate affinities.

Crabs make up greater than 10% by weight of the diets of cod, halibut, barndoor skate, clearnose skate, little skate, ocean pout, rosette skate, and windowpane flounder (Table 88). Most crabs, particularly the true (Brachyuran) crabs, are easily recognized by large carapaces and dorsoventrally flattened bodies. Hermit crabs, which have twisted, soft abdomens, and typically occupy empty gastropod shells, are a notable exception. Regional species include the jonah crabs *Cancer borealis* and rock crabs, *C. irroratus*, hermit crabs (*Pagurus* spp.), spider crabs such as *Libinia emarginata*, and swimming crabs such as *Ovalipes ocellatus* and *Callinectes sapidus*. Crabs occur on a wide variety of substrates (Table 89). *C. irroratus* is found from Labrador to South Carolina in intertidal habitats north of Cape Cod and is mostly subtidal and in progressively deeper water southward, occurring as deep as 780 meters on all types of bottom (Gosner 1978). Jonah crabs have a slightly different range (Nova Scotia to Florida) and usually occur in deeper water than rock crabs (Gosner 1978). The common spider crab (*L. emarginata*) ranges from Nova Scotia to the Gulf of Mexico and is common all types of bottom from the shoreline to depths of 48 meters or more. Lady crabs (belonging to the family Portunidae, the swimming crabs) are common in the summer south of Cape Cod in shallow water on sandy bottoms. Another common portunid crab south of Cape Cod, the blue crab (*Callinectes sapidus*), occurs offshore to at least 36 meters, but is most common in estuaries like Chesapeake Bay. Blue crabs are also sometimes found in Massachusetts Bay and in coastal waters further north in the Gulf of Maine.

Shrimp make up greater than 10% by weight of the diets of redfish, barndoor skate, little skate, pollock, red hake, rosette skate, silver hake, and smooth skate (Table 88Table 88). Shrimp species commonly identified in the food habits data include the sand shrimp, *Crangon septemspinosa*, and northern, or pink, shrimp, *Dichelopandalus leptoceros*, and *Pandalus* spp. As its name implies, the sand shrimp occupies sandy bottom, whereas the pandalids occur on mud. Sand shrimp range along the entire east coast from the lower intertidal zone to depths of 90 meters or more (Gosner 1978). Sand shrimp and mysids are the only common shallow-water shrimp between Cape Ann and the Bay of Fundy. The pandalids are circumpolar. The largest species in the Northeast region, *Pandalus borealis*, is common in the Gulf of Maine in deep water, but its range does not extend south of Cape Cod (Gosner 1978). *P. montagui* is found as far south as Rhode Island, *P. propinquus* is found as far south as Delaware, and *D. leptoceros* inhabits deep water down to North Carolina. In New England waters, *P. propinquus* is generally restricted to deeper water (165-330 m) while *D. leptocerus* occurs over a broader depth range (33-340 m) (Wigley 1960). *D. leptocerus* appears to have less restricted habitat requirements than either *P. montagui* or *P. borealis*, since it has been collected in areas where sediments contained low, medium, and high quantities of organic matter, whereas *P. montagui* was more associated sediments with relatively low organic matter content (Wigley 1960). The crustacean order Mysidacea also includes some benthic shrimps. Unlike crabs, crustacean shrimps are generally restricted to mud and sand bottom habitats (Table 89).

12.1.1.3Echinoderms

There are several classes of echinoderms with fairly distinct substrate associations. Sea stars, or starfish, are predators and are found on all types of substrate, whereas sea urchins are restricted to rocky bottom areas, sand dollars occupy sandy bottom habitats, and brittle stars are found on mud and sand. Thus, as a single benthic prey feature, echinoderms of some kind can be found on all substrates (Table 89). Echinoderms are important components of the diets of only three managed species of fish (Table 88). American plaice feed on brittle stars, sea urchins, sand dollars, and starfish, ocean pout feed on brittle stars, sea urchins, and sand dollars, and haddock feed on brittle stars. Species commonly identified in the diets of these three species are the brittle stars *Ophiura sarsi* and *Ophiopholis aculeata*, the sand dollar, *Echinarachnius parma*, the sea urchin *Strongylocentrotus droebachiensis*, and the sea star *Asterias vulgarias*.

12.1.1.4Mollusks, infaunal bivalves

Bivalve mollusks make up approximately 15% of the winter skate's diet and 7-8% of the diets of ocean pout, cod, and little skate (Table 88). Infaunal bivalves burrow into mud and sand, but not into gravel. Species commonly identified in the food habitats data include *Astarte* spp., *Cyclocardia borealis*, *Chlamys islandica*, *Ensis directus*, and *Sphenia sincera*.

12.1.1.5 Polychaetes

The polychaete worms are a large and diverse group that includes both sessile and mobile forms living both in and on all types of substrates. Some species create and occupy tubes, which may be hard (calcareous) or soft. Many are associated with other invertebrate fauna. Polychaetes may be filter feeders, deposit feeders, or carnivores, and most release gametes into the water column. Polychaetes comprise greater than 70% by weight of the diet of witch flounder, about 40% of the diets of winter flounder and yellowtail flounder, 24% for thorny skate, and 12-14% for little skate, rosette skate, and winter skate (Table 88). Families commonly identified in the food habits data include the Nephtyidae, Glyceridae, Lumbrineridae, Terebellidae, Maldanidae, Ampharetidae, Flabelligeridae, and Nereidae.

12.1.1.6 Benthic Fish

Benthic species of fish account for 40% of the diet of Atlantic halibut and 10-20% of diets of barndoor skate, clearnose skate, monkfish, thorny skate, windowpane flounder, and winter skate (Table 15). A large variety of benthic fish species are eaten by larger fish, including sand lance, sculpins, cod, haddock, red, white, and spotted hake, sea ravens, sea robins, ocean pout, witch and summer flounder, plaice, cusk eels, wrymouth, tonguefish, and scup. Obviously, fish that are preyed upon by larger fish are small, either young-of-the-year or slightly older juveniles. Despite the importance of this benthic prey feature, susceptibility and recovery scores are not determined for benthic fish for the following reasons:

- Unlike infaunal prey, fish are mobile and in many cases do not have well-defined substrate associations, or if they do, it often changes as they get older and is dependent on the time of year (e.g., temperature);
- Their susceptibility to capture (catchability) in trawls and dredges varies according to species and size;
- Habitat impact studies focus on infaunal prey species, not fish, so very little is known about the removal rates (bycatch) of juvenile fish by fishing gear or how fishing gear affects the functional value of benthic habitats utilized by juvenile fish.

12.1.2 Vulnerability of prey features to fishing gear impacts

The following section summarizes the scientific literature related to fishing gear impacts on the five benthic invertebrate prey features identified in Section 12.1.1. This information, along with detailed information on the principal types of prey eaten by individual managed species in Volume 1 of this EIS, can be used to supplement model results during the development of management alternatives. Because benthic invertebrate prey types are not included in the spatial SASI model, this analysis of susceptibility and recovery potentials does not include a determination of S and R scores, a process that would have required the application of professional judgment, and, in order to estimate recovery potentials, detailed biological information for an enormous number of invertebrate species with highly variable life history strategies, in addition to an evaluation of the scientific literature. This evaluation does, however, focus on the results of experimental studies of the effects of single or multiple passes of trawls and dredges, not comparative studies of prey populations in areas that are open and closed to fishing. Thus, even though they are not scored, these results should be consistent with the impact results for geological and biological structure features that are included in the model.

References cited in the following summary of impacts (numbers in parentheses) refer to citations listed in Table 17. This table describes the location and depth range for each study, along with some details on the energy environment and substrate for each one. Table 26 provides more information on the gear used, and Table 25 has a brief description of the experimental design, whether or not the study area was open or closed to commercial fishing, and, in some cases, the methods used to collect data.

12.1.2.1Otter trawls

Six studies included in this analysis evaluated the impacts of bottom otter trawls on infaunal prey organisms in mud. One of them (Drabsch et al 2001) was conducted at a muddy site and two nearby sandy sites, so the results are summarized separately under “mud” and “sand.” Five of them are conducted in low energy environments; the energy regime for the fifth (De Biasi 2004) was not certain. The depth range for all six studies was 20-90 meters. All studies except one (Sanchez et al 2000) are conducted in areas that had been closed to commercial trawling for varying periods of time. Four studies were short-term experiments that examined the effects of 1-4 tows per unit area of bottom in a single day, and two were longer-term studies, with repeated tows every two weeks for a year and every month for 16 months, with an estimated 24 tows per unit area in both cases. One was done in the Gulf of Maine (Sparks-McConkey and Watling 2001), one in Scotland (Tuck et al 1998), one in a Swedish fjord (Hansson et al 2000), one in Australia (Drabsch et al 2001), and two in the Mediterranean Sea (Sanchez et al 2000, De Biasi 2004). Recovery was monitored for maximum periods of six days to 18 months in four of them. Polychaete and bivalve prey organisms were present in all six study areas, amphipods and brittle stars in three of them, and sea urchins in two.

Three of the short-term studies showed that 1-2 tows had very little or no impact on infaunal communities in mud. The results of Sanchez et al (2000) indicate that trawling may, in fact, have positive effects on infaunal abundance. Species richness and diversity did not change during the first 102 hours after a single pass of the trawl, and, after 150 hours, the abundance of a number of species actually decreased significantly in the control area compared with the trawled line. Furthermore, no differences were detected after 72 hours in another line that was trawled twice. Results of the Australian study (Drabsch et al 2001) showed a significant reduction in total infaunal abundance a week after trawling (two tows per unit area), with some taxa increasing and some decreasing. One family of polychaetes (Ctenodrilidae) decreased significantly, but there were no significant differences between treatment and control samples for any other taxon. In De Biasi (2004), for each of 35 major taxa, there were no significant differences in densities between treatment and control sites prior to trawling and one month after trawling. There were small significant differences after 48 hours, with some taxa more abundant at treatment sites and some more abundant at control sites.

In the fourth short-term experiment (Sparks-McConkey and Watling 2001), there was an immediate, significant effect of four tows on infaunal abundance and species diversity, with 30% fewer individuals five days after trawling. The reduction in abundance was especially noticeable for polychaetes and infaunal bivalves. Three and-a-half months after the initial disturbance, after mobile invertebrates recruited to the benthic community, there were no longer any significant differences between the numbers of individuals and species at the treatment and control sites, although one bivalve still had not recovered. This study also showed that bottom trawling affected the sedimentary habitat for infaunal invertebrates, significantly reducing the porosity of the mud (so that it retained less water), increasing the food value (organic matter) of the upper 2 cm of sediment, and stimulating benthic chlorophyll production. All geochemical sediment properties returned to pre-trawling conditions within 3.5 months, thus the impacts on infaunal prey and their habitat were temporary.

The two long-term, multiple tow studies produced completely contradictory results. In one of them (Hansson et al 2000), brittle stars were highly affected by trawling, with 31% fewer in treatment sites 7-12 months after the experiment began, but little or no effect on polychaetes, amphipods, or mollusks. For 61% of the species sampled, abundances tended to be negatively affected by trawling (i.e., abundances decreased more or increased less in the trawled sites compared to the control sites during the experiment). Total biomass decreased significantly at all three trawled sites, and the total number of individuals decreased significantly at two trawled sites, but in both cases significant reductions were also observed at one of the control sites; thus, these changes could not be attributed solely to trawling. Total abundance and biomass at trawled sites were reduced by 25% and 60%, respectively, after a year of continuous trawling, compared to 6% and 32% in control sites.

In the other long-term, multiple tow study (Tuck et al 1998), there were significantly more individuals in trawled sites before trawling began and after 6 and 12 months of recovery. After 18 months of recovery, there was no difference between the two sites. There were no significant differences in the number of infaunal species in the experimental and reference sites during the first 10 months of disturbance, but there were more species in the trawled site after 16 months of disturbance and throughout the recovery period. Biomass was significantly higher in the trawled site before trawling started, but not during the rest of the experiment. Some species, primarily opportunistic polychaetes, increased significantly in abundance in the trawled plot in response to the disturbance, while others (a bivalve and some other polychaete species) declined significantly. Community structure became significantly different after only five months of the experiment and remained so until the end of the recovery period, or beyond (two different measures of community structure were applied). Brittle stars were also significantly more (not less, as in Hansson et al (2000)) abundant in the trawled plot at the end of the disturbance period.

Six studies evaluated the impacts of bottom otter trawls on prey organisms in sand and muddy sand. Four of them were conducted in high energy environments (20-50 m deep) and two in low energy (20 m and 120-146 m). Three studies were conducted in areas that had been closed to commercial trawling for varying periods of time, two in open areas, and one at a lightly-trawled and a nearby untrawled site. One (Burridge et al 2003) was a depletion study in which the average biomass removed per tow for a number of taxonomic classes of epifauna was calculated after 13 tows in each of six trawl lanes. This study was of limited value since it only examined removal rates of epifauna large enough to be caught in the net, many of which are not prey organisms. One of the open area experiments (Bergman and VanSantbrink 2000) also examined direct mortality rates of epifaunal and infaunal organisms caught in an otter trawl, but also estimated indirect mortality caused by exposure and damage of organisms that remained on the bottom after the passage of the net. Studies Boat Mirarchi and CR Environmental (2003), Brown et al (2005a), and Kenchington et al (2001) also analyzed impacts on infaunal and epifaunal organisms, many of which are prey species, whereas Drabsch et al (2001) was limited to infaunal organisms. Infaunal bivalves were present in all six study areas, polychaetes in all but one, brittle stars and sea urchins in four, amphipods, crabs, and sea stars in three, sand dollars in two, and decapod shrimp in one.

Five studies were short-term experiments that examined the effects of 1-6 tows in a single day, and one (Kenchington et al 2001) was a longer-term study conducted in a closed area on the Grand Banks, with 3-6 tows per unit area of bottom in five days in three successive years. The short-term studies were done in the Gulf of Maine (Boat Mirarchi and CR Environmental 2003), the North Sea (Bergman and VanSantbrink 2000), the Gulf of Alaska (Brown et al 2005a), and on the Great Barrier Reef and in a coastal gulf in Australia (Burridge et al 2003 and Drabsch et al 2001). Recovery was evaluated in the Grand Banks study in two one-year time periods, between the first and second trawling episode and between the second and third. Recovery was not evaluated in any of the short-term experiments.

Three of the five short-term experiments reported either no effect or very subtle effects on benthic prey organisms. Responses of benthic macrofauna to experimental trawling in the Gulf of Alaska (Brown et al 2005a) were limited to a reduction in the total number of taxa - with an absence of rare taxa such as brittle stars, cumaceans, and isopods – but large, mobile amphipods and polychaetes increased in abundance after trawling. In the Gulf of St. Vincent, Australia (Drabsch et al 2001), there was no effect on total infaunal abundance. The only significant change that could be attributed to the two experimental tows was a reduction in the density of one order of crustaceans (Tanaidaceae) one week later; there were no significant differences in infaunal abundance between treatment and control samples at a second sandy site three months after trawling. In the Gulf of Maine study (Boat Mirarchi and CR Environmental 2003) there were no significant differences in infaunal density or species composition between treatment and control areas; the only noticeable change in epifaunal invertebrates was a reduction in rock crabs in the trawled lanes immediately after trawling, but not 4-18 hours later.

Two of the short-term experiments conducted in sandy benthic habitats estimated removal rates of benthic macrofauna by bottom trawls. These two studies have limited application to an evaluation of trawling impacts on prey species because many of the types of organisms caught and retained in trawls are not consumed by fish. Larger benthic organisms that are caught in bottom trawls and which make up a portion of the diets of NEFMC-managed fish species include crabs, bivalves, and various kinds of echinoderms (see Table 88). Densities for nine species of infaunal bivalves in the North Sea (Bergman and VanSantbrink 2000) were reduced, on average, by 0.5-52%, by 16-26% for a sea urchin, 12% for brittle stars, 3-30% for crabs, and 2-33% for polychaetes within 24-48 hours after towing a unit area of bottom 1.5 times. Fragile species were more vulnerable. Estimates of the mean percent biomass removed per tow (after 13 tows) in the depletion study (Burridge et al 2003) were 13-14% for crustaceans and echinoids and 9% for brittle stars and all bivalves. These values would obviously be higher – probably considerably so – for the first tow.

There were significant short-term reductions in total abundance and the abundance of 15 individual infaunal and epifaunal taxa (mostly polychaetes) within several hours or days after trawling in the Grand Banks study (Kenchington et al 2001), but only in one of the three years of the experiment; benthic organisms that were reduced in abundance in that year had recovered a year later. There were no short-term effects on biomass or taxonomic diversity.

Results of three experimental trawl impact studies done on "hard bottom" substrates were evaluated. One was a short-term experiment in a primarily pebble, low-energy environment (depth 206-274 m) in the Gulf of Alaska (Freese et al 1999) and the other two were three-year studies in the same high-energy environment on the Scotian Shelf, in 70 m on pebbles and cobbles overlaying medium to gravelly sand (Kenchington et al 2005, Kenchington et al 2006). All three studies were conducted in areas that were closed to commercial fishing. Detailed information on the gear used can be found in Table 16 and on methodology in Table 15. The Alaskan study examined the effects of eight individual tows on epifauna 2 hours to 5 days after trawling. The Scotian shelf studies assessed the effects of 12-14 repeated tows on epifauna and infauna in the same trawl lane in three consecutive years. The objective of Kenchington et al (2005) was to evaluate changes in prey consumed by five demersal species (cod, haddock plaice, winter flounder, and yellowtail flounder) with increasing trawling disturbance. All three experiments assessed impacts on seastars, brittle stars, and bivalves, two of them on sea urchins and polychaetes, one on decapod shrimp, one on crabs, and one on amphipods.

In the short-term study (Freese et al 1999), mean densities of brittle stars were 43% lower in trawled transects than in reference transects and 23% of them were damaged, compared to 2% in the reference transects. Similar effects were observed for sea urchins (49% fewer in the trawled transects), but other prey organisms such as pandalid shrimp were more abundant in the trawled transects, and none of the differences were statistically significant.

On the Scotian shelf (Kenchington et al 2006), multiple tows had few detectable immediate effects on the abundance or biomass of individual taxa and none on community composition; a few taxa, primarily polychaetes and amphipods, decreased significantly after trawling, some because of scavenging by demersal fish. Fifteen taxa showed significant decreases 1-5 days after trawling when the data for all three years of the experiment were combined; the species affected were primarily high turn-over species, such as polychaetes and amphipods, and mussels. Organisms that were most affected were those living on or just below the sediment surface. Apart from a long-term decrease in the abundance of horse mussels, all of the detectable impacts were short-term, apparently persisting for less than a year, and minor, at least in comparison with the natural inter-annual variation seen in the control lines.

The other Scotian Shelf study (Kenchington et al 2005) is especially relevant since it found that there were significant quantitative and qualitative changes in the diets of five demersal fish species that were caught during successive experimental tows. All five species are managed by the NEFMC. Large increases in consumption of a number of prey taxa were observed between the first two and the next three to 10 or 12 experimental tows, especially for a tube-dwelling polychaete and horse mussels. Consumption of infauna and species living on or near the bottom (above or below) increased markedly. The results clearly show that the disturbance of benthic habitats by trawling causes short-term increases in prey availability for bottom-feeding fish and that the fish can easily shift their feeding habits in response to changes in the availability of prey items.

Overall, there was very little evidence of significant short-term impacts of bottom trawling on prey organisms in any substrate. In cases where there were negative impacts of sustained trawling for a year or more on total infaunal abundance or the abundance of certain taxa, recovery occurred within a year to 18 months after the disturbance ended. Recovery from the effects of 1-4 tows was faster, occurring within a few months or even days. Some opportunistic species were more abundant soon after trawling. Total abundance was reduced more often than biomass or species diversity. Trawling clearly "stirs up" infaunal organisms and organisms that live on or near the bottom, providing more for fish to eat in the first few hours after the passage of the gear (this was evident even in rocky habitats). Trawling impacts on prey were hard to detect in many cases because they are subtle, and because they take place against a background of considerable spatial and temporal variability in benthic community structure.

12.1.2.2Scallop Dredges

Two scallop dredging experiments were evaluated, one in an estuary in the Gulf of Maine and one on the continental shelf in the Mid-Atlantic Bight. Both were done in high-energy environments. Study #391 was done in shallow water (15 m) on silty sand and examined the effects of 23 tows in one day in a small unfished area adjacent to a commercially exploitable population of scallops. Study in Sullivan et al (2003) was done at three sites and depths of 45, 67, and 88 meters in sand. Impact "boxes" at each site were "thoroughly dredged" by a commercial scallop vessel in order to assess the effects on habitat structure for young-of-the-year yellowtail flounder; benthic cores were collected during pre-dredge and post-dredge surveys with a submersible two days, three months, and one year after dredging. Impacts on macrofauna (mostly infauna) in the Damariscotta River were evaluated one day and four and six months after dredging. The shallower of the three continental shelf study sites may have been commercially dredged in the months leading up to the experiment; the two deeper sites were located in an area closed to scallop dredging (but not otter trawling).

Prey organisms (amphipods, isopods, cumaceans, crabs, and sand dollars) sampled on the continental shelf did not exhibit any change in abundance, positive or negative, that was consistent with a dredging impact, but did reflect seasonal variability. Dredging "vigorously reworked" the top 2-6 cm of sediment and reduced the frequency of amphipod tube mats – compared with control plots – and mobile epifauna such as sand dollars were typically dislodged or buried under a thin layer of silt. In the estuary, the total number of individuals was greatly - and significantly - reduced one day and four months after dredging, but not after six months. Some taxa (families) were nearly as abundant in treatment and control plots the day after dredging, while others were less abundant and there were no discernible changes in the number of taxa. Significant reductions were noted for one family of polychaetes (Nephtyidae) one day after dredging and one family of amphipods (Photidae) one day and four months after dredging. The nephtyid polychaetes returned to the drag track sometime during the first four months, whereas the photid amphipods did not return to pre-dredge abundances until September, six months after dredging, following the summer larval recruitment period. Dredging in the estuary also affected the habitat for infaunal prey by removing the top few centimeters of fine sediment, thereby reducing the food value of the surficial sediments (by reducing amino acid content, chlorophyll a, and microbial biomass). Food value was restored within six months.

12.1.2.3Hydraulic dredges

Six experimental hydraulic dredge impact studies were evaluated, three of which examined the effects of single tows, and three the effects of repeated tows in the same area during a day or less. All were conducted on sand substrates. Two were done in low energy environments – one in a very shallow coastal lagoon in the Adriatic Sea (Pranovi and Giovanardi 1994) and the other in 70-80 m of water on the Scotian Shelf (Gilkinson et al 2005a). The four high-energy experimental studies were all conducted in depths less than 10 m, two in Scotland (Hall et al 1990 and Tuck et al 2000), one in the Adriatic (Morello et al 2005), and one in Iceland (Thorarinsdottir et al 2008). All six experiments examined impacts on infaunal organisms and two of them (Pranovi and Giovanardi 1994 and Morello et al 2005) also analyzed effects on epifauna. Results were presented in all cases for infaunal bivalves, for amphipods in four, isopods in two, and for crabs, shrimp, brittle stars, and starfish in one. Recovery was evaluated in all six studies, for relatively short time periods (18 days to 11 weeks) in four cases and, in two cases, for two years (see Table 15 for details). Four experiments (Gilkinson et al 2005a, Hall et al 1990, Thorarinsdottir et al 2008, and Tuck et al 2000) were done either in areas closed to commercial dredging, or areas where no dredging had taken place prior to the experimental tows, one was done in a heavily dredged area (Morello et al 2005), and one at two study sites, one inside and one outside a clam fishing ground (Pranovi and Giovanardi 1994).

In all three of the single tow experiments there were immediate reductions in the density of sampled organisms. In Tuck et al (2000), there was a significant reduction in the number of infaunal organisms a day after dredging, but not after five days. Some species were less abundant, some moreso, after five days, but at the end of the experiment (11 weeks), the infaunal community had completely recovered. Similar results were obtained in Pranovi and Giovanardi (1994): there was an immediate and significant decrease in total abundance, biomass, and species diversity (infauna and epifauna) in the experimental versus the control plot in the fishing ground. The same downward trend in total abundance was observed outside the fishing ground, but the difference between the experimental plot and the control plot was not as dramatic (26% versus 45%) and was not significant. After two months, abundance had recovered in both sites, but not biomass. The third single tow study (Thorarinsdottir et al 2008) also reported large reductions in infaunal density (45% immediately after dredging and 36% three months later), but the results were not significant due in part to low sample sizes. Reductions in crustacean and bivalve densities were only observed immediately after dredging, whereas effects on polychaetes, cumaceans, and other taxa lasted for three months, and hydrozoa were not impacted at all. Full recovery occurred at some point between the three month and one year sampling times.

The three repeat tow experiments were meant to simulate the effects of commercial clam dredging operations in which multiple tows are made in a small area until most of the clams are harvested. Experimental dredging in previously undredged areas (Gilkinson et al 2005a and Hall et al 1990) had broad scale effects on the benthic fauna, but the impacts in a heavily dredged area (Morello et al 2005) were limited to infaunal bivalves. On the Scotian Shelf (Gilkinson et al 2005a), most species were less abundant (numbers and biomass typically by more than 40%) immediately after dredging, especially polychaetes and amphipods, and especially inside vs outside dredge furrows. Recovery times could not really be evaluated because the study area was not re-sampled for an entire year, but none of the impacts lasted more than a year. One year after dredging, there were marked increases in abundance of opportunistic species (e.g., amphipods and polychaetes) that were even more dramatic two years after dredging. In Scotland (Hall et al 1990), there was a significant, immediate, reduction in total infaunal abundance, but no significant effect on any individual species. The mean densities of the ten most common species were all lower, however, and for the whole group, the reduction was significant. Infaunal abundance fully recovered within 40 days, but densities of four of the ten most common species were still lower in the treatment plots than in the reference plots after 40 days. In the heavily dredged study area in the Adriatic Sea (Morello et al 2005), repeated dredge tows had no impact on infaunal abundance or on the abundance of polychaetes, crustaceans, detritivores, or suspension-feeders. Only non-target bivalves (those not retained in the dredge) were affected: abundance and biomass was significantly reduced, with no recovery after 18 days.

Hydraulic dredging had a greater impact on benthic prey organisms than bottom trawls or scallop dredges, causing significant and immediate reductions in the densities of infaunal organisms in dredge paths, but at the same time making them readily available to foraging fish and scavengers for a short time. In some cases, *in situ* biomass and species diversity were also reduced. Different types of infaunal (and epifaunal) organisms responded differently to dredging: polychaetes and amphipods were more likely to be affected by the excavating action of the gear on sandy bottom sediments. Recovery times varied, but were generally fairly rapid, at least in shallow-water, highly energetic environments. In the five experimental studies that were conducted in shallow water (<10 meters), total infaunal abundance recovered within five days to over three months, but in less than a year. Some individual taxa recovered from disturbance within 40 days, but others took longer, perhaps as long as 11 weeks. In deeper water (70-80 m), there were marked increases in abundance of opportunistic polychaete and amphipod species within one year and even more dramatic increases after two years, but recovery times were not evaluated at any higher temporal resolution (e.g., months).

12.1.3 Summary of prey information by study

Table 90 – Summary of literature relating to impacts of otter trawls (OT), scallop dredges (SD), and hydraulic clam dredges (HD) on benthic invertebrate prey types, experimental studies only. Substrate classifications include mud (M), muddy sand (MS), sand (S), granule-pebble (GP), cobble (C), and boulder (B); energy classifications are high (H) and low (L).

Study description						*Benthic invertebrate prey types evaluated*										
Citation	*#*	*GEAR*	*FISHING INTENSITY*	*SUBSTRATE*	*ENERGY*	*Amphipods*	*Isopods*	*Decapod crabs*	*Decapod shrimp*	*Polychaetes*	*Infaunal bivalves*	*Brittlestars*	*Sea urchins*	*Sand dollars*	*Seastars*	*Prey impact description*
Hansson et al 2000	149	OT	2/wk for 1 yr, est 24 tows per unit area	M	L	X				X	X	X				Brittlestars highly affected by trawling (31% fewer after 7-12 mos); little or no effect on polychaetes, amphipods, mollusks; for 61% infaunal species sampled, abundance was negatively affected by trawling
Sanchez et al 2000	320	OT	1 or 2 in a day (2 sites)	M	L	X				X	X					No changes due to trawling in community structure, or infaunal species or taxa present; abundance of a number of species decreased S on unfished line compared to fished line 150 h after fishing
Sparks-McConkey and Watling 2001	338	OT	4 in 1 day (in same area of bottom)	M	L					X	X					Immediate, S impacts on infauna (30% fewer individuals 5d after trawling), esp 4 polychaetes/2 bivalves, also fewer species/species diversity); NS differences between trawled and control areas after 3.5mo following recruitment of mobile species.
Tuck et al 1998	372	OT	Multiple tows once a month for 16 mos, est 1.5/unit area each month	M	L					X	X					More infaunal species after 16 mos of disturbance (but not after 10) and throughout recovery period, but fewer individuals during 16 mos disturbance and 12 mos of recovery, no differences between control and treatment sites 18 mos after trawling ended.
De Biasi 2004	88	OT	14 parallel tows 160 m apart in one day	M	?					X	X		X			For 35 major taxa, NS differences prior to or 1 mo after fishing, but small S differences after 48 hrs; some taxa more abundant at treatment sites after 48 hrs, some less so.
Bergman and VanSantbrink 2000	21	OT	Average 1.5 tows per unit area	S MS	H			X		X	X	X	X		X	Percent reductions <0.5-52% for 9 bivalves, 16-26% for a sea urchin, 12% brittle stars, 3-30% for crabs, and 2-33% for polychaetes, no effect on sea stars; some reductions significant (see paper); fragile species more vulnerable

Study description						***Benthic invertebrate prey types evaluated***										
Citation	***#***	***GEAR***	***FISHING INTENSITY***	***SUBSTRATE***	***ENERGY***	***Amphipods***	***Isopods***	***Decapod crabs***	***Decapod shrimp***	***Polychaetes***	***Infaunal bivalves***	***Brittlestars***	***Sea urchins***	***Sand dollars***	***Seastars***	***Prey impact description***
Boat Mirarchi and CR Environmental 2005	408	OT	6 tows in same trawl lane in 1 day	S MS	H	X		X	X	X	X			X	X	No difference in infaunal density, richness, or species composition between treatment and control lanes after experimental tows
Brown et al 2005a	34	OT	10 single tows in 30 hrs, no overlap	S MS	H	X				X	X					Immediate responses to experimental trawling were subtle (reduced richness, absence of rare taxa such as brittle stars and several bivalve families), large, mobile polychaetes and amphipods increased in abundance
Burridge et al 2003	38	OT	Depletion study	S	H			X			X	X	X		X	Study limited to epifauna that were caught in trawl, some of which are prey for some species: mean 13-14% reduction per tow for crustaceans and echinoids, 9% brittle stars and all bivalves.
Kenchington et al 2001	192	OT	12 tows in ca 36 hrs once a year for 3 yrs, est 3-6 tows per unit area/yr	S	L					X	X			X		No effects on biomass or taxonomic diversity; full recovery of species affected by end of first year (when sampling resumed)
Drabsch et al 2001	97	OT	2 series of 10 adjacent tows in one trawl lane in 1 day	M S	L	X				X	X	X	X			No effect on total infaunal abundance in sand, but S reduction in mud; some taxa increased, some decreased; inconsistent results perhaps due to different disturbance regimes in each location tested plus high natural disturbance.
Freese et al 1999	111	OT	8 single tows, no overlap	GP C,B	L				X		X	X	X		X	23% NS reduction in density of non-structure forming motile epifauna, 43% fewer brittle stars with 23% damage to those remaining in trawl transects
Kenchington et al 2005	193	OT	12-14 tows in 1 day on same line each yr for 3 yrs	S GP C	H	X		X	X	X	X	X	X		X	S changes in abundance of prey consumed (esp between first two tows and subsequent tows) and diet composition of cod, plaice, haddock, winter flounder, and yellowtail flounder, opportunistic feeding on prey made more available by trawling (infauna and spp living on or near the sediment surface (below or above)

Study description						***Benthic invertebrate prey types evaluated***										
Citation	***#***	***GEAR***	***FISHING INTENSITY***	***SUBSTRATE***	***ENERGY***	***Amphipods***	***Isopods***	***Decapod crabs***	***Decapod shrimp***	***Polychaetes***	***Infaunal bivalves***	***Brittlestars***	***Sea urchins***	***Sand dollars***	***Seastars***	***Prey impact description***
Kenchington et al 2006	194	OT	12-14 tows in 1 day on same line each yr for 3 yrs	S GP C,B	H	X				X	X	X	X		X	15 taxa (eg polychaetes/amphipods) S reduced after trawling when results of 3 yrs of experimental tows were combined, some consumed by predators, organisms living in or just below sediment surface most affected; most impacts <1 yr and minor compared to annual changes in control lines.
Sullivan et al 2003	359	SD	Multiple tows in short time period at 3 sites	M MS	H	X	X	X						X		Prey items failed to exhibit a positive or negative change consistent with a dredging impact - but did reflect S seasonal variability
Watling et al 2001	391	SD	23 tows in 1 day	MS	H	X				X						Large, S reductions in numbers of individuals, esp one family of amphipods (Photidae) and one of polychaetes (Nephtyidae); little difference between control and treatment plots for some taxa the day after dredging
Gilkinson et al 2005a	122	HD	12 overlapping tows in 12 hrs	S	L	X	X			X	X	X		X		Most species (esp polychaetes/amphipods) less abundant (average 40%) immediately after dredging, esp inside dredge furrows; marked increase in polychaetes and amphipods after 1 yr, densities generally elevated by >>100% after 2 yrs relative to pre-dredging levels
Pranovi and Giovanardi 1994	287	HD	Single tows	S	L		X				X					Immediately S decrease in total abundance (45% fewer individuals in experimental vs control plot), biomass, diversity of macrofauna in fishing ground, NS effects outside (but still 26% fewer individuals); recovery in abundance, but not biomass, after 2 mos.
Hall et al 1990	140	HD	Repeated tows for 5 hrs	S	H	X				X	X					S reductions in numbers of infauna, NS effect on abundance of any individual species, but mean abundances of 10 most common species all lower 1 day after dredging (S reduction for whole group); recovery of total abundance and 6 of 10 species within 40 days.
Morello et al 2005	249	HD	Repeated tows in 1 day	S	H			X	X	X	X					No impacts of experimental tows on entire sampled macrobenthic community or on polychaetes, crustaceans, detritivores, or suspensivores, but abundance/biomass of non-target mollusks S reduced by dredging; no recovery after 18 days (end of experiment).

Study description						*Benthic invertebrate prey types evaluated*										
Citation	***#***	***GEAR***	***FISHING INTENSITY***	***SUBSTRATE***	***ENERGY***	***Amphipods***	***Isopods***	***Decapod crabs***	***Decapod shrimp***	***Polychaetes***	***Infaunal bivalves***	***Brittlestars***	***Sea urchins***	***Sand dollars***	***Seastars***	***Prey impact description***
Thorarinsdottir et al 2008	669	HD	3 discrete tows	S	H	X				X	X					Immediate NS 45% reduction in density of all infauna, still 36% fewer 3 mos later; only immediate effects on crustaceans and bivalves, no effects on hydrozoa, effects on polychaetes, other taxa lasted 3 mos; full recovery after 1 yr.
Tuck et al 2000	373	HD	Single tows	S	H	X				X	X					S decrease in number of infaunal individuals a day after dredging, but no difference after 5 days, fewer polychaetes and more amphipods after 5 days,but not after 11 wks; some species less abundant, some more after 5 days, full recovery after 11 weeks.

Note: M=mud, S=sand, MS=muddy sand, GP=granule-pebble, C=cobble, B=boulder, L=low energy, H=high energy, S in last column=statistically significant

12.2 Deep-sea corals

Deep-sea corals are both long lived and slow growing. A critical question during SASI model development was the terminal recovery year assumed for a value of R=3. A value of 10 years was suggested, consistent with the team's reading of the fishing impacts literature and with the lifespan of most of the biological features. For deep-sea corals, however, a terminal R assumption of 10 years was deemed inappropriately short. The addition of a plus group R score for corals was suggested as a possible solution to this problem and rejected, because very long recovery times were expected to have a large influence on model results. If the number of years associated with R=3+ could be incorporated only where corals are known to occur, this approach might be appropriate. However, at this stage, feature distributions in the model are not regionally-specific. In addition, the substrates on which corals are known to occur (i.e. rock outcrops and larger size classes of gravel) are not captured in the unstructured grid due to limited off-shelf sampling of large substrates. If better off-shelf and shelf-break data on hard substrates were available, and regional feature distributions were incorporated, coral susceptibility and recovery values could be introduced without unduly biasing the results.

Furthermore, the reauthorized Magnuson Stevens Act grants Councils broad discretionary authority to close areas for coral protection. With these discretionary provisions in mind, the goal of the following sections is to summarize the species diversity, known location information, and vulnerability to fishing gear impacts for the various regional deep-sea coral species. Although they are also addressed in the matrix-based vulnerability assessment, sea pens are included below for completeness, and because additional deep-water sea pens are known to occur in off-shelf areas not subject to much fishing pressure.

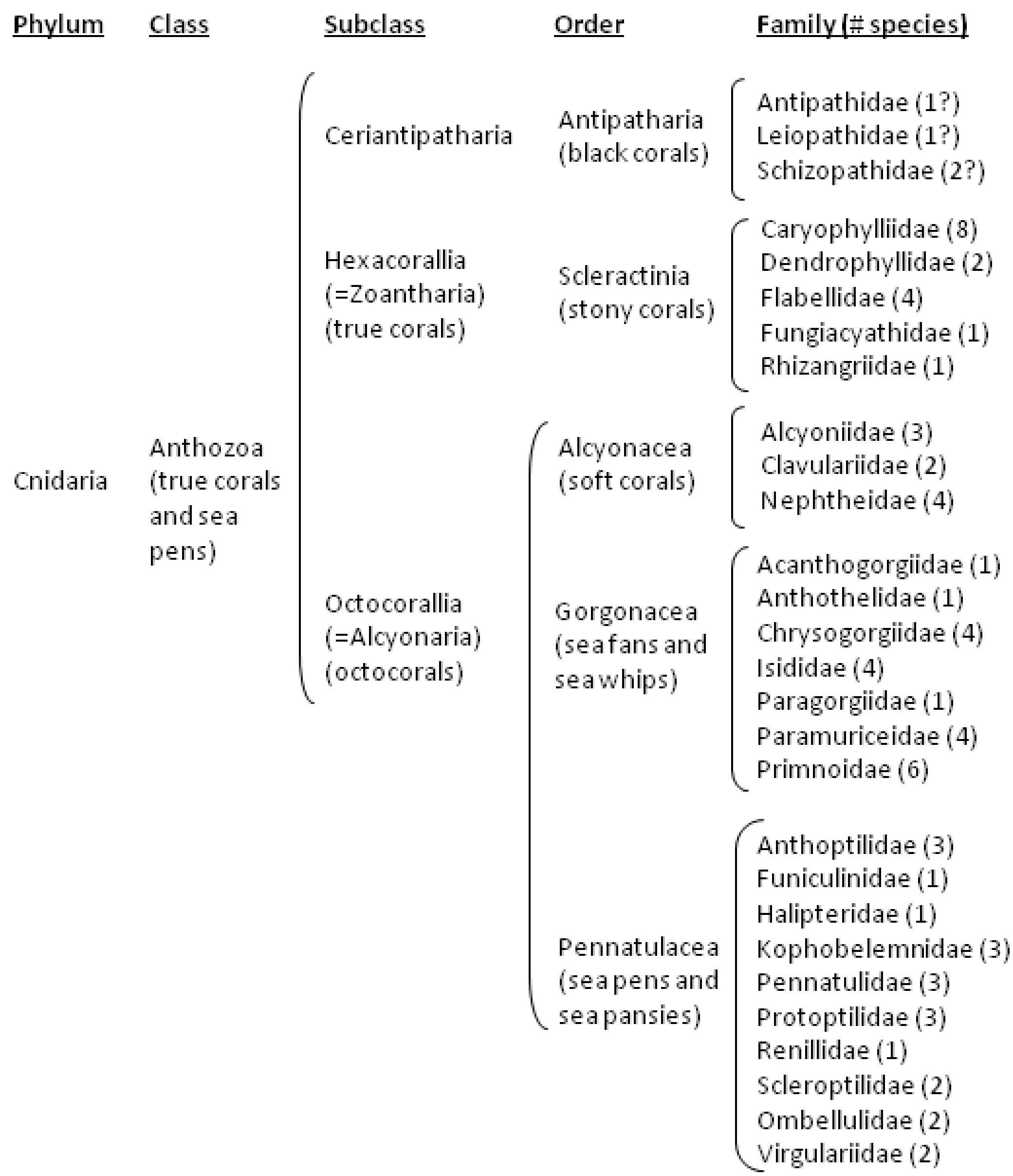
12.2.1 Description of deep-sea coral features

Cold-water or deep-sea corals in the northwest Atlantic are a diverse assortment of Anthozoa that include the subclass Hexacorallia (Zoantharia), which includes the hard or stony corals (order Scleractinia) and black and thorny corals (order Antipatharia); and subclass Octocorallia (Alcyonaria or octocorals), which includes the true soft corals (order Alcyonacea), gorgonians (sea fans, sea whips, order Gorgonacea), and sea pens (order Pennatulacea). Worldwide, deep corals can build reef-like structures or occur as thickets, isolated colonies, or solitary individuals, and often are significant components of deep-sea ecosystems, providing habitat (substrate, refugia) for a diversity of other organisms, including many commercially important fish and invertebrate species. They are suspension feeders, but unlike most tropical and subtropical corals, do not require sunlight and do not have symbiotic algae (zooxanthellae) to meet their energy needs. Deep corals can be found from near the surface to 6000 m depth, but most commonly occur between 50-1000 m on hard substrate (Puglise and Brock 2003), hence their "deep-sea" appellation.

The deep corals of the continental margin and several canyons off the northeastern U.S. were surveyed in the 1980s via submersible and towed camera sled (Hecker et al. 1980, 1983). Corals were denser and more diverse in the canyons, and some species, such as those restricted to hard substrates, were found only in canyons while the soft substrate types were found both in canyons and on the continental slope (Hecker and Blechschmidt 1980). They appear to be mostly restricted to hard substrates on the shelf.

The vulnerability assessment focuses on five groups of deep corals (Figure 26): the stony corals (scleractinians), the gorgonians (gorgonaceans), the true soft corals (alcyonaceans), the black corals (antipatharians) and the sea pens (pennatulaceans). The following sections summarize distributional information about these corals, with a table listing all the corals found in the region (minus the black corals on the seamounts). Often, records in databases or discussions of true soft corals and gorgonians in the literature are often combined or referred to as "octocorals" or just "soft corals," so for convenience these two orders will be discussed simultaneously.

Figure 26 – Deep-sea coral taxonomy for those taxa found in the northwest Atlantic.



Sea pens (Order Pennatulacea)

Records of sea pens in are drawn from Smithsonian Institution collections and the Wigley and Theroux benthic database (Packer et al. 2007). Nearly all materials from the former source were collected either by the U.S. Fish Commission (1881-1887) or for the Bureau of Land Management (BLM) by the Virginia Institute of Marine Sciences (1975-1977) and Battelle (1983-1986). These latter collections heavily favor the continental slope fauna. The Wigley and Theroux collections

(1955-1974) were made as part of a regional survey of all benthic species (Theroux and Wigley 1998), heavily favoring the continental shelf fauna. A list of 21 sea pen species representing ten families was compiled from these sources for the northeastern U.S.[8] The majority of these species have been reported exclusively from continental slope depths (200-4300 m), although two uncommon species have been recorded from shallow depths (e.g., < 30 m) off the North Carolina coast. The most common and fairly widespread species found in this region in the deeper parts of the continental shelf (80-200 m) are *Pennatula aculeata* (common sea pen) and *Stylatula elegans* (white sea pen). *P. aculeata* is common in the Gulf of Maine (Langton et al. 1990), and there are numerous records of *Pennatula* sp. on the outer continental shelf as far south as the Carolinas in the Theroux and Wigley database. *S. elegans* is abundant on the Mid-Atlantic coast outer shelf (Theroux and Wigley 1998).

See Table 42, below for additional information about sea pen distribution in the submarine canyons and other areas of the continental shelf and slope.

Hard (stony) corals (Order Scleractinia)

Cairns and Chapman (2001) list 16 species of stony corals from the Gulf of Maine and Georges Bank to Cape Hatteras (See also Cairns 1981). Most of the stony corals in this region are solitary organisms and one species, *Astrangia poculata*, can occur in very shallow water, at depths of only a few meters.

Theroux and Wigley (1998) described the distribution of deep corals in the northwest Atlantic, based on samples taken from 1956-1965. They often do not distinguish between taxonomic groups; e.g., stony corals such as *Astrangia* sp. and *Flabellum* sp. are lumped together with the various types of anemones in the subclass Zoantharia. The distributions of only the stony corals, specifically *Astrangia*, *Dasmosmilia*, and *Flabellum*, from the Theroux and Wigley (1998) database in the Gulf of Maine/Georges Bank, and Mid-Atlantic can be found in Packer et al. (2007). There appears to be a general lack of stony corals on Georges Bank, but they are present along the continental margin. They are found mostly on hard substrates.

Moore *et al*. (2003, 2004) reported several species of solitary and colonial stony corals on Bear Seamount; one notable solitary species, *Vaughanella margaritata*, represents the first record of this species since its original description over 100 years ago, and is endemic to the northwest Atlantic (Cairns and Chapman 2001). Other recent expeditions to the New England and Corner

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[8] An additional sea pen, *Virgularia mirabilis* (Müller, 1776), was mentioned in Hecker and Blechschmidt (1980): "Seven specimens of this sea pen were seen on the slope between Baltimore and Norfolk Canyons at depths from 1500 to 1800 meters." It has been recorded in Europe and is said to occur in the western Atlantic, but this is the only mention of this species in these waters that we have been able to find.

Rise Seamounts have also found stony corals (Adkins *et al*. 2006; Watling *et al*. 2005, Shank *et al*. 2006).

Further information on the distributions of stony corals off the northeastern U.S., including the submarine canyons and the four seamounts within the EEZ (Bear, Physalia, Mytilus, and Retriever) can be found in Packer et al (2007) and Table 42, below.

Black Corals (Class Anthozoa, Order Antipatharia)
Antipatharians are predominantly tropical, but some species are known to occur in the northwest Atlantic. Watling et al. (2005) collected at least 8 species of black coral from the seamounts during their 2004 expedition; Brugler and France (2006) observed and collected 15 species of black coral during their 2005 expedition to the New England and Corner Rise Seamounts, including 7 species that they did not previously observe on the seamounts. Among the black corals that have been positively identified from the four seamounts within the EEZ to date include *Bathypathes* (Schizopathidae) from Bear (1195–1402 and 1843–1888 m) and Retriever (1983 m) and *Parantipathes* (Schizopathidae) from Retriever (2045 m) (Thoma et al. 2009). Bushy black coral (*Leiopathes* sp.) has been collected from 1643 m on Bear Seamount (Brugler 2005); it is also found in the collections of the Smithsonian Institution, having been collected in 1883 by the R/V Albatross from 1754 m near the same area off Georges Bank. Another black coral, *Cirrhipathes* sp., is also found in the Smithsonian Institution collections, and was also collected in 1883 by the R/V Albatross at 262 m off Virginia.

Gorgonians (Order Gorgonacea) and true soft corals (Order Alcyonacea)
Seventeen species in seven gorgonian families were recorded for the northeastern U.S. shelf and slope north of Cape Hatteras (Packer et al. 2007). These families (Acanthogorgiidae, Paramuriceidae, Anthothelidae, Paragorgiidae, Chrysogorgiidae, Primnoidae, and Isiddae) are the best documented because of their larger sizes, as well as being most abundant in the deeper waters of the continental slope (Watling and Auster 2005). Nine species of true soft corals in three families were recorded for the northeastern U.S. shelf and slope north of Cape Hatteras (Packer et al. 2007). Two species that are very numerous in nearshore records are the true soft corals *Gersemia rubiformis* and *Alcyonium* species (Watling and Auster 2005). It should be noted that, for a variety of reasons, there is uncertainty about the accuracy of the identifications of species from these two orders from the various historical surveys (Watling and Auster 2005), so these identifications and surveys should be interpreted with caution.

Theroux and Wigley (1998) found that both gorgonians and true soft corals were present along the outer margin of the continental shelf and on the slope and rise, and were sparse and patchy in all areas, particularly in the northern section. They were not collected in samples taken at < 50 m in depth, and were most abundant between 200-500 m. Identified species include gorgonians such as *Acanella* sp., *Paragorgia arborea*, and *Primnoa reseda* [now *resedaeformis*, see Cairns and Bayer (2005)] and the true soft coral *Alcyonium* sp. Gorgonians and true soft corals were collected from gravel and rocky outcrops (Theroux and Wigley 1998).

Watling and Auster (2005) noted two distinct distributional patterns for the gorgonians and true soft corals. Most are deepwater species that occur at depths > 500 m; these include species of gorgoninans in the genera *Acanthogorgia*, *Acanella*, *Anthothela*, *Lepidisis*, *Radicipes*, and *Swiftia*, and true soft corals in the genera *Anthomastus* and *Clavularia*. Other species occur throughout shelf waters to the upper continental slope and include the gorgonians *Paragorgia arborea*, *Primnoa resedaeformis*, and species in the genus *Paramuricea*. *Paragorgia arborea* was described by Wigley (1968) as a common component of the gravel fauna of the Gulf of Maine, while Theroux and Grosslein (1987) reported *Primnoa resedaeformis*, as well as *Paragorgia arborea*, to be common on the Northeast Peak of Georges Bank. Both species are widespread in the North Atlantic (Tendal 1992); *Primnoa resedaeformis* has been reported south to off Virginia Beach, Virginia (37°03'N) (Heikoop et al. 2002). The majority of records for *Acanthogorgia armata*, *Paragorgia arborea*, and *Primnoa resedaeformis* in the Watling et al (2003) database come from Lydonia, Oceanographer, and Baltimore canyons. In addition, *Primnoa resedaeformis* was found throughout the Gulf of Maine and on the Northeast Peak of Georges Bank, affirming Theroux and Grosslein's (1987) observations.

Further information on the distributions of gorgonians and soft corals off the northeastern U.S., including the submarine canyons and the four seamounts within the EEZ (Bear, Physalia, Mytilus, and Retriever) can be found in Packer et al. (2007); newer records of gorgonians found on the seamounts are noted in Table 91, below.

Table 91 – Deep-sea coral species of the Northeast Region. Does not include black corals on the seamounts (Antipatharians)

Coral group	*Species*	*Distribution on East Coast*	*Depth Range (m)*	*References*
Order Scleractinia, Family Caryophillidae	*Caryophyllia ambrosia ambrosia* Alcock, 1898	Cosmopolitan; found on Bear Seamount	1487-2286	Cairns and Chapman 2001; Moore et al. 2003
Order Scleractinia, Family Caryophillidae	*Caryophyllia ambrosia caribbeana* Cairns, 1979	Endemic to western Atlantic	183-1646	Cairns and Chapman 2001
Order Scleractinia, Family Caryophillidae	*Dasmosmilia lymani* (Pourtales, 1871)	Cosmopolitan. Found on soft substrates. Continental slope south of New England, Lydonia Canyon, continental shelf between Baltimore and Hudson Canyons, in Baltimore Canyon, and between 100-200 m on the shelf south of Hudson Canyon and in the head of Hudson Canyon	37-366	Hecker 1980; Hecker et al. 1983; Hecker 1990; Cairns and Chapman 2001; V. Guida (unpublished data, NMFS James J. Howard Marine Sciences Lab, Highlands, NJ).
Order Scleractinia, Family Caryophillidae	*Deltocyathus italicus* (Michelotti, 1838)	Amphi-Atlantic with a disjunct distribution	403-2634	Cairns and Chapman 2001

Coral group	*Species*	*Distribution on East Coast*	*Depth Range (m)*	*References*
Order Scleractinia, Family Caryophillidae	*Desmophyllum dianthus* (Esper, 1794)	Cosmopolitan; outcrops and underhangs from 1000-1900 m. Outcrops of Corsair Canyon. Found in Heezen Canyon. Deeper parts of Lydonia Canyon. Boulders and outcrops in Oceanographer Canyon, 650-1600 m. On an outcrop near Hudson Canyon. Occasionally on axis of Norfolk Canyon. Continental slope on the southwestern edge of Georges Bank, between Veatch and Hydrographer Canyons; in the Mid-Atlantic on the slope between Lindenkohl Canyon on the south and Carteret Canyon on the north; in the Mid-Atlantic on the slope bounded by Toms Canyon to the south and Meys Canyon to the north; Bear Seamount	183-2250	Hecker 1980; Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Malahoff et al. 1982; Cairns and Chapman 2001; Moore et al. 2003
Order Scleractinia, Family Caryophillidae	*Lophelia pertusa* (L, 1758)	Cosmopolitan; west wall of Oceanographer Canyon wall at 1100 m, dead rubble also found on wall at depths from 700-1300 m; Bear Seamount	146-1200; 700-1300	Hecker 1980; Hecker and Blechschmidt 1980; Hecker et al. 1980; Cairns and Chapman 2001; Moore et al. 2003
Order Scleractinia, Family Caryophillidae	*Solenosmilia variabilis* Duncan, 1873	Cosmopolitan; Lydonia canyon; on the slope bounded by Toms Canyon to the south and Meys Canyon to the north; large colony recovered from east flank of Lydonia Canyon. Bear Seamount	220-1383	Hecker 1980; Hecker et al. 1983; Cairns and Chapman 2001; Moore et al. 2004
Order Scleractinia, Family Caryophillidae	*Vaughanella margaritata* (Jourdan, 1895)	Endemic to northwestern Atlantic; Bear Seamount	1267	Cairns and Chapman 2001; Moore et al. 2003
Order Scleractinia, Family Dendrophylliidae	*Enallopsammia profunda* (Pourtales, 1867)	Endemic to western Atlantic	403-1748	Cairns and Chapman 2001
Order Scleractinia, Family Dendrophylliidae	*Enallopsammia rostrata* (Pourtales, 1878)	Cosmopolitan; Bear Seamount	300-1646	Cairns and Chapman 2001; Moore et al. 2004
Order Scleractinia, Family Flabellidae	*Flabellum alabastrum* Moseley, 1873	Amphi-Atlantic with contiguous distribution. Bear Seamount. Canyons and slope from 600-2500 m. Seen in Corsair Canyon. Found in Heezen and Oceanographer Canyons on soft substrate. Seen on deep continental slope near Alvin Canyon. Found on slope south of Baltimore Canyon. Found in deeper parts of the continental slope south of Norfolk Canyon and in axis of Norfolk Canyon on soft substrate. Some may be *F. angular or* or *F. moseleyi* (the latter identification is doubtful, however)	357-1977	Hecker 1980; Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Cairns and Chapman 2001; Moore et al. 2003, 2004
Order Scleractinia, Family Flabellidae	*Flabellum angulare* Moseley, 1876	Amphi-Atlantic with contiguous distribution; see also *F. alabastrum*	2266-3186	Hecker 1980; Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Cairns and Chapman 2001; Moore et al. 2003
Order Scleractinia, Family Flabellidae	*Flabellum macandrewi* Gray, 1849	Amphi-Atlantic with contiguous distribution; see also *F. alabastrum*	180-667	Hecker 1980; Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Cairns and Chapman 2001; Moore et al. 2003
Order Scleractinia, Family Flabellidae	*Javania cailleti* (Duch. & Mich., 1864)	Cosmopolitan; Lydonia Canyon, axis of Oceanographer Canyon between 935-1220 m	30-1809	Hecker 1980; Hecker et al. 1983; Cairns and Chapman 2001

Coral group	*Species*	*Distribution on East Coast*	*Depth Range (m)*	*References*
Order Scleractinia, Family Fungiacyathidae	*Fungiacyathus fragilis* Sars, 1872	Cosmopolitan	412-460	Cairns and Chapman 2001
Order Scleractinia, Family Rhizangiidae	*Astrangia poculata* (Ellis & Solander, 1786)	Endemic to western Atlantic	0-263	Theroux and Wigley 1998; Cairns and Chapman 2001
Order Alcyonacea, Family Alcyoniidae	*Alcyonium digitatum* Linné, 1758	?	?	Watling and Auster 2005
Order Alcyonacea, Family Alcyoniidae	*Anthomastus agassizii* Verrill, 1922	Hard substrates from Corsair Canyon to Hudson Canyon from 750-1900 m; outcrops in Corsair Canyon; in Heezen Canyon. Found in depper parts of Lydonia Canyon. On boulders and outcrops in Oceanographer Canyon from 1057-1326 m. On deep continental slope near Alvin Canyon; on slope on the southwestern edge of Georges Bank, between Veatch and Hydrographer Canyons; in Mid-Atlantic on slope flanked by Lindenkohl Canyon to south and Carteret Canyon to north and on slope bounded by Toms Canyon to south and Meys Canyon to north (i.e. betweenBaltimore and Hudson Canyons); Bear Seamount	750-1326	Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Opresko 1980; Valentine et al. 1980; Hecker 1990; Moore et al. 2003; Watling and Auster 2005
Order Alcyonacea, Family Alcyoniidae	*Anthomastus grandiflorus* Verrill, 1878	Soft substrates, highest densities in canyons; found in Corsair, Heezen (west wall), Oceanographer Canyons; seen near Hudson Canyon, Toms Canyon, in Baltimore Canyon, in axis of Norfolk Canyon. In the northern canyons found from 700-1500 m, southern canyons from 1500-2200 m; as deep as 2600 m. Frequently seen where a species of *Pennatula* was also common.	700-2600	Hecker and Blechschmidt 1980; Hecker et al. 1980; Opresko 1980; Watling and Auster 2005
Order Alcyonacea, Family Clavulariidae	*Clavularia modesta* (Verrill, 1874)	?	greater than 500 m?	Watling and Auster 2005
Order Alcyonacea, Family Clavulariidae	*Clavularia rudis* (Verrill, 1922)	Found in axis of Heezen (1100 m), Lydonia (900 m), Oceanographer Canyons (750 and 900 m)	750-1099	Hecker and Blechschmidt 1980; Hecker et al. 1980; Opresko 1980; Watling and Auster 2005
Order Alcyonacea, Family Nephtheidae	*Capnella florida* (Rathke, 1806)	Lydonia, Oceanographer, Baltimore Canyons, but only high abundances in Lydonia at 350-1500 m; axis of Heezon Canyon from 1100-1200 m; wall of Corsair Canyon from 600-1000 m; continental slope south of New England off Georges Bank	350-1500	Hecker and Blechschmidt 1980; Hecker et al. 1980; Opresko 1980; Hecker 1990; Watling and Auster 2005
Order Alcyonacea, Family Nephtheidae	*Capnella glomerata* (Verrill, 1869)	Several individuals found in Lydonia Canyon	200-561	Hecker et al. 1980; Opresko 1980; Watling and Auster 2005

Coral group	*Species*	*Distribution on East Coast*	*Depth Range (m)*	*References*
Order Alcyonacea, Family Nephtheidae	*Gersemia fruticosa* (Sars, 1860)	Near and in deep portion of Hudson Canyon around 2250-2500 m; at the mouth of Norfolk Canyon; seen near heads of Toms and Carteret Canyons (i.e., between Baltimore and Hudson Canyons). Southern part of study area at depths from 2300-3100 m. Different form seen in Corsair and Heezen Canyons between 600-1200 m	600-3100	Hecker and Blechschmidt 1980; Opresko 1980; Watling and Auster 2005
Order Alcyonacea, Family Nephtheidae	*Gersemia rubriformis* (Ehrenberg, 1934)	?	?	Watling and Auster 2005
Order Gorgonacea, Family Acanthogorgiidae	*Acanthogorgia armata* Verrill, 1878	Found in many canyons from 600-2500 m. Seen on boulders or outcrops in Corsair and Oceanographer Canyons; found in Lydonia and Oceanographer Canyons between 400-1299 m. Seen on deep continental slope near Alvin Canyon. Found on an outcrop near Hudson Canyon. Found at 350 m in Baltimore Canyon. Occasionally in axis of Norfolk Canyon on exposed outcrops.	350-1300	Hecker and Blechschmidt 1980; Hecker et al. 1980; Opresko 1980; Malahoff et al. 1982; Watling and Auster 2005
Order Gorgonacea, Family Anthothelidae	*Anthothela grandiflora* (Sars, 1856)	Lydonia, Oceanographer, Baltimore Canyons	450-1150	Hecker et al. 1980; Opresko 1980; Watling and Auster 2005
Order Gorgonacea, Family Chrysogorgiidae	*Chrysogorgia agassizii* (Verrill, 1883)	Several individuals that may be *C. agassizii* found in the vicinity of Hudson Canyon. Genus also noted on Bear, Retriever Seamounts (Thoma et al. 2009)	2150. Bear: 1559, 1994–2031; Retriever: 3860	Watling and Auster 2005; Thoma et al. (2009)
Order Gorgonacea, Family Chrysogorgiida	*Metallogorgia melanotrichos* (Wright and Studer, 1889)	Bear, Physalia, Retriever Seamounts. Genus also noted on Bear, Retriever by Thoma et al. 2009	Bear: 1491, 1559, (Mosher and Watling 2009); 1559, 1639 (Thoma et al. 2009). Retriever: 1983, 2012 (Thoma et al. 2009)	Mosher and Watling 2009; Thoma et al. 2009
Order Gorgonacea, Family Chrysogorgiida	*Iridogorgia pourtalesii* Verrill, 1883	?	?	Watling and Auster 2005
Order Gorgonacea, Family Chrysogorgiida	*Radicipes gracilis* (Verrill, 1884)	Genus noted on continental slope (38.5461, –70.7995) and on Bear Seamount by Thoma et al. 2009; species noted on Bear by Moore et al. 2004.	Continental slope: 3000; Bear: 1431–1464, 1428–1650	Moore et al. 2004; Watling and Auster 2005; Thoma et al. 2009

Coral group	***Species***	***Distribution on East Coast***	***Depth Range (m)***	***References***
Order Gorgonacea, Family Isididae	*Acanella arbuscula* (Johnson, 1862)	Found in Corsair, Heezen, Oceanographer Canyons; Oceanographer Canyon between 1046-1191 m; on deep continental slope near Alvin Canyon and just south of Baltimore Canyon; in Mid-Atlantic on slope flanked by Lindenkohl Canyon to south and Carteret Canyon to north and on slope bounded by Toms Canyon to south and Meys Canyon to north; continental slope south of New England off Georges Bank; seen on soft substrates from 600-1300 m depth in the north and 1500-2000 m depth in the south. Northern and southern forms may be different species. Genus noted in Gilbert Canyon, on continental slope (39.7807 –70.7091) and on Retriever Seamount by Thoma et al. 2009. Maciolek et al. 1987: between Toms Canyon to the north and Wilmington Canyon to the south: 38° 35.98N, 72° 52.97W, prefer shallower flat ridges.	600-2278 Gilbert Canyon: 2097; continental slope: 1600; Retriever: 2035, 2040; Maciolek et al. 1987: peak in abundance of 0.3 individuals per m^2 between 2000-2150.	Hecker and Blechschmidt 1980; Hecker et al 1980; Opresko 1980; Maciolek et al. 1987; Hecker 1990; Theroux and Wigley 1998; Watling and Auster 2005; Thoma et al 2009
Order Gorgonacea, Family Isididae	*Keratoisis grayi* Wright, 1869	?	?	Watling and Auster 2005
Order Gorgonacea, Family Isididae	*Keratoisis ornata* Verrill, 1878	?	?	Watling and Auster 2005
Order Gorgonacea, Family Isididae	*Lepidisis caryophyllia* Verrill, 1883	Bear Seamount?	?	Moore et al. 2003; Watling and Auster 2005
Order Gorgonacea, Family Paragorgiidae	*Paragorgia arborea* (Linné, 1758)	Gulf of Maine, Georges Bank, and Canyons [Lydonia (300-900 m), Oceanographer (300-1100 m), axis of Baltimore (400 m, 500 m), Norfolk (4000-600 m)]; probably Bear Seamount	300-1100	Wigley 1968; Hecker and Blechschmidt 1980; Hecker et al. 1980; Opresko 1980; Theroux and Grosslein 1987; Theroux and Wigley 1998; Moore et al. 2003; Watling and Auster 2005
Order Gorgonacea, Family Paramuriceidae	*Paramuricea grandis* Verrill, 1883	Gulf of Maine and canyons from Corsair to near Hudson Canyon between 750-215- m. On wall and axis of Oceanographer Canyon on boulders and outcrops. Depths between 400-1349 m in Lydonia and Oceanographer Canyons. Seen from Corsair Canyon to near Hudson Canyon from 700-2200 m on hard substrates. Outcrops in Corsair Canyon. Found in Heezen Canyon and deeper parts of Lydonia Canyon. Deep continental slope near Alvin Canyon; on slope on the southwestern edge of Georges Bank, between Veatch and Hydrographer Canyons; in Mid-Atlantic on slope flanked by Lindenkohl Canyon to south and Carteret Canyon to north and on slope bounded by Toms Canyon to south and Meys Canyon to north. Not seen in Norfolk Canyon. Genus also noted in Gulf of Maine, Oceanographer Canyon, and on Bear, Retriever Seamounts by Thoma et al. 2009.	400-2200;Thoma et al 2009 Gulf of Maine: 220, 228, 241; Oceanographer Canyon: 814, 1078; Bear Seamount: 1378–1431; Retriever Seamount: 1981, 1984, 1985, 2040	Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Opresko 1980; Valentine et al. 1980; Watling and Auster 2005; Thoma et al 2009
Order Gorgonacea, Family Paramuriceidae	*Paramuricea placomus* (Linné, 1758)	Gulf of Maine	?	Watling and Auster 2005
Order Gorgonacea, Family Paramuriceidae	*Paramuricea* n. sp.	?	?	Watling and Auster 2005

Coral group	*Species*	*Distribution on East Coast*	*Depth Range (m)*	*References*
Order Gorgonacea, Family Paramuriceidae	*Swiftia casta* (Verrill, 1883)	Bear Seamount?	?	Moore et al. 2003; Watling and Auster 2005
Order Gorgonacea, Family Primnodidae	*Narella laxa* Deichmann, 1936	?	?	Watling and Auster 2005
Order Gorgonacea, Family Primnodidae	*Primnoa resedaeformis* Gunnerus, 1763)	Gulf of Maine, Georges Bank, and Canyons [Lydonia (560 m), Oceanographer, Baltimore (450 m), Norfolk (400 m)]; south to off Virginia Beach, VA; probably Bear Seamount	91-548	Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Opresko 1980; Valentine et al. 1980; Theroux and Grosslein 1987; Theroux and Wigley 1998; Moore et al. 2003; Cairns and Bayer 2005; Watling and Auster 2005; Heikoop et al. 2002
Order Gorgonacea, Family Primnodidae	*Thouarella grasshoffi* Cairns, 2006	North Atlantic; Oceanographer Canyon, Bear Seamount	720-1760 in North Atlantic (Cairns 2006)	Watling and Auster 2005 = *Thouarella* n. sp.; Cairns 2006, 2007
Order Gorgonacea, Family Primnodidae	*Parastenella atlantica,* new species	Type Locality: Retriever Seamount, 39°48.5454'N, 66 ° 14.9883'W. 23 May 2004	1984	Cairns 2007
Order Gorgonacea, Family Primnodidae	*Calyptrophora antilla* Bayer, 2001	Bear Seamount, 39°53'42"N, 66°23'07"W. 17 July 2003	1684	Cairns 2007
Order Gorgonacea, Family Primnodidae	*Paranarella watlingi,* new species	Type locality: Retriever Seamount, 39 °48.0754'N, 66°14.9408'W. 23 May 2004	3855	Cairns 2007
Order Pennatulacea, Family Anthoptilidae	*Anthoptilum grandiflorum*	Newfoundland to Bahamas	274-3651[9];	US NMNH collection, OBIS; Hecker and Blechschmidt 1980; Opresko 1980
Order Pennatulacea, Family Anthoptilidae	*Anthoptilum murrayi*	Lydonia Canyon to Puerto Rico, Brazil (up to 75 cm in height; Pires et al 2009)	430-2491 (1538 m min in NE US)	US NMNH collection, OBIS
Order Pennatulacea, Family Anthoptilidae	*Benthoptilum sertum* Verrill, 1885	North Carolina, near Roanoke Island; New Jersey near Hudson Canyon	NC: 1542; NJ: 1962	US NMNH collection
Order Pennatulacea, Family Funiculinidae	*Funinculina armata* Verrill, 1879	South of Nantucket Shoals, MA; Hudson Canyon; NJ, Hog Island, VA	1538-2601	US NMNH collection
Order Pennatulacea, Family Halipteridae	*Halipteris (=Balticina) finmarchica*	Newfoundland to Massachusetts; Opresko 1980: found near Atlantis Canyon and in Heezen Canyon (as *Balticina*).	37-2249 (229 m min in NE US) as *Balticina*[10]	US NMNH collection as *Balticina*; Hecker and Blechschmidt 1980 and Opresko 1980 as *Balticina*; see Williams 1995 for current taxonomy

[9] Hecker and Blechschmidt 1980 note that "six individuals of this species were seen in the northern region of the study area between depths of 900-2200 m." Opresko 1980: one at 1800 m off Cape Hatteras, three at 2150 m near Atlantis Canyon, six on wall of Heezen Canyon between 850-1050 m.

[10] Hecker and Blechschmidt 1980 note that "six individuals of this species were seen in the northern region of the study area between depths of 900-2200 m." Opresko 1980: near Atlantis Canyon and in Heezen Canyon between 900-2200 m. Found as shallow as 360-380 m off Nantucket Shoals and Martha's Vineyard based on Smithsonian records, has been found off of Brown's Ledge, off Newport R.I. at 23.8 m depth in 1880, and the NE edge of Georges Bank at 229 m by Verrill.

Coral group	*Species*	*Distribution on East Coast*	*Depth Range (m)*	*References*
Order Pennatulacea, Family Kophobelemnidae	*Kophobelemnon stelliferum*	Newfoundland to South Carolina. Hecker et al. 1980: Lydonia Canyon: soft substrates, in the axis and on the east wall. Opresko 1980: common on slope north of Baltimore Canyon, off Cape Hatteras, in Heezon and Corsair Canyons (Hecker et al 1980). In Mid-Atlantic was found on slope areas by Hecker et al (1983): Slope Area I was flanked by Lindenkohl Canyon on the south and Carteret Canyon on the north; Slope II was about 70 miles north of Slope I, and bounded by Toms Canyon to the south and Meys Canyon to the north. Further north Slope III, a 25 mile wide section of the continental slope on the southwestern edge of Georges Bank, between Veatch and Hydrographer Canyons. Maciolek et al. 1987: between Toms Canyon to the north and Wilmington Canyon to the south: 38° 35.98N, 72° 52.97W; highest densities in flat depressions,	393-2350 (1330 m min in NE US)[11],	US NMNH collection, OBIS; Hecker et al. 1980, 1983; Opresko 1980; Maciolek et al. 1987
Order Pennatulacea, Family Kophobelemnidae	*Kophobelemnon scabrum*	Nova Scotia to Virginia	1977-2249	US NMNH collection
Order Pennatulacea, Family Kophobelemnidae	*Kophobelemnon tenue*	Massachusetts to Virginia	2491-4332	US NMNH collection
Order Pennatulacea, Family Pennatulidae	*Pennatula aculeata*	Newfoundland to Virginia, including submarine canyons (e.g., Lydonia, Oceanographer, Norfolk).	119-3316[12].	US NMNH collection, OBIS. Hecker et al. 1980, 1983; Hecker and Blechschmidt 1980; Opresko 1980
Order Pennatulacea, Family Pennatulidae	*Pennatula grandis*	New Jersey	1850-2140	US NMNH collection, OBIS
Order Pennatulacea, Family Pennatulidae	*Pennatula borealis*	Newfoundland to North Carolina	219-2295; has been found as shallow as 360-380 m off Nantucket Shoals and Martha's Vineyard based on Smithsonian records.	US NMNH collection, OBIS

[11] Hecker et al. 1980: found throughout study area at depths ranging from 1300-1800 m; also seen at comparable depths in Hatteras Canyon region. Opresko 1980: states known range from 215-2369 m. Lydonia Canyon between 700-800 m, common on slope north of Baltimore Canyon between 1550-1800 m, also at 200 m north of Baltimore Canyon, between 1750-1900 m off Cape Hatteras, between 1300-1600 m in Heezon and Corsair Canyons. Hecker et al. 1983: found between 1510-2060 m on Slope III; 1140-2190 on Slope I; mostly 1460-1540 m on muddy substrate with some gravel on Slope II. Maciolek et al. 1987: became increasingly abundant below 2200 m. Found in highest densities between 2300-2350 m.

[12] Hecker and Blechschmidt 1980 note that the genus is "found throughout the study area, but it appeared in high concentrations only in the canyons. It was found at shallow depths in the northern canyons (600-1500 m) and deeper in the southern canyons (1500-2400 m). "Quite common near head of Lydonia Canyon between 400-600 m, soft substrates in the shallow axis and on the west wall; Hecker et al. 1983 reports high concentrations between 300-450 or 550 m in the silty axis. Opresko 1980: exceptionally high concentrations 2150-2300 m in axis of Norfolk Canyon; 1700-1799 m in Oceanographer (deep part of axis), 350-1375 in Lydonia.

Coral group	***Species***	***Distribution on East Coast***	***Depth Range (m)***	***References***
Order Pennatulacea, Family Protoptilidae	*Distichoptilum gracile*	Nova Scotia to North Carolina. Oceanographer Canyon: soft substrates, lower east wall and in the axis (Hecker et al 1980). In Mid-Atlantic was found on slope areas by Hecker et al, 1983: Slope Area I was flanked by Lindenkohl Canyon on the south and Carteret Canyon on the north; Slope II, was about 70 miles north of Slope I, and bounded by Toms Canyon to the south and Meys Canyon to the north. Also Baltimore Canyon. Further north Slope III, a 25 mile wide section of the continental slope on the southwestern edge of Georges Bank, between Veatch and Hydrographer Canyons.	1211-2844 (doubtful report at 59 m)[13]	US NMNH collection, OBIS; Hecker et al 1980, 1983; Opresko 1980
Order Pennatulacea, Family Protoptilidae	*Protoptilum abberans*	Nova Scotia to Virginia	1483-2359	US NMNH collection
Order Pennatulacea, Family Protoptilidae	*Protoptilum carpenteri*	Massachusetts to North Carolina	1334-2194	US NMNH collection, OBIS
Order Pennatulacea, Family Scleroptilidae	*Scleroptilum gracile*	Massachusetts to Virginia	2513-4332	US NMNH collection
OrderPennatulacea, Family Scleroptilidae	*Scleroptilum grandiflorum*	Massachusetts to North Carolina	1502-2505	US NMNH collection, OBIS
Order Pennatulacea, Family Ombellulidae	*Ombellula guntheri*	Massachusetts to Virginia	2683-3740 (3166 m min in NE US)	US NMNH collection, Williams 1995
Order Pennatulacea, Family Ombellulidae	*Ombellula lindahlii*	Massachusetts to the Virgin Islands	549-3338 (1538 m min in NE US)	US NMNH collection, OBIS, Williams 1995
Order Pennatulacea, Family Virgulariidae	*Balticina finmarchica*	Newfoundland to Massachusetts; Opresko 1980: found near Atlantis Canyon and in Heezen Canyon.	37-2249 (229 m min in NE US)[14]	US NMNH collection; Hecker and Blechschmidt 1980; Opresko 1980
Order Pennatulacea, Family Virgulariidae	*Stylatula elegans*	New York to Florida; noted in Baltimore Canyon (Hecker et al. (1980, 1983) and Lydonia Canyon (Opresko 1980); on continental shelf off NJ (Smithsonian collections) and near head of Hudson Canyon (V. Guida, unpublished data), In Mid-Atlantic was found on two slope areas by Hecker et al 1983: Slope Area I was flanked by Lindenkohl Canyon on the south and Carteret Canyon on the north; Slope II, was about 70 miles north of Slope I, and bounded by Toms Canyon to the south and Meys Canyon to the north.	20-812 (51 m min in NE US)[15]	US NMNH collection, OBIS; Hecker et al. 1980, 1983; Opresko 1980; V. Guida, (unpublished data, NMFS James J. Howard Marine Sciences Lab, Highlands, NJ)

[13] Opresko 1980 reports might be found 600-2500 m; Oceanographer and Lydonia Canyons between 1100-1800 m. Hecker et al. 1983: below 990 m in Lydonia, esp. 1000-1500 m; dominant on east wall 1200-1500 m. Found below 1200 m and common below 1600 m in Slope III; Slope I below 1330 m, mud bottom and especially below 1900 m; Slope II in Hendrickson Canyon 640 -1640 m and also common in “zone 4” between 1460-1540 m and “zone 5” between 1510-2290. Baltimore Canyon 1190-2040 m; north flank dominant between 1500-1700 m.

[14] Hecker and Blechschmidt 1980 note that “six individuals of this species were seen in the northern region of the study area between depths of 900-2200 m.” Opresko 1980: near Atlantis Canyon and in Heezen Canyon between 900-2200 m. Found as shallow as 360-380 m off Nantucket Shoals and Martha’s Vineyard based on Smithsonian records, has been found off of Brown’s Ledge, off Newport R.I. at 23.8 m depth in 1880, and the NE edge of Georges Bank at 229 m by Verrill.

[15] Opresko 1980: one specimen found at about 600 m in Lydonia Canyon. Hecker et al 1983: high densities found 100-300 m Slope II, 200-300 m Slope I, less in Baltimore Canyon at about 150-300 m.

12.2.2 Vulnerability of corals to fishing gear impacts

The following is a review of research studies concerned with the impacts of commercial fishing on deepwater corals and coral reefs. The literature addressed several gear types as well as study locations. While the studies sites cover a variety of locations globally, the impacts of commercial fishing on the local corals and seafloor are virtually identical throughout the literature. The disturbances seen ranged from scarring left by trawl gear, to complete destruction of coral and stripping of the seafloor to underlying rock. The surviving coral in fished areas was often located on undesirable fishing terrain, or at depths not targeted by fishermen. This section describes the methods of research, gear types evaluated, and impact on corals and the surrounding seafloor. The potential for coral recovery as evidenced by growth rates and other biological factors is also discussed.

12.2.2.1Study methods

Each of the study sites was observed using some form of photographic or continuous video transects. Several studies mapped the area using sidescan sonar (Wheeler et al 2005, Fosså et al 2002) or multibeam sonar in conjunction with a deep camera system (Althaus et al 2009, Grehan et al 2005). This technique allowed them to determine the damage caused by dragging gear over the seafloor.

The logs of fishing trips, reports from fishermen, and other literature on fishing activities at each of the areas, were utilized by a number of the studies from each of the different regions (Althaus et al 2009, Koslow et al 2001, Heifetz et al 2009, Fosså et al 2002, Cryer et al 2002). Anecdotal reports acted as a guide to further research areas, as well as providing information about to the history of fishing and practices in the area (Fosså et al 2002).

Samples were examined in three of the studies to determine the associated fauna in the area of the corals, as well as to assess the bycatch in commercial fisheries. One study (Cryer et al 2002) used previously collected and stored samples from other research trips to determine fauna of the area. Another (Hall-Spencer et al 2002) collected samples while accompanying two French trawlers on a fishing trip to examine commercial bycatch. A third study (Koslow et al 2001) used dredge, drop line with hooks, and traps to sample benthic, as well as motile, fauna associated with the corals.

12.2.2.2Gear types evaluated

In reviewing the research there was frequently a lack of adequate gear descriptions being examined by each study, however, three papers gave a general description of what gears are commonly employed in each of the fisheries, as well as the gear used for research. While gear descriptions can be found via other sources, the variety of gear types as well as techniques used to fish them leaves much to be inferred when the only description provided by the researcher is that a "trawl" was used. A few studies were successful at providing gear descriptions, but the dimensions of gear size can vary and a universal description and size should not be assumed for all fishing effort with each gear type. It appears that the gear could be lumped into categories, based on door size and net width for the example of trawls, however larger boats are most likely going to pull larger gear, in theory causing more damage.

The best attempt at describing the gear associated with fishing impacts provided typical gear set up and use for deepwater fishing using long-lines, gill nets, traps, and trawls. It stated that for long-lines 85 hooks were typically set 3m apart on a line, and 100-120 lines were often set out (averaging 8000-9600 hooks on 28-35km of line). Gill nets in the industry were 50m long x 12m high. These were worked in stings of 700 nets. Trawls were usually fitted with rockhopper gear and held open by otter boards weighing around 1000kg each, set at a distance of 60-70m apart. The trawls are then towed for about 4 hours at a around 5-8km/h (Grehan et al 2005).

There was only one study (Cryer et al 2002) that gave a short description of the gear in use, observing that the trawl doors were set at about 40m apart, but when towing (at 5.0-5.4 km/h) the net had an effective width of around 25m. It also mentioned the use of a "Florida Flyer" net (85mm mesh and 35mm mesh) set up between "Bison" doors being used in the trawl. This at least provides a starting point for researching further descriptions of the gear used during the study.

The gear used by two 38m commercial trawlers in another study (Hall-Spencer et al 2002) was briefly described, stating that both boats used trawls with rockhopper gear and 900kg otter boards, with the boards set at approximately 22m apart. The speed was the same 4.5-5.5 km/h towing speed that appeared to be the general towing speed mentioned for fishing, or camera-towed research.

12.2.2.3Study Sites and Findings

The research area of the studies can be broken down into larger regions. Three of the studies took place in the southern Pacific Ocean. Two of these (Althaus et al 2009, Koslow et al 2001) focused on seamounts south of Tasmania while the other (Cryer et al 2002) examined the Bay of Plenty on the north shore of New Zealand.

On the Tasmanian seamounts, areas that had never been trawled, or were lightly fished (determined via trip logs), were dominated by the coral *Solenosmilia variabilis*, making up 89-99% of coral cover in never trawled areas (Althaus et al 2009) as well as seamounts peaking below 1400m (Koslow et al 2001). It was found that active trawling at sites removed most, or all, of the coral and associated substrate, leaving bare rock in heavily trawled areas, and coral rubble and sand at the lower limits of fishing activity (Koslow et al 2001) (Figure 27 and Figure 28). This was supported by photographic transects by Althaus et al (2009) showing coral in less than 2% of trawled areas. "Trawling ceased" areas, where trawling had effectively stopped 5-10 years earlier, showed coral in approximately 21% of the transects. Figure 29 shows how coral has been affected in areas that are actively trawled, never trawled, and where trawling has ceased.

This study also found a higher abundance of the faster growing hydroids colonizing cleared areas, smaller corals and octocorals, as well as noting whip-like chrysogorgiid which were flexible and could presumably bend and pass under the trawls.

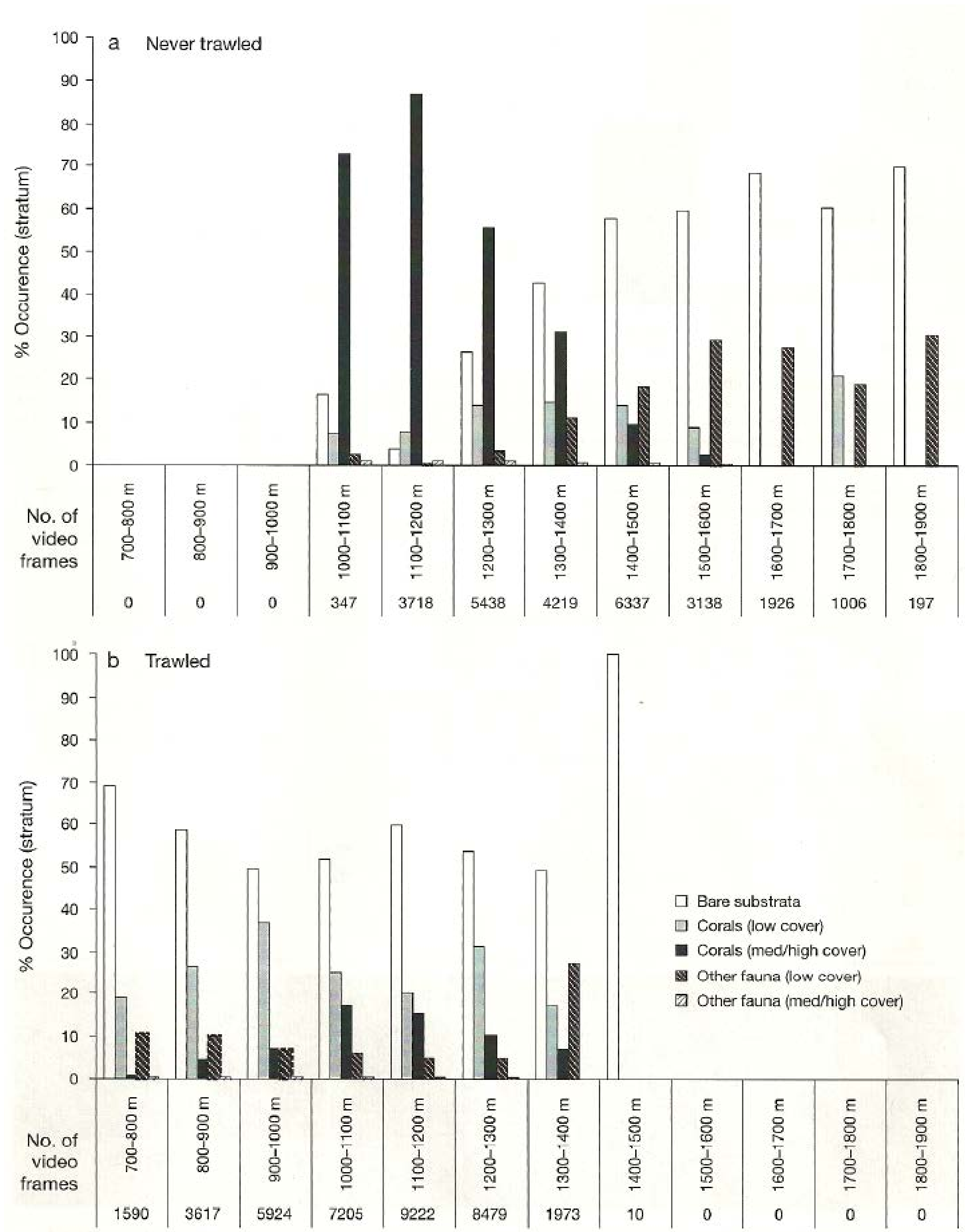

Figure 27 – Percent occurrence of coral, bare substrate, and other fauna at depths on a) never trawled and b) trawled seamounts. (Althaus et al 2009)

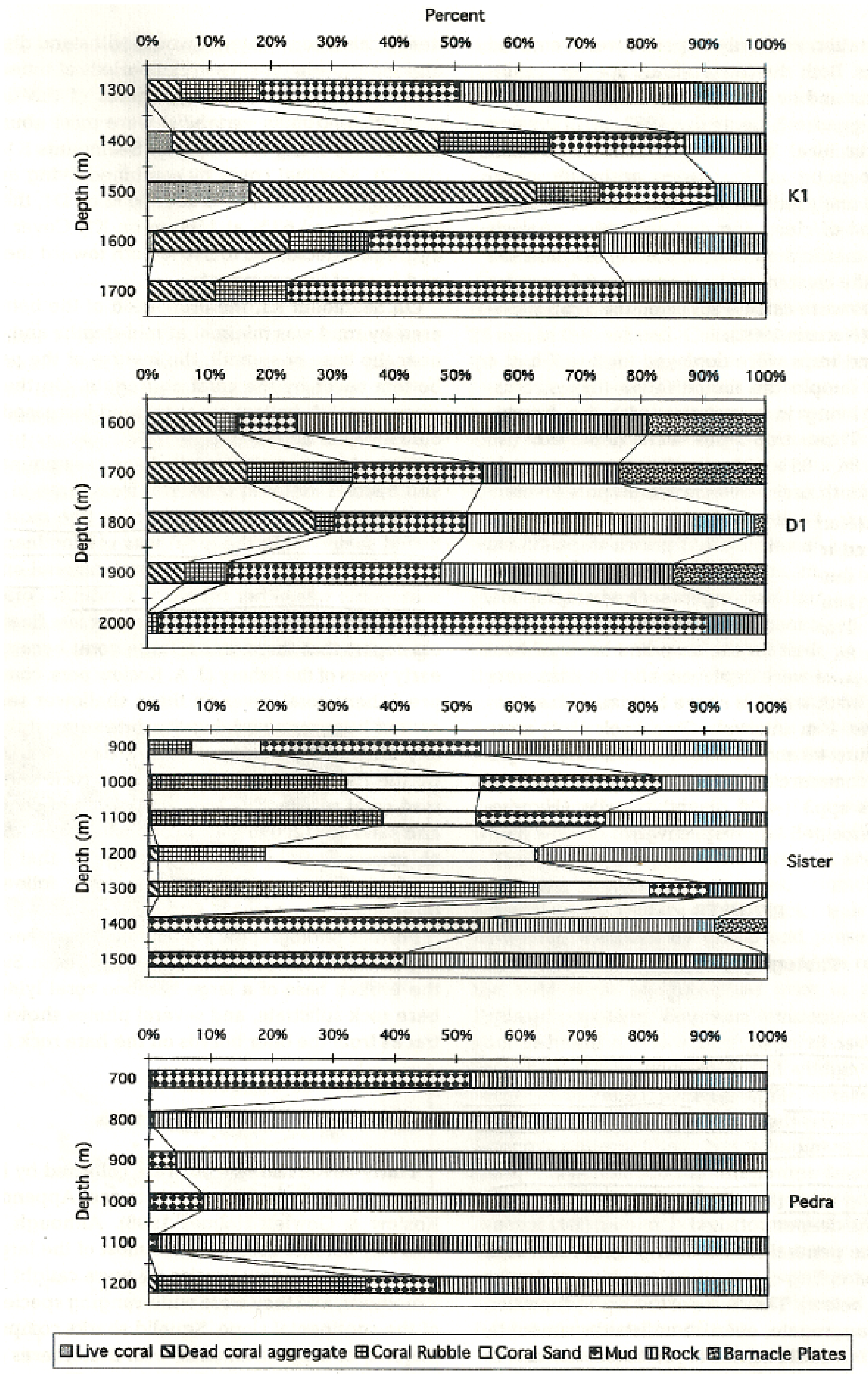

Figure 28 – Percent cover of Tasmanian seamounts. K1 and D1 are within the protected area, while Sister and Pedra are heavily fished. (Koslow et al 2001)

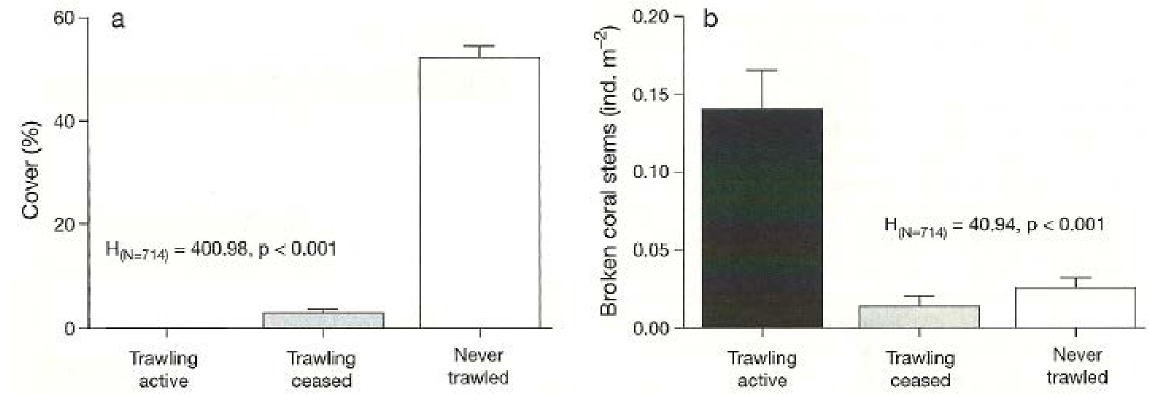

Figure 29 – a) Percent cover of *Solenosmilia variabilis* in areas of varying trawling activity; and b) broken coral per image of photographic transects on seamounts. ("Trawling ceased" indicates areas that were closed 5-10 years prior to study.) (Althaus et al 2009)

Two studies (Heifetz et al 2009, Stone 2006) were focused in the northern Pacific Ocean around the Aleutian Islands. In these studies, longline gear was observed on 76% of transects, but were found to only result in 5% of the disturbed area. Trawling, on the other hand, was only seen at 28% of the transects, but disturbed 32.7% of the observed seafloor, indicating a relatively greater impact of trawls. Overall, 22 of the 25 transects showed disturbance to the seafloor (approximately 39% disturbance) (Stone 2006). This was supported by the second study in this region (Heifetz et al 2009) with evidence of trawling, indicated by uniform parallel striations in the seafloor, seen on several dives. Damage caused by traps was not statistically significant between the fished and unfished areas at this site. The mean percent of damage caused by trawling activity was calculated in this study and can be found in Table 92, determining that the least amount of damage done to corals was in areas of little to no trawling activity. This can be compared to the relative abundance of each coral type as presented in Table 93.

Table 92 - Mean percent damage to coral types in areas of varying trawling intensity (Heifetz et al 2009)

	Untrawled	*Low-intensity*	*Med-intensity*	*High-intensity*
Gorgonian	5.0%	9.4%	10.0%	23.1%
Hydrocorals	10.1%	15.5%	23.3%	Absent (100%)
Sea Pens	<1.0%	<1.0%	<1.0%	~40%
All Corals	6.8%	7.1%	13.6%	49.2%

Table 93 – Percent abundance of coral types in transects at Aleutian Islands site (Stone 2006)

Coral type	*Percent abundance*
Gorgonian	68.4%
Hydrocorals	17.1%
Sea Pens	7.8%
Stoloniferans	2.6%
Stony coral	2.5%
Soft Coral	1.6%

Coral type	*Percent abundance*
Density = 1.23 corals/m^2	

Both studies observed that the most damage done to corals and the seafloor occurred at depths where commercial fishing intensity was the highest (100-200m), with higher population densities occurring at 200-300m (Figure 30 and Figure 31).

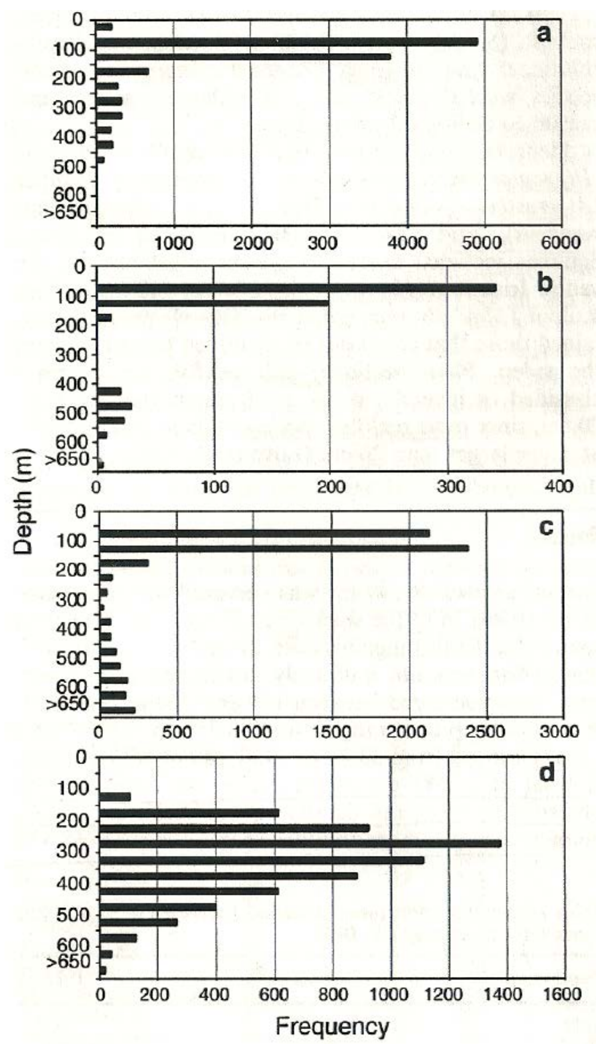

Figure 30 – Depth distribution of a) trawl, b) fish pots, c) longline and d) crab pots in the Aleutian Islands. (Stone 2006)

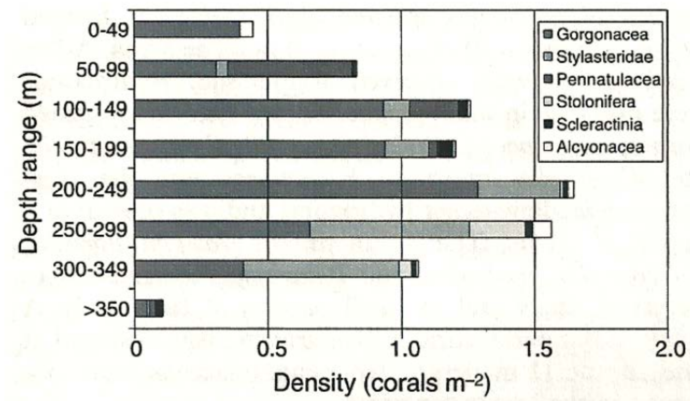

Figure 31 – Density and diversity of corals at depths. (Stone 2006)

Four studies took place in the north-eastern Atlantic Ocean. Two examined the corals on raised carbonate mounds off the western (Grehan et al 2005) and northern coasts (Wheeler et al 2005) of Ireland. The third (Hall-Spencer et al 2002) focused on the West Ireland continental shelf break, and the last study (Fosså et al 2002) dealt with deepwater reefs in Norwegian waters.

The observations made off the coasts of Ireland and Norway were both similar to, and supported, findings at the Aleutian Islands. Damage at the reefs (*Lophelia pertusa*) of Norway was most severe at shallower depths where commercial fishing primarily took place. The continental shelf, at approximately 200-400m (below the highest levels of fishing), had the highest abundance of corals. These corals were intact and developed, whereas the shallower sites contained crushed coral and coral rubble, where damages were estimated at 30-50%. Accounts from local fishermen claim this is due to the fact that often the gear, chains, and otter doors of trawlers were used to crush and clear the seafloor prior to the start of fishing (Fosså et al 2002).

Another study (Hall-Spencer et al 2002) found scars from trawl doors (indicated by parallel marks or furrows on the sea floor) that were up to 4km long, as well as coral rubble on trawled areas. Locations lacking observable trawl scars contain living, unbroken, *L. pertusa*. These findings were observed at the site off the northern coast of Ireland **(**Wheeler et al 2005**)** as well. Trawl marks were located on side scan sonar records, and video showed parallel marks left by trawl doors, as well as the net and ground line gear, on the seafloor. The amount of dead coral and coral rubble increased at sites that were obviously trawled.

The various study sites of Fosså et al (2002) presented a range of disturbance due to fishing. While the deeper water corals were intact and living at one site, almost all corals were crushed or dead at another. A third demonstrated multiple stages of coral degradation, from living to dead and crushed, as well as the base aggregate the reefs often form and grow on being crushed and spread out. The percent of damage to the area was correlated with the number of reports by the fishermen of fishing activity, bycatch, and corals in the area; ranging from 5-52% damaged. More of these reports from an area indicated a larger coral community at that location, and with that, higher proportions of the area were found to be damaged.

Hall-Spencer et al (2002) also noted that fishermen avoided uneven ground due to the loss of time and money from resulting gear upkeep of tangled and damaged gear. Areas of large coral bycatch were avoided in the future, as known trouble areas for the fishermen. Because of this only 5 of the 229 trawls in the study contained large amounts of coral bycatch. Thus, the areas where corals were present and undamaged tended to have a higher topographic complexity of the seafloor.

The effect of seafloor topography on fishing and the resulting impact on corals was observed in a study site west of Ireland (Grehan et al 2005). While evidence of active trawling was seen, indicated by trawl scars in mud and non-coral habitat, there was no damage to corals on the mounds observed caused by fishing. This was due to the fact that the slope of the mounds where coral growth occurred was greater than 20 degrees. This makes the terrain is too steep to trawl and the corals were naturally protected from the gear and relatively undamaged.

One of the studies (Mortensen and Buhl-Mortensen 2004) examined the distribution of corals in the Northeast Channel in the Gulf of Maine. This site could be similar to the sites off of Ireland and Norway, however because of the distance and somewhat different environmental factors it was considered a separate region. This study was concerned with the distribution of corals relative to the benthic habitat. It found that the corals were located on the shelf break and along valleys. This habitat was subject to daily tidal water movement into and out of the Gulf of Maine, aiding in the regulation of temperature, salinity, and food supply. Similar water movement is found on seamounts and shelf breaks, as currents flow over the change in topography, providing the corals with a regulated area in which to grow (Thiem et al 2006; Pires et al 2009).

12.2.2.4Coral growth and recovery potential

The approximate growth rates of deepwater corals have been calculated in several studies on different species of corals. *Oculina* reefs occur in waters off the east coast of Florida. By observing these corals at 6m and at 80m it was found that the corals found at the deepwater (80m) site grew relatively more quickly (16.1 mm/yr) than the same corals at the 6m site (11.3 mm/yr). When transplanted from 6m to 80m the coral polyps lost their zooxanthellae and fed off the food supply provided by the colder deep currents containing more nutrients (Reed 2002).

Two studies done off Atlantic Canada worked at finding the growth rates for *Primnoa resedaeformis*. The corals were found at approximately 200-600m and were dated to 2600-2920 years old ± 50-60 years using C^{14} dating techniques. Using the dated age and size of the colony (~0.5-0.75m in height) the average radial growth at the base of the coral was found to be 0.44 mm/yr and tip extension growth rates were around 1.5-2.5 mm/yr (Risk et al 2002), slower than the estimated rate found for *Oculina* reefs.

The difference in growth rates calculated in these studies can potentially be explained by the other study working with *P. resedaeformis*, as well as *Paragorgia arborea*. The height of colonies ranged from 5-180cm for *P. arborea* (averaging 57cm) and 5-80cm for *P. resedaeformis* (averaging 29.5cm). The maximum age of samples collected was 61 years (found by counting annual growth rings under a dissecting microscope and x-ray examination). It estimated that the rate of growth for the first 30 years was around 1.8-2.2 cm/yr. After the coral began to age (>30 years), growth slowed to 0.3-0.7 cm/yr. This shows that initially the coral grows at a speed concurrent with the first study, and then dramatically slows to only a few millimeters a year, suggested by the second study (Mortensen and Buhl-Mortensen 2005). With a growth rate of, at most, a centimeter or two year, the complete destruction and clearing of the seafloor of corals can result in very long recovery time for both the coral, and associated fauna.

Deepwater coral reproduction is a subject that has not been the topic of research until recently. While the physiology of reproduction in corals has been studied, little is known about the process of timing involved and the survival of resulting offspring. Studies have, however, shown that much of the deepwater corals are gonochoristic (having separate sexes) (Brooke and Stone 2007; Roberts et al 2006; Waller et al 2002; Waller et al 2005). Brooke and Stone (2007) collected samples of corals (*Stylaster*, *Errinopora*, *Distichopora*, *Cyclohelia*, and *Crypthelia*) around the Aleutian Islands and discovered that the collection held a mix of females containing mature eggs, developing embryos, and planulae, males producing spermatozoa, and organisms with no reproductive material. As was pointed out the gametes within the collection were not synchronized which indicates that reproduction is either continuous, or prolonged during a certain season of the year (Brook and Stone 2007).

Waller et al (2002) also found *Fungiacyathus marenzelleri* (collected from the Northeast Atlantic at 2200m) to be gonochoric, with a sex ratio of near 1:1. The fecundity of *F. marenzelleri* was calculated to be 2892 ± 44.4 oocytes per polyp. The mean diameter of oocytes did not vary significantly from month to month and all levels of sperm development were noted. The coral was thus considered quasi-continuous reproducers, with gametogenesis for spermacysts and oocytes occurring continuously as in Brooke and Stone (2007). An interesting finding of the study was that while *F. marenzelleri* is gonochoric, it can also undergo asexual reproduction and budding was present during the study. However, this was limited to no more than one bud found on any individual and no more than two individuals were found to bud at the same time (Waller et al 2002), not nearly the kind of reproductive rate to sustain a population in highly disturbed areas.

Fecundity and reproductive traits for three other corals collected in the Northeast Atlantic were also determined in a study by Waller et al (2005). *Caryophyllia ambrosia* (collected from 1100-1300m), *C. cornuformis* (from 435-2000m), and *C. seguenzae* (from 960-1900m) were all found to be cyclical hermaphroditic. The corals possessed both sexes but only one sex was dominant at a time, corals transitioning between sexes were seen in the study and labeled as "intermediates". The fecundity of the corals was calculated at 200-2750 oocytes per polyp for *C. ambrosia*, 52-940 oocytes per polyp for *C. seguenzae* and no data due to insufficient samples of *C. cornuformis*. As with the other studies there was no significant difference in the average number of oocytes per month and continuous reproduction is assumed for both *C. ambrosia* and *C. cornuformis* (Waller et al 2005).

The effects of mechanical disturbance and trauma to the soft coral *Gersemia rubiformis* (collected from the Bay of Fundy) was examined in a lab setting by Henry et al (2003). In the study, eight colonies of soft coral, four control and four experimental, were set up in separate aquariums to determine damage and recovery rate of the organisms. The experimental colonies were rolled over and crushed every two weeks to simulate bottom contact trawling. Four days and one week after disturbance observations were recorded. It was found that crushing the corals caused retraction of the entire colony. Damaged tissue was repaired and healed between 18 and 21 days. The effect the crushing had on coral reproduction was surprising to the researchers. Thirteen days after the initial disturbance daughter colonies were seen forming at the base of the corals, and by the end of the experiment 100% of the corals had daughter colonies at one point during the study. The mortality rate of the juveniles was 100%, however, and no colonies survived past the polyp stage. Upon testing it was determined that these colonies were sexually derived, and since they had been separated for the experiment it is assumed that the corals were brooding when collected, as they were not visibly fertile prior to the experiment. It should be noted that the control group did not have any daughter colonies during the experiment, and only after (when they were experimentally also crushed) did daughter colonies appear. It is thought that the reason for this was the expulsion of premature planulae (resulting in their ultimate death) due to stress placed on the coral and the need to allocate resources to repair damaged tissue. While adult *G. rubiformis* was able to withstand the mechanical rolling and crushing, the increased mortality of offspring due to ejecting premature planulae may have increased long term effects as the corals are repeatedly disturbed and not able to produce surviving offspring (Henry et al 2003).

While the physiology of these corals has been recently studied, more research is needed to determine the ability of corals to recolonize disturbed areas. Brooke and Stone (2007) concluded that a lightly impacted area would be able to recover via colony growth alone. However, heavily impacted areas, where the seafloor has been scoured and stripped of cover would require coral larvae to be dispersed via currents and settle the area again, which could be a slow, timely process.

12.2.2.5Conclusions

The conclusions drawn by these studies are that commercial fishing gear damages deepwater corals. Trawling, specifically, is very detrimental to coral and the seafloor. The level of damage between trawled and untrawled sites is large enough to conclude that fishing had a negative impact on both the corals and associated fauna. The substrates of heavily fished areas have been stripped to bare rock or reduced to coral rubble and sand, whereas unfished and lightly fished areas did not see such degradation (Grehan et al 2005). Passive gear, such as pots or longlines, while still affecting localized area of corals, were not as destructive as trawl gear. Coral mortality is markedly increased due to corals being crushed, buried and wounded by gear as it is dragged over the bottom (Fosså et al 2002). The degree of disturbance to the coral and seafloor ranges from lightly disturbed areas of overturned cobble with attached, living, coral, to complete stripping of the seafloor (Stone 2006).

The deepwater reefs attract fauna and promote areas of high diversity in an otherwise low diversity area. Fishermen have reported that as the damage to the reefs increase, areas that were once fertile fishing grounds have seen fewer successful fishing trips (Fosså et al 2002). The fauna associated with corals are primarily "removed" along with the destruction of the coral substrate.

While much of the coral on fishing grounds was damaged or destroyed there were areas that avoided contact. As stated previously, corals growing on steep slopes had a natural protection from commercial fishing gear as a slope >20 degrees cannot be trawled. Areas of higher three dimensional complexity were also relatively untouched, as these were avoided by the fishermen for fear of damage and loss of their gear.

The studies have concluded that deepwater corals are especially fragile and the greatest disturbance and destruction occurs at depths targeted by commercial fishing (Heifetz et al 2009, Hall-Spencer et al 2002). Bottom contact gear is especially detrimental and there is a correlation between the highest rates of coral damage and the depths targeted by that industry in particular. Slow growth rates and reproductive processes that are so easily disrupted result in a timely recovery period of disturbed areas.

13.0 Research needs and future work

Development of the model has highlighted gaps in our knowledge of fishing impacts on habitat. The model might be updated in a variety of ways given additional research/data, including:

- Regionalize implementation to account for different feature distributions
- Incorporate observer data more fully, and incorporate vessel monitoring system data to estimate area swept data layers
- Continue to update substrate data, and perhaps add multibeam data
- Adjust geological and biological component weightings, or feature weightings within each component, to reflect importance of features to managed species
- Adjust contact indices, and/or make them substrate-specific
- Better specify fixed gear area swept models given data on the movement of fixed gear along the seabed
- Change the assumption that the impacts of subsequent tows are additive
- Shorten the minimum time interval to less than one year to allow for estimation of seasonal effects (this might require seasonal estimation of vulnerability parameters as well)

14.0 References

14.1 Acronyms used

EFH	Essential Fish Habitat
GIS	Geographic Information System
NEFMC	New England Fishery Management Council
MAFMC	Mid-Atlantic Fishery Management Council
PDT	Plan Development Team
R	Recovery
S	Susceptibility
SASI	Swept Area Seabed Impact (model)
VA	Vulnerability Assessment

14.2 Glossary

A	Refers to the area swept by a piece of fishing gear, adjusted for contact of gear with the seabed (contact index). *A* is added to the SASI model in annual time steps.
Adverse effect	An impact to EFH that is 'more than minimal and not temporary in nature'
Biological feature	Any living seabed structure assumed to be used for shelter by managed species of fish or their prey
Contact index	The proportion of a gear component that is assumed to touch the seabed during fishing
Essential Fish Habitat	Those waters and substrate necessary to fish for spawing, breeding, feeding, and growth to maturity
Geological feature	Any non-living seabed structure assumed to be used for shelter by managed species of fish or their prey
Prey feature	One of six benthic invertebrate taxa commonly consumed by managed species in the Northeast Region
Realized	Refers to an area swept data layer that is intended to realistically represent actual fishing effort, where gear dimensions, fishing locations, and number of trips/tows/sets are based on observer, trip report, or other data sources. Realized area swept is aggregated on an annual basis.
Recovery, R	Recovery is defined as the time in years that would be required for the functional value of that habitat feature to be restored.
SASI model	The combination of vulnerability assessment and geo-referenced fishing effort and habitat data used to estimate the magnitude and location of the adverse effects of fishing on habitat
Simulated	Refers to an area swept data layer that is intended to allow for spatial visualization the underlying seabed vulnerability, independent of the magnitude of area swept. Simulated area swept might be uniformly distributed, or non-uniformly distributed.
Substrate classes	Mud, sand, granule-pebble, cobble, and boulder, as defined by the Wentworth particle grade scale

Susceptibility, S	Susceptibility is defined as the percentage of total habitat features encountered by fishing gear during a hypothetical single pass fishing event that have their functional value reduced.
Structured grid	A regular grid of consisting of 100 km^2 cells to which area swept estimates are inferred.
Unstructured grid	An irregular grid based on the distribution of substrate data points. High or low energy and a suite of features are inferred to each unstructured grid cell
Vulnerability	The combination of a feature's susceptibility to fishing gear impact and its ability to recover from fishing gear impact
Wentworth	A size-based sediment classification scheme
Voronoi tessellation	A mathematical procedure used to develop the unstructured substrate grid based on point data
Z	A measure of the adverse effect of fishing effort on seabed habitat features, measured in km^2 units. Z is area swept (A) that has been adjusted for susceptibility (S) and recovery (R). Z is considered a "stock" effect that accumulates over time based on the amount of adverse effect entering the fishery in any particular time step (Y), and the amount of adverse effect deemed to have recovered in that time step (X), such that $Z = X - Y$.
Z	The adverse effect of fishing effort on seabed habitat features, measured in km^2 units. Z is area swept (A) that has been adjusted for susceptibility (S) and recovery (R). Z is considered a "stock" effect that accumulates over time based on the amount of adverse effect entering the fishery in any particular time step (Y), and the amount of adverse effect deemed to have recovered in that time step (X), such that $Z = X - Y$
Z_{∞}	The asymptotically stable equilibrium level of Z. Z_{∞} is reached when a constant annual level of fishing area swept is applied to the all grid cells in the model for a length of time just slightly greater than the greatest terminal year of recovery estimated for all features in the Vulnerability Assessment.
Z_{net}	An instantaneous estimate of all the adverse effect that occurs as a result of a single fishing event. Z_{net} sums the annual Z value from the year the fishing event occurred until Z decays to 0 (i.e. until recovery is complete).

$Z_{realized}$	The actual distribution of Z by gear type based on past area swept estimates. Annual $Z_{realized}$ estimates for each 100 km^2 grid cell include the current year Z summed across all area swept in the cell, adjusted for feature susceptibility, plus Z accumulated from fishing events in past years that has not yet decayed.

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Table 94 - References from literature review by number.

#	Cite	#	Cite	#	Cite
11	Auster et al 1996	141	Hall et al 1993	292	Queiros et al 2006
17	Ball et al 2000	146	Hall-Spencer et al 2002	313	Rosenburg et al 2003
21	Bergman and VanSantbrink 2000	149	Hansson et al 2000	320	Sanchez et al 2000
24	Blanchard et al 2004	157	Henry et al 2006	325	Schwinghamer et al 1998
34	Brown et al 2005a	158	Hermsen et al 2003	330	Sheridan and Doerr 2005
35	Brown et al 2005b	164	Hixon and Tissot 2007	333	Simpson and Watling 2006
38	Burridge et al 2003	184	Kaiser et al 2000	334	Smith et al 1985
42	Caddy 1968	192	Kenchington et al 2001	335	Smith et al 2000
43	Caddy 1973	193	Kenchington et al 2005	336	Smith et al 2003
64	Clark and O'Driscoll 2003	194	Kenchington et al 2006	338	Sparks-McConkey and Watling 2001
69	Collie et al 1997	203	Knight 2005	352	Stokesbury and Harris 2006
70	Collie et al 2000	209	Koslow et al 2001	355	Stone et al 2005
71	Collie et al 2005	211	Koulouri et al 2005	359	Sullivan et al 2003
88	De Biasi 2004	214	Kutti et al 2005	360	Tanner 2003
89	de Juan et al 2007a	217	Langton and Robinson 1990	368	Tillin et al 2006
90	de Juan et al 2007b	225	Lindholm et al 2004	372	Tuck et al 1998
92	DeAlteris et al 1999	228	Link et al 2005	373	Tuck et al 2000
97	Drabsch et al 2001	232	MacKenzie 1982	382	Van Dolah et al 1987
101	Engel and Kvitek 1998	236	Mayer et al 1991	387	Wassenberg et all 2002
102	Eno et al 2001	238	McConnaughey et al 2000	391	Watling et al 2001
108	Fossa et al 2002	239	McConnaughey et al 2005	393	Wheeler et al 2005
110	Freese 2001	244	Medcof and Caddy 1971	404	Asch and Collie 2007
111	Freese et al 1999	245	Meyer et al 1981	406	Dellapenna et al 2006
113	Frid et al 1999	247	Morais et al 2007	407	Nilsson and Rosenberg 2003
119	Gibbs et al 1980	248	Moran and Stephenson 2000	408	Boat Mirarchi and CR Environmental 2003
120	Gilkinson et al 1998	249	Morello et al 2005	409	Boat Mirarchi and CR Environmental 2005
121	Gilkinson et al 2003	254	Mortensen et al 2005	414	Coggan et al 2001
122	Gilkinson et al 2005a	256	Murawski and Serchuk 1989	541	Probert et al 1997
123	Gilkinson et al 2005b	277	Palanques et al 2001	575	Lindegarth et al 2000
128	Gordon et al 2005	283	Pilskaln et al 1998	599	Simboura et al 1998
136	Grehan et al 2005	287	Pranovi and Giovanardi 1994	658	Hinz et al 2009
140	Hall et al 1990	291	Prena et al 1999	669	Thorarinsdottir et al 2008