PACIFIC COAST GROUNDFISH FISHERY MANAGEMENT PLAN

FOR THE CALIFORNIA, OREGON, AND WASHINGTON GROUNDFISH FISHERY

APPENDIX C
PART 2

THE EFFECTS OF FISHING ON HABITAT: WEST COAST PERSPECTIVE

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Pacific Coast Groundfish EFH

The Effects of Fishing Gears on Habitat: West Coast Perspective

DRAFT 6

Prepared for

Pacific States Marine Fisheries Commission

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1 INTRODUCTION

The U.S. District Court for the District of Columbia has found that the EAs prepared by NOAA Fisheries' for the Councils' amendments on the subject of EFH were inadequate and in violation of NEPA. The suit that gave rise to this finding specifically contested the adequacy of the evaluations of fishing gear impacts on EFH in the fishery management plan amendments, and the analyses of environmental impacts in the EAs. In response, NOAA Fisheries has initiated a project to complete new NEPA analyses for Amendment 11 to the Pacific Coast Groundfish FMP.

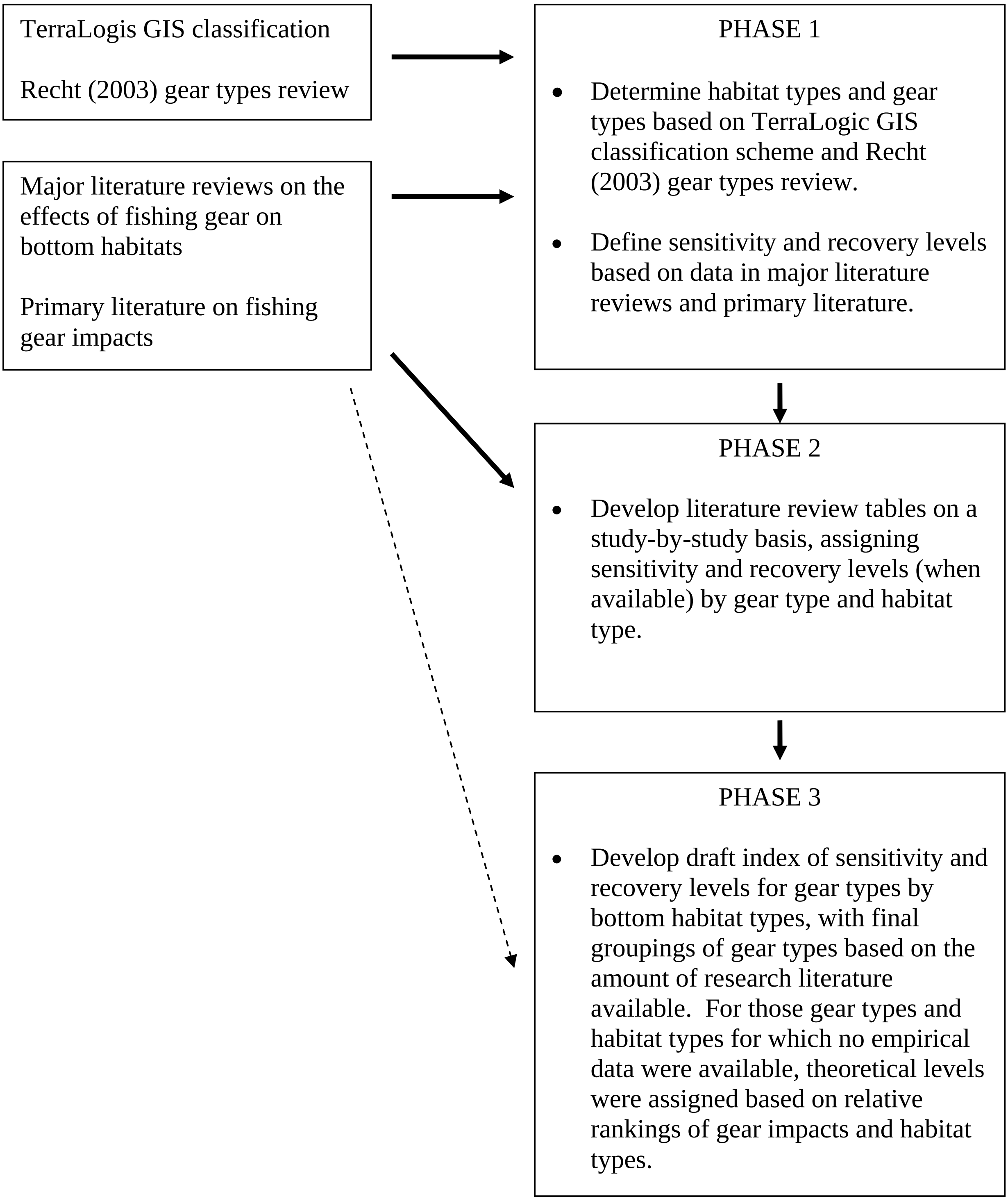
Pre-planning for this NEPA process requires an understanding of the status of groundfish habitat and associated risks and a conceptual framework for predicting the costs and benefits of conservation strategies. The pre-planning effort is being overseen by the Pacific Fishery Management Council's (Council) *ad hoc* Groundfish Habitat Technical Review Committee (Committee). On February 19-20, 2003, the Committee reviewed the proposed risk assessment framework and recommended that Pacific States Marine Fisheries Commission contract for development of an index of fishing gear impacts by gear type that will serve as an input into the model. The Committee suggested that, while several literature review and indices exist that may be utilized for this project, there is no clear direction on how that information should be applied to the west coast. As justification for the recommendation, the committee cited the general lack of west coast specific studies and the need to determine specifically how to make inferences from studies that occurred in other parts of the world.

This document describes the process followed in the development of a draft index of adverse effects for fishing gears that are utilized on the west coast of the US. The draft index consists of two matrices (spreadsheets), one describing the sensitivity levels of bottom habitats to gear impacts and another describing recovery times from gear impacts. The values in the matrices will be used as input variables for a Bayesian risk assessment model being developed to form the basis for developing fishing impacts alternatives for the overall EIS. The form of each matrix is based on gear types used on the west coast, bottom habitat type designations used in the GIS mapping of habitat (See Analytical Framework Document), and the available literature on gear impacts. Development of the final two matrices required several preliminary steps. The overall process is described in the following sections.

2 METHODS

The overall analysis consisted of three phases, each building upon the preceding phase, with the final Phase 3 being development of the draft index of gear impacts. Three major sources of information were drawn from in the process: TerraLogic's GIS-based classification scheme of habitat types; Recht's (2003) review of gear types used on the west coast; and recent major reviews (particularly Johnson 2002) of the impacts of fishing gear on bottom habitats. The overall "information flow" is shown schematically below (Fig. 1).

Information Flow for Development of Impact Matrices for Pacific Gear Effects



TerraLogis GIS classification

Recht (2003) gear types review

Major literature reviews on the effects of fishing gear on bottom habitats

Primary literature on fishing gear impacts

PHASE 1

- Determine habitat types and gear types based on TerraLogic GIS classification scheme and Recht (2003) gear types review.
- Define sensitivity and recovery levels based on data in major literature reviews and primary literature.

PHASE 2

- Develop literature review tables on a study-by-study basis, assigning sensitivity and recovery levels (when available) by gear type and habitat type.

PHASE 3

- Develop draft index of sensitivity and recovery levels for gear types by bottom habitat types, with final groupings of gear types based on the amount of research literature available. For those gear types and habitat types for which no empirical data were available, theoretical levels were assigned based on relative rankings of gear impacts and habitat types.

Fig. 1. Information flow diagram showing how information from other components of the overall project were used in relation to the literature that provided the “raw data” for the present analysis (see text for details).

Phase 1: Descriptors for gear types, habitat types, and impact levels

The first phase of the analysis was designed to set the limits on the universe of west coast gear types and habitat types examined. The approach to quantifying the relative levels of sensitivity of the habitats to contact from the various gear types, and the scaling of the time taken for the habitats to recover from different types of impacts, was also determined during Phase 1.

2.1.1 Gear types

Recht (2003) describes gear types used on the west coast of the US. This paper provided the primary basis for the gear classification scheme used in this analysis. Seven major categories – trawls, nets, dredges, traps and pots, hook and line, trolling, and miscellaneous – were expanded into a total of approximately thirty (30) types of gear:

- **Trawls (TWL)**
    - Otter Trawl
    - Shrimp Trawl
    - Beam Trawl
    - Midwater Trawl
- **Nets (NET)**
    - Demersal Seine
    - Round Hall Seine
    - Gillnet
    - Trammel Net
    - Dip Net
    - Salmon Reef Net
- **Dredges (DRG)**
    - New Bedford Dredge
    - Hydraulic Clam Dredge
    - Oyster Dredge
- **Traps & Pots (POT)**
    - Pots
- **Hook & Line (HKL)**
    - Hook & Line
    - Bottom Longline
    - Pelagic Longline
    - Handline, Jig
    - Stick (Pipe)
    - Rod & Reel
    - Vertical Hook & Line
    - Mooching
- **Trolling (TLS)**
    - Trolling
- **Miscellaneous (MSC)**
    - Diving, Hand/ Mech.
    - Herring Spawn Kelp
    - Herring Brush Weir
    - Ghost Shrimp Pump
    - Poke Pole
    - Bait Pen
    - Live Fish, Shellfish

2.1.2 Habitat types

The Analytical Framework document (MRAG 2003) describes the classification of benthic habitat based on physical features in several levels of a hierarchical system. The levels, in order, are: megahabitat, seafloor induration, meso/macrohabitat, and modifier(s). For the west coast, the following types have been delineated:

Level 1: Megahabitat:

- Continental Rise/Apron;
- Basin Floor;
- Continental Slope;
- Ridge;
- Continental Shelf.

Level 2: Seafloor Induration:

- Hard substrate;
- Soft substrate.

Level 3: Meso/macrohabitat:

- Canyon wall;
- Canyon floor;
- Exposure, bedrock;
- Gully;
- Gully floor;
- Ice-formed feature;
- Landslide.

Level 4: Modifier:

- Bimodal pavement;
- Outwash;
- Unconsolidated sediment.

Each unique combination of these four characteristics defines a unique benthic habitat type. For the west coast EFH project, 35 unique benthic habitat types have been delineated (see Analytical Framework document for details). A total of forty-three (43) megahabitat/substrate/macrohabitat types are described in the present analysis. It should be noted that the extra habitat types are a result of adding the "Estuarine" megahabitat (with three substrate types) and the "Biogenic" substrate type to all other megahabitat types. These forty-three and, if available, their assigned Pencil Codes were used in the present analysis.

2.1.3 Sensitivity and Recovery scales

The final step in Phase 1 was the development of scales for habitat sensitivity levels to gear impacts and recovery times for habitat impacted by fishing gears. The sensitivity scale consists of four levels (0, 1, 2, and 3) representing relative sensitivity to gear impacts. The descriptors for the sensitivities at each level are based on the actual impacts reported in the references listed in the tables in Annex 1. The recovery scale is in units of time (years) with the values taken directly from each report cited.

2.2 Phase 2: Literature summaries

The second phase of the analysis was the construction of summaries of the literature on gear impacts on a study-by-study basis. These summaries were tabulated in spreadsheet format and grouped by habitat and gear types. This arrangement allows appropriate mean values (and variability around the means) to be calculated for direct entry into the final two spreadsheets (Phase 3). For example, referring to Table A1.1, the mean value ‘0.5’ is the mean of the six sensitivity levels for the impact of otter trawls on Soft Sediment substrates in Estuarine megahabitats. There are six references listed in the rows above that row, and the actual sensitivity levels (as described in Table 2) reported in those references ranged from 0 to 1. Mean values with standard errors were calculated in this way for various combinations of gear and habitat categories so that they could be directly entered into the final impact matrices (Tables 3 - 5). At present, variability around each mean is presented as standard error of the mean.

Johnson (2002) provides a major review of the national and international literature on fishing impacts on bottom habitats and was relied upon heavily for constructing these tables. Other reviews that provided additional literature and/or interpretations of the literature were Watling and Norse (1998), Auster and Langton (1999), Dayton et al. (2002), National Research Council (2002), and Morgan and Chuenpagdee (2003).

Several points should be noted regarding the literature summary tables (Tables A1.1 – A1.6):

- References were used only if they provided quantitative information on sensitivity and/or recovery of habitat. Hence, the reviews cited above contain references that are not listed in the results tables. In some cases, however, these references may have contributed to the theoretical analysis used to derive sensitivity and recovery values for gear/habitat combinations for which no empirical data were available (see below).

- More than thirty fishing gear types are used on the west coast (Recht 2003). There have been no studies on the impacts of most of these on bottom habitats. Hence, most gear types are not listed in the summary tables. Those for which useful studies were found included eight gear types: otter trawls, beam trawls, shrimp trawls, New Bedford/scallop dredges, hydraulic dredges, oyster dredges, pots, and hand/mechanical harvesting. Nearly all (69 of 73) of the studies listed, however, have been done on two major gear categories "trawls" and "dredges" (see references listed in Tables A1.1 - A1.6 in Annex 1).

- Only two studies directly on west coast gears were found to be useful. Hence, research from areas other than the Pacific coast provided most of the information on which this analysis is based.

2.3 Phase 3: Draft indices of sensitivity and recovery for the effects of fishing gear on bottom habitats

The existing literature dealing with fishing gear impacts on the seabed is substantial, consisting of well over 100 studies globally (Johnson 2002). Much of this research, however, does not provide data useful for quantitative modeling. Moreover, the vast majority of the research has been done only on trawls and dredges, and there has been very little work done in water exceeding 200 meters in depth. Therefore, development of a comprehensive (in terms of gear and habitat types) index required using a combination of empirical data with theoretical information. It also required making decisions with respect to how many gear and habitat types should be included.

Indices of sensitivity and recovery for the effects of fishing gear on bottom habitats were prepared by converting the mean values in the literature summary tables into a form useful for modeling. For example, referring to Table 3, the value ‘0.7’ for the sensitivity of "Estuarine, Soft Sediment" habitats to "Bottom Trawls" is the mean of the first seven studies listed in Table A1.1 in Annex 1; these seven included six studies on otter trawls and one on beam trawls, both being combined into the category "Bottom Trawls" in Table 4. All the mean values in Tables 4 and 5 were derived in this fashion by combining the appropriate categories in the tables in Annex 1.

3 RESULTS

3.1 Phase 1: Descriptors for gear types, habitat types, and impact levels

Table 1. Habitat descriptors based on water depth, substrate, megahabitat, and macrohabitat. Megahabitat/substrate/macrohabitat taxonomy and Pencil Codes (as provided by TerraLogic GIS). Tables 1a, b and c are provided to show how the final habitat categories in Table 1d are related to environmental features (e.g. water depth) commonly used as habitat descriptors. NOTE: Only the Megahabitat/Substrate/Macrohabitat designations shown in Table 1d are used further in the report (and therefore listed in Tables 4 - 5, and Table A1.1) because these are the "habitat types" used in the GIS analysis.

Table 1a. Habitat descriptors

WATER DEPTH	**SUBSTRATE**	**MEGAHABITAT**
0 to 10+ m	Rocky	Estuarine
10 to 200 m	Boulder	Shelf
200 to 4000 m	Cobble	Slope
	Gravel	Basin
	Halimeda	Ridge
	Pebble	
	Sedimentary	
	Mud	
	Sand	
	Mixed (Rocky+Sedimentary)	
	Biogenic	
	Algae	
	Seagrass	
	Invertebrates	

Table 1b. Habitat descriptors based on water depth and substrate

0 to 10+ m water depth (Estuarine)			
Rocky Estuarine	**Sedimentary Estuarine**	**Mixed (Rocky+ Sedimentary)**	**Biogenic Estuarine**
Boulder	Mud		Algae
Cobble	Sand		Seagrass
Gravel			Invertebrates
Halimeda			
Pebble			
10 to 200 m water depth (Shelf)			
Rocky Shelf	**Sedimentary Shelf**	**Mixed (Rocky+ Sedimentary)**	**Biogenic Shelf**

Boulder	Mud		Algae
Cobble	Sand		Seagrass
Gravel			Invertebrates
Halimeda			
Pebble			
200 to 4000 m (Slope/Basin/Ridge)			
Rocky Slope/ Basin/ Ridge	**Sedimentary Slope/ Basin/ Ridge**	**Mixed (Rocky+ Sedimentary)**	**Biogenic Slope/ Basin/ Ridge**
Boulder	Mud		Algae
Cobble	Sand		Seagrass
Gravel			Invertebrates
Halimeda			
Pebble			

Table 1c. Habitat descriptors based on megahabitat and substrate

Estuarine (0 to 10+ m water depth)			
Rocky Estuarine	**Sedimentary Estuarine**	**Mixed (Rocky+ Sedimentary)**	**Biogenic Estuarine**
Boulder	Mud		Algae
Cobble	Sand		Seagrass
Gravel			Invertebrates
Halimeda			
Pebble			
Shelf (10 to 200 m water depth)			
Rocky Shelf	**Sedimentary Shelf**	**Mixed (Rocky+ Sedimentary)**	**Biogenic Shelf**
Boulder	Mud		Algae
Cobble	Sand		Seagrass
Gravel			Invertebrates
Halimeda			
Pebble			
Slope (200 to 3000 m)			
Rocky Slope	**Sedimentary Slope**	**Mixed (Rocky+ Sedimentary)**	**Biogenic Slope**
Boulder	Mud		Invertebrates
Cobble	Sand		
Gravel			
Halimeda			
Pebble			
Basin (1000 to 2500 m)			
Rocky Basin	**Sedimentary Basin**	**Mixed (Rocky+ Sedimentary)**	**Biogenic Basin**
Boulder	Mud		Invertebrates
Cobble	Sand		
Gravel			

Halimeda			
Pebble			
Ridge (200 to 2500 m)			
Rocky Ridge	**Sedimentary Ridge**	**Mixed (Rocky+ Sedimentary)**	**Biogenic Ridge**
Boulder	Mud		Invertebrates
Cobble	Sand		
Gravel			
Halimeda			
Pebble			

Table 1d. Habitat descriptors based on megahabitat, substrate, and macrohabitat

MEGAH X SUBSTRATE X MACROH		**Habitat Code**
Estuarine (0 to 10+ m water depth)		
	Estuarine, Hard	
	Estuarine, Soft Sediment	
	Estuarine, Biogenic	
Shelf (10 to 200 m water depth)		
	Shelf, Hard, Exposure	She
	Shelf, Soft Sediment	Ss_u
	Shelf, Hard, Canyon Wall	Shc
	Shelf, Soft Sediment, Canyon Wall	Ssc_u
	Shelf, Hard, Canyon Floor	
	Shelf, Soft, Canyon Floor	Ssc/f_u
	Shelf, Hard, Gully	
	Shelf, Soft, Gully	Ssg
	Shelf, Hard, Glacial Pavement	Shi_b/p
	Shelf, Soft, Glacial Outwash	Ssi_o
	Shelf, Biogenic	
Slope (200 to 3000 m)		
	Slope, Hard, Exposure	Fhe
	Slope, Soft Sediment	Fs_u
	Slope, Hard, Canyon Wall	Fhc
	Slope, Soft Sediment, Canyon Wall	Fsc_u
	Slope, Hard, Canyon Floor	Fhc/f
	Slope, Soft, Canyon Floor	Fsc/f_u
	Slope, Hard, Gully	Fhg
	Slope, Soft, Gully	Fsg
	Slope, Hard, Landslide	Fhl
	Slope, Soft, Landslide	Fsl
	Slope, Hard, Glacial Pavement	
	Slope, Soft, Glacial Outwash	
	Slope, Biogenic	

MEGAH X SUBSTRATE X MACROH		Habitat Code
Basin (200 to 4000 m)		
	Basin, Hard, Exposure	Bhe
	Basin, Soft Sediment	Bs_u
	Basin, Hard, Canyon Wall	
	Basin, Soft Sediment, Canyon Wall	Bsc_u
	Basin, Hard, Canyon Floor	
	Basin, Soft, Canyon Floor	Bsc/f_u
	Basin, Hard, Gully	
	Basin, Soft, Gully	Bsg
	Basin, Hard, Landslide	
	Basin, Soft, Landslide	
	Basin, Hard, Glacial Pavement	
	Basin, Soft, Glacial Outwash	
	Shelf, Biogenic	
Ridge (200 to 2500 m)		
	Ridge, Hard, Exposure	Rhe
	Ridge, Soft Sediment	Rs_u
	Ridge, Biogenic	
Cont. Rise (3000 to 5000 m)		
	Rise, Hard, Exposure	Ahe
	Rise, Soft Sediment	As_u
	Rise, Hard, Canyon Wall	Ahc
	Rise, Soft Sediment, Canyon Wall	Asc_u
	Rise, Hard, Canyon Floor	
	Rise, Soft Sediment, Canyon Floor	Asc/f
	Rise, Hard, Gully	
	Rise, Soft, Gully	Asg

Table 2. Descriptions of sensitivity levels and recovery time (years) for gear impact assessments.

Sensitivity Level	Sensitivity Description
0	No detectable adverse impacts on seabed; i.e. no significant differences between impact and control areas in any metrics.
1	Minor impacts such as shallow furrows on bottom; small differences between impact and control sites, <25% in most measured metrics.
2	Substantial changes such as deep furrows on bottom; differences between impact and control sites 25 to 50% in most metrics measured.
3	Major changes in bottom structure such as re-arranged boulders; large losses of many organisms with differences between impact and control sites >50% in most measured metrics.
Recovery Time	**Recovery Description**
0	No recovery time required because no detectable adverse impacts on seabed.
n	n = time (years) required for return to pre-impact condition; i.e. no significant differences between impact and control areas in any metrics

As indicated in Table 2, the sensitivity levels 0 to 3 were intended to provide a relative scale for defining the actual sensitivity descriptions which were based on literature values. The range of sensitivity impacts found in the existing literature (see references listed in the tables in Annex 1) is from no detectable impacts (level 0) to major changes in various seabed characteristics (level 3). This range of levels corresponds to a range of actual measured changes ranging from "no significant differences" in any metrics measured to 100% (or nearly so) losses of some organisms. Sensitivity range intervals as indicated in Table 2 (no significant differences, <25% difference, etc) were chosen and assigned to the four sensitivity levels. The values for recovery times were the actual times (converted to years) reported in the literature for the metrics measured. This procedure was developed because there was a wide range of metrics measured and reported in the literature, and it was necessary to assess each study on a quantitative scale that could be applied to all studies.

3.2 Phase 2: Literature summaries

Six tables summarizing the available literature are provided in Annex 1. Table A1.1 is a summary of references on impacts of all gear types on estuarine habitats. Table A1.2 is a summary of references on impacts of trawls on shelf habitats. Table A1.3 is a summary of references on impacts of dredges on shelf habitats. Table A1.4 is a summary of references on impacts of multiple mobile gears on shelf habitats. Table A1.5 is a summary of references on impacts of pots and traps on shelf habitats. Table A1.6 is a summary of references on impacts of trawls on slope habitats.

These tables represent the "raw data" of subsequent analyses. As an illustration of how the values in the tables were derived, consider the study by Brylinsky et al. (1994) on the effects of otter trawls on estuarine soft sediment bottoms (Table A1.1). A sensitivity level of "1" was assigned based on the reported impacts of relatively shallow trawl marks (5 cm deep) and decreases in some invertebrate populations but no differences in others. A recovery time of "0.6 yr" was assigned because the recovery times reported ranged from 2 to 7 months for the trawl marks to 4 to 6 weeks for some invertebrate taxa. The derivation of the actual sensitivity and recovery time levels assigned for each study can be checked by examining the information provided in the corresponding "Sensitivity Comments" and "Recovery Comments" cells.

Phase 3: Draft index of effects of fishing gear on bottom habitats

In order to develop as many mean values as possible with reasonable error terms, it was necessary to re-combine the detailed data in the literature review tables in Annex 1 by collapsing the categories of gear types listed above (page 5) to five major categories, and collapsing the habitat types to six megahabitat/substrate types (Table 3). In most cases for which empirical data were available, these combinations resulted in samples sizes sufficient to derive useful means. However, it should be noted that several gear/habitat combinations have only one or two studies (n < 2) providing useable data on sensitivity and/or recovery levels.

It should also be noted that as a result of comments received at the SSC Groundfish Subcommittee meeting in Seattle in February 2004, the bottom habitat type "Biogenic" was subdivided into as many categories as practicable based on the amount of gear impacts literature available. Studies have been conducted on four major biogenic bottom types: shellfish reefs (mussels and oysters), macrophytes (mostly seagrasses), sponges, and corals. Other comments received at the February meeting included the suggestion that recovery levels be re-defined and calculated based on actual recovery time. Therefore, the existing literature summaries in Annex 1 were revised to show the above four biogenic subcategories for each of the megahabitat types (Estuarine, Shelf, etc) where appropriate, and recovery levels were presented as time in years (Table 3).

Two important general observations can be made concerning the biogenic habitats. First, most research has been done on trawls and dredges, as is the case generally for gear impacts research. Second, most of the values for both sensitivity and recovery are based on only one study (n=1). Clearly, much more work must be done before we have a good understanding of how the full range fishing gear types impact the many kinds of biogenic habitats. Nonetheless, research has been done on several major biogenic habitat types, particularly on the continental shelf, and some trends appear to be emerging. For example, dredges and trawls appear to be nearly equally damaging to biogenic habitats on the shelf regardless of the kind of biogenic bottom. And recovery times can be substantial for those habitats dominated by long-lived species; e.g., see Slope, Corals entry.

Two gear by habitat combinations in Table 3 warrant further comment because they show very low impacts of gear types that have been shown to be quite damaging on some biogenic bottoms. The impact of bottom trawls in estuarine macrophyte habitats is shown as "0.0, SE=0.0, n=3" for sensitivity and recovery. Although these means are based on three studies, they probably do not represent the situation for estuarine macrophytes generally. The three studies were all done on turtle grass (*Thalassia testudinum)* using a relatively light-weight (75 kg) trawl with the footrope rigged with rollers designed for catching shrimp in seagrasses. Turtle grass has leaves that range from several centimeters to a meter or so long and they are quite flexible, capable of lying nearly flush against the substrate in tidal currents. Hence, it may be expected that this type of gear could move above the turtle grass with minimal impact. The authors of these studies noted that certain gear specifications are needed to minimize damage to seagrasses. Hence, these studies should not be interpreted to represent the range of macrophyte and gear type combinations that may occur on the west coast.

The second gear by habitat combination that warrants comment is dredges in estuarine shellfish habitats, where sensitivity and recovery values were also quite low. All studies to date have been done on previously harvested oyster reefs where the natural vertical structure probably had already been greatly reduced. Oyster reefs that have not been harvested can have vertical relief ranging from < 1 m to several meters. Mechanical harvesting gears (whether hand-held or towed under power) typically used to harvest oysters are capable of greatly reducing this vertical structure because their effect is to destroy the natural aggregated nature of the reef, typically resulting in a reef that largely consists of individual oysters lying flat on the bottom. The studies summarized in Table 3 indicate that once the vertical structure of a reef is destroyed, further dredging apparently has only minimal impact on reef characteristics, including productivity. This is an important finding, but as in the case of the three trawl studies on one kind of seagrass, must not be pressed too far.

In conclusion, it should be emphasized that we only have a preliminary understanding of how fishing gear impacts biogenic habitats. Some trends are emerging, but further consideration of the two gear/habitat combinations that departed from general trends should be a warning that the relationships involved can be quite complex.

Table 3. Summary of mean sensitivity levels and recovery times for all combinations of five major gear types and bottom habitat types (i.e. three megahabitats, two induration types [hard and soft] and biogenic) for which empirical data were available.

Sensitivity Levels (range: 0 to 3)

Megahabitat, Induration, Meso/macrohabitat	**Habitat Code**	**Dredges**	**Bottom Trawls**	**Nets**	**Pots & Traps**	**Hook & Line**
Estuarine, Biogenic/Macrophytes		**2.9 (SE=0.07 , n=4)**	**0.0 (SE=0.00, n=3)**	(nd)	(nd)	(nd)
Estuarine, Biogenic/Shellfish		**0.9 (SE=0.93, n=3)**	(nd)	(nd)	(nd)	(nd)

Estuarine, Soft		**1.3 (SE=0.34, n=9)**	**0.7 (SE=0.25, n=7)**	(nd)	(nd)	(nd)
Shelf, Biogenic/Macrophytes		**2.8 (SE= , n=1)**	**2.0 (SE= , n=1)**	(nd)	(nd)	(nd)
Shelf, Biogenic/Shellfish		**1.0 (SE= , n=1)**	**1.0 (SE= , n=1)**	(nd)	**0.8 (SE= , n=1)**	(nd)
Shelf, Biogenic/Sponges		(nd)	**2.2 (SE=0.15 , n=2)**	(nd)	(nd)	(nd)
Shelf, Biogenic/Corals		(nd)	**1.0 (SE= , n=1)**	(nd)	(nd)	(nd)
Shelf, Hard, Exposure	She	**1.7 (SE=0.40, n=3)**	**2.5 (SE=0.50, n=2)**	(nd)	**0.3 (SE=0.30, n=2)**	(nd)
Shelf, Soft	Ss_u	**1.0 (SE=0.10, n=22)**	**1.2 (SE=0.14, n=29)**	(nd)	(nd)	(nd)
Slope, Biogenic, Sponges		(nd)	**3.0 (SE=0.00 , n=2)**	(nd)	(nd)	(nd)
Slope, Biogenic, Corals		(nd)	**3.0 (SE=0.00 , n=2)**	(nd)	(nd)	(nd)
Slope, Soft	Fs_u	(nd)	**1.0 (SE= , n=1)**	(nd)	(nd)	(nd)

Recovery Time (years)

Megahabitat, Induration, Meso/macrohabitat	**Habitat Code**	**Dredges**	**Bottom Trawls**	**Nets**	**Pots & Traps**	**Hook & Line**
Estuarine, Biogenic/Macrophytes		**3.8 (SE=1.17, n=3)**	**0.0 (SE=0.00, n=3)**	(nd)	(nd)	(nd)

Estuarine, Biogenic/Shellfish		**0.0 (SE=0.00, n=2)**	(nd)	(nd)	(nd)	(nd)
Estuarine, Soft		**0.4 (SE=0.17, n=8)**	**0.2 (SE=0.07, n=6)**	(nd)	(nd)	(nd)
Shelf, Biogenic/Macrophytes		**4.0+ (SE= , n=1)**	**3.0 (SE= , n=1)**	(nd)	(nd)	(nd)
Shelf, Biogenic/Shellfish		(nd)	(nd)	(nd)	**0.1 (SE= , n=1)**	(nd)
Shelf, Biogenic/Sponges		(nd)	**1.3 (SE=0.25 , n=2)**	(nd)	(nd)	(nd)
Shelf, Biogenic/Corals		(nd)	**1.0 (SE= , n=1)**	(nd)	(nd)	(nd)
Shelf, Hard, Exposure	She	(nd)	(nd)	(nd)	**0.0 (SE= , n=1)**	(nd)
Shelf, Soft	Ss_u	**0.5 (SE=0.17, n=9)**	**0.4 (SE=0.18, n=8)**	(nd)	(nd)	(nd)
Slope, Biogenic, Sponges		(nd)	(nd)	(nd)	(nd)	(nd)
Slope, Biogenic, Corals		(nd)	**7.0+ (SE= , n=1)**	(nd)	(nd)	(nd)
Slope, Soft	Fs_u	(nd)	(nd)	(nd)	(nd)	(nd)

Table 4 below is a first-draft "sensitivity matrix" and Table 5 is a first draft "recovery matrix." Each impact level is expressed as a range, which represents plus or minus one standard error around the mean for the values based on empirical data and plus or minus 50% of the mean for the derived values. The following 4-step protocol was used to derive the levels in both tables.

1) Empirical data were used as the starting point for all gear x habitat combinations, when available.

2) Empirical data were analyzed for trends in relative impacts by major gear types across all habitats and by habitat for all gear types.

3) Expert opinion and/or theoretical considerations were used to determine relative impacts for gear x habitat combinations where no empirical data were available. This was done by assigning impact levels across a range of gear x habitat cells following the general trends identified in steps 2 and 3 and reducing the impact level by approximately 50% at each step along the trend gradient for gear and habitats.

4) When empirical data came from only one study or were apparently anomalous and departed strongly from the overall trends in impact levels (step 2), trend data were used.

The values in the two matrices are color-coded based on how they were determined. Those in cells highlighted in green are means calculated from the literature summaries in Annex 1 and summarized in Table 3; i.e. these are the empirical data derived from step 1 in the above protocol. Those in the un-highlighted cells were derived by adjusting the appropriate empirical literature values using the relative rankings of gear impacts determined in the present analysis as well as information in recent reviews (Auster and Langton 1999; Hamilton 2000; Barnette 2001; Johnson 2002; Morgan and Chuenpagdee 2003); using steps 2 and 3 in the above protocol. Those in the yellow highlighted cells were derived using step 4 above. Some example calculations are given below.

The present analysis (Table 3) suggests the following relative rankings of gear from highest to lowest impact: dredges > bottom trawls > pots & traps (no empirical data available for nets and hook & line gears). Although very little research exists, the various types of nets are generally considered to have much less impact on the seabed than dredges and trawls, and hook & line methods have the least impact (Hamilton 2000; Barnette 2001; Johnson 2002). Hence, the derived values reflect this relative ranking of impacts: dredges > trawls > nets > pots and traps > hook and line.

In addition to the relative gear rankings, the present analysis of empirical research also showed a nearly consistent ranking by substrate/macrohabitat type almost regardless of gear type from most adversely impacted to least: biogenic > hard bottom > soft sediment. This ranking is the same as that in two recent conceptual models of gear impacts by bottom type (Auster and Langton 1999; NRC 2002).

Inspection of Tables 4 and 5 shows that all values for the Basin and Ridge megahabitats, and most for the Slope are derived values and not means calculated from empirical values in the literature. This is because there has been very little research useful for the present analysis on gear impacts in water depths exceeding 200 m. Therefore, in most cases for both matrices, the values from the appropriate shelf substrate/macrohabitat categories were transferred without change to the Slope, Basin, and Ridge cells. It should be noted, however, that there are theoretical bases for adjusting values from these deeper habitats. Benthic communities in deeper waters where wind and waves do not disturb the seabed are probably less adapted to resisting and recovering from physical disturbances generally. No such adjustments, however, were attempted for the present analysis.

To illustrate the general process for obtaining the values given in Tables 4 and 5, consider the "Dredges" column in "Estuarine" habitats and the relative ranking of sensitivity by habitat type discussed above (biogenic > hard > soft). Note that the derived cell (dredges on estuarine hard bottom) was assigned a range of 0.9-2.6, which falls below the sensitivity range for biogenic habitat but above the range for soft sediments. In similar fashion, consider The empirical values for the sensitivity of "Shelf, Biogenic" habitat. The literature values reflect the ranking of dredges having the most impact (1.0-2.8), followed by trawls (1.4-2.2). There were no studies on nets, so it was assigned a value (0.9-1.8) less than Trawls but more than Pots and Traps for which there were empirical values (0.4-1.2). And Hook and Line was assigned the smallest range (0.0-0.9).

In similar fashion, moving across most rows in the two tables, note that the ranges reflect the relative rankings of impacts of gear types (dredges > trawls > nets > pots and traps > hook and line). It should be noted, however, that where empirical data departed from either of these trends (e.g. the effects of bottom trawls in estuarine habitats) the empirical data were used to control the derived values.

As noted above, the ranges given in the highlighted cells reflect plus or minus one standard error around the means for each gear-by-habitat combination given in Table 3. For example, the range of sensitivity for Bottom Trawls on Estuarine, Soft Sediments in Table 4 is 0.5-1.0 (column 4 and row 4). This is the mean (0.70) plus or minus the 0.25, the standard error around the mean given in Table 3 (column 4, row 3), rounded to the nearest 0.1 of a unit. All values in Tables 4 and 5 were rounded to the nearest tenth. The ranges given for the derived (un-highlighted) values represent approximately plus or minus 50% of the midpoint of each range. This range of variability was chosen because it is representative of the variability in those empirical means for which sample sizes (n values in Table 3) were 3 or more.

Table 4. Sensitivity level ranges for five major gear categories for all mapped habitat types. Sensitivity levels range from 0 to 3 (see Table 2 for descriptions). Values in green shaded cells are ranges from the literature, showing + or - one SE around the calculated means in Table 5. Others are derived values (see text for details).

MEGAHAB, SUBSTRATE, MESO/MACROHAB	Habitat Code	Dredges	Bottom Trawls	Nets	Pots & Traps	Hook & Line
Estuarine, Biogenic/Macrophytes		2.8-3.0 (n=4)	1.0-2.0 (n=3)	0.5-1.0	0.0-0.5	0.0-0.5
Estuarine, Biogenic/Shellfish		2.0-3.0 (n=3)	1.0-2.0	0.5-1.0	0.0-0.5	0.0-0.5
Estuarine, Hard		1.5-2.5	1.0-2.0	0.5-1.0	0.0-0.5	0.0-0.5
Estuarine, Soft		1.0-1.6 (n=9)	0.5-1.0 (n=7)	0.0-0.5	0.0-0.5	0.0-0.5
Shelf, Biogenic/Macrophytes		1.4-3.0 (n=1)	1.0-3.0 (n=1)	0.5-2.5	0.3-1.3	0.3-1.3
Shelf, Biogenic/Shellfish		1.4-3.0 (n=1)	1.4-2.2 (n=1)	0.9-1.8	0.4-1.2 (n=1)	0.2-1.0
Shelf, Biogenic/Sponges		2.0-3.0	2.0-2.4 (n=2)	0.9-1.8	0.4-1.2	0.2-1.0
Shelf, Biogenic/Corals		2.0-3.0	2.0-3.0 (n=1)	0.5-2.5	0.3-1.3	0.3-1.3
Shelf, Hard, Canyon Wall	Shc	1.3-2.1	2.0-3.0	0.8-1.6	0.0-0.6	0.0-0.6
Shelf, Hard, Exposure	She	1.3-2.1 (n=3)	2.0-3.0 (n=2)	0.8-1.6	0.0-0.6 (n=2)	0.0-0.6
Shelf, Hard, Ice-formed feature	Shi_b/p	1.3-2.1	2.0-3.0	0.8-1.6	0.0-0.6	0.0-0.6
Shelf, Soft	Ss_u	0.9-1.1 (n=22)	0.5-1.0 (n=29)	0.5-1.0	0.0-0.5	0.0-0.2
Shelf, Soft, Canyon Floor	Ssc/f_u	0.9-1.1	0.5-1.0	0.2-0.8	0.0-0.5	0.0-0.2
Shelf, Soft, Canyon Wall	Ssc_u	0.9-1.1	0.5-1.0	0.2-0.8	0.0-0.5	0.0-0.2
Shelf, Soft, Gully	Ssg	0.9-1.1	0.5-1.0	0.2-0.8	0.0-0.5	0.0-0.2
Shelf, Soft, Gully floor	Ssg/f	0.9-1.1	0.5-1.0	0.2-0.8	0.0-0.5	0.0-0.2
Shelf, Soft, Ice-formed feature	Ssi_o	0.9-1.1	0.5-1.0	0.2-0.8	0.0-0.5	0.0-0.2
Ridge, Biogenic		2.0-3.0	2.0-3.0	0.5-2.5	0.3-1.3	0.3-1.3
Ridge, Hard, Exposure	Rhe	1.3-2.1	2.0-3.0	0.8-1.6	0.0-0.6	0.0-0.6
Ridge, Soft	Rs_u	0.9-1.1	0.5-1.0	0.8-1.6	0.0-0.6	0.0-0.6
Slope, Biogenic/Sponges		2.5-3.0	2.5-3.0 (n=2)	1.0-2.0	0.5-1.0	0.5-1.0
Slope, Biogenic/Corals		2.5-3.0	2.5-3.0 (n=2)	1.0-2.0	0.5-1.0	0.5-1.0
Slope, Hard, Canyon Wall	Fhc	2.5-3.0	2.5-3.0	1.0-2.0	0.5-1.0	0.5-1.0

Slope, Hard, Canyon Floor	Fhc/f	**2.5-3.0**	**2.5-3.0**	**1.0-2.0**	**0.5-1.0**	**0.5-1.0**
Slope, Hard, Exposure	Fhe	**2.5-3.0**	**2.5-3.0**	**1.0-2.0**	**0.5-1.0**	**0.5-1.0**
Slope, Hard, Gully	Fhg	**2.5-3.0**	**2.5-3.0**	**1.0-2.0**	**0.5-1.0**	**0.5-1.0**
Slope, Hard, Landslide	Fhl	**2.5-3.0**	**2.5-3.0**	**1.0-2.0**	**0.5-1.0**	**0.5-1.0**
Slope, Soft	Fs_u	**1.0-2.0**	**0.5-1.5** **(n=1)**	**0.5-1.0**	**0.2-0.6**	**0.2-0.6**
Slope, Soft, Canyon Floor	Fsc/f_u	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Slope, Soft, Canyon Wall	Fsc_u	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Slope, Soft, Gully	Fsg	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Slope, Soft, Gully floor	Fsg/f	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Slope, Soft, Landslide	Fsl	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Basin, Biogenic		**2.0-3.0**	**2.0-3.0**	**0.5-2.5**	**0.3-1.3**	**0.3-1.3**
Basin, Hard, Exposure	Bhe	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Basin, Soft	Bs_u	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Basin, Soft, Canyon Floor	Bsc/f_u	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Basin, Soft, Canyon Wall	Bsc_u	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Basin, Soft, Gully	Bsg	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Basin, Soft, Gully floor	Bsg/f_u	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Continental Rise, Biogenic		**2.0-3.0**	**2.0-3.0**	**0.5-2.5**	**0.3-1.3**	**0.3-1.3**
Continental Rise, Hard, Canyon Wall	Ahc	**2.5-3.0**	**2.5-3.0**	**1.0-2.0**	**0.5-1.0**	**0.5-1.0**
Continental Rise, Hard, Exposure	Ahe	**2.5-3.0**	**2.5-3.0**	**1.0-2.0**	**0.5-1.0**	**0.5-1.0**
Continental Rise, Soft	As_u	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Continental Rise, Soft, Canyon Floor	Asc/f_u	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Continental Rise, Soft, Canyon	Asc_u	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Continental Rise, Soft, Gully	Asg	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Continental Rise, Soft, Landslide	Asl	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**

Table 5. Recovery time (years) ranges for five major gear categories and all mapped habitat types. Values in green shaded cells are ranges from the literature, showing + or - one SE around the calculated means in Table 5. Others are derived values (see text for details).

MEGAHAB, SUBSTRATE, MESO/MACROHAB	Habitat Code	Dredges	Bottom Trawls	Nets	Pots & Traps	Hook & Line
Estuarine, Biogenic/Macrophytes		2.6-5.5 (n=3)	1.5-4.5	0.5-2.0	0.0-0.5	0.0-0.5
Estuarine, Biogenic/Shellfish		2.5-5.5	1.5-4.5	0.5-2.0	0.0-0.5	0.0-0.5
Estuarine, Hard		1.5-2.5	1.0-2.0	0.5-1.0	0.0-0.5	0.0-0.5
Estuarine, Soft		0.2-0.6 (n=8)	0.1-0.3 (n=6)	0.0-0.5	0.0-0.5	0.0-0.5
Shelf, Biogenic/Macrophytes		2.0-6.0 (n=1)	1.5-4.5 (n=1)	0.5-2.5	0.3-1.3	0.3-1.3
Shelf, Biogenic/Shellfish		2.0-6.0	1.0-3.0	0.5-1.5	0.0-0.2 (n=1)	0.0-0.2
Shelf, Biogenic/Sponges		2.0-3.0	1.0-1.6 (n=2)	0.5-1.5	0.4-1.2	0.2-1.0
Shelf, Biogenic/Corals		2.0-3.0	1.0-1.6	0.5-1.5	0.4-1.2	0.2-1.0
Shelf, Hard, Canyon Wall	Shc	1.0-3.0	1.0-2.0	0.5-1.5	0.0-0.5	0.0-0.5
Shelf, Hard, Exposure	She	1.0-3.0	1.0-2.0	0.5-1.5	0.0-0.1 (n=1)	0.0-0.5
Shelf, Hard, Ice-formed feature	Shi_b/p	1.0-3.0	1.0-2.0	0.5-1.5	0.0-0.5	0.0-0.5
Shelf, Soft	Ss_u	0.3-0.7 (n=9)	0.2-0.6 (n=8)	0.1-0.5	0.0-0.5	0.0-0.2
Shelf, Soft, Canyon Floor	Ssc/f_u	0.3-0.7	0.2-0.6	0.1-0.5	0.0-0.5	0.0-0.2
Shelf, Soft, Canyon Wall	Ssc_u	0.3-0.7	0.2-0.6	0.1-0.5	0.0-0.5	0.0-0.2
Shelf, Soft, Gully	Ssg	0.3-0.7	0.2-0.6	0.1-0.5	0.0-0.5	0.0-0.2
Shelf, Soft, Gully floor	Ssg/f	0.3-0.7	0.2-0.6	0.1-0.5	0.0-0.5	0.0-0.2
Shelf, Soft, Ice-formed feature	Ssi_o	0.3-0.7	0.2-0.6	0.1-0.5	0.0-0.5	0.0-0.2
Ridge, Biogenic		2.0-3.0	2.0-3.0	0.5-2.5	0.3-1.3	0.3-1.3
Ridge, Hard, Exposure	Rhe	1.3-2.1	2.0-3.0	0.8-1.6	0.0-0.6	0.0-0.6
Ridge, Soft	Rs_u	0.9-1.1	0.5-1.0	0.8-1.6	0.0-0.6	0.0-0.6
Slope, Biogenic/Sponges		3.5-10.5	3.5-10.5	2.0-8.0	0.0-3.0	0.0-3.0
Slope, Biogenic/Corals		3.5-10.5	3.5-10.5 (n=1)	2.0-8.0	0.0-3.0	0.0-3.0
Slope, Hard, Canyon Wall	Fhc	2.5-3.0	2.5-3.0	1.0-2.0	0.5-1.0	0.5-1.0

Slope, Hard, Canyon Floor	Fhc/f	**2.5-3.0**	**2.5-3.0**	**1.0-2.0**	**0.5-1.0**	**0.5-1.0**
Slope, Hard, Exposure	Fhe	**2.5-3.0**	**2.5-3.0**	**1.0-2.0**	**0.5-1.0**	**0.5-1.0**
Slope, Hard, Gully	Fhg	**2.5-3.0**	**2.5-3.0**	**1.0-2.0**	**0.5-1.0**	**0.5-1.0**
Slope, Hard, Landslide	Fhl	**2.5-3.0**	**2.5-3.0**	**1.0-2.0**	**0.5-1.0**	**0.5-1.0**
Slope, Soft	Fs_u	**1.0-2.0**	**1.0-2.0**	**0.5-1.0**	**0.2-0.6**	**0.2-0.6**
Slope, Soft, Canyon Floor	Fsc/f_u	**1.0-2.0**	**1.0-2.0**	**0.5-1.0**	**0.2-0.6**	**0.2-0.6**
Slope, Soft, Canyon Wall	Fsc_u	**1.0-2.0**	**1.0-2.0**	**0.5-1.0**	**0.2-0.6**	**0.2-0.6**
Slope, Soft, Gully	Fsg	**1.0-2.0**	**1.0-2.0**	**0.5-1.0**	**0.2-0.6**	**0.2-0.6**
Slope, Soft, Gully floor	Fsg/f	**1.0-2.0**	**1.0-2.0**	**0.5-1.0**	**0.2-0.6**	**0.2-0.6**
Slope, Soft, Landslide	Fsl	**1.0-2.0**	**1.0-2.0**	**0.5-1.0**	**0.2-0.6**	**0.2-0.6**
Basin, Biogenic		**3.5-10.5**	**3.5-10.5**	**2.0-8.0**	**0.0-3.0**	**0.0-3.0**
Basin, Hard, Exposure	Bhe	**2.5-3.0**	**2.5-3.0**	**1.0-2.0**	**0.5-1.0**	**0.5-1.0**
Basin, Soft	Bs_u	**1.0-2.0**	**1.0-2.0**	**0.5-1.0**	**0.2-0.6**	**0.2-0.6**
Basin, Soft, Canyon Floor	Bsc/f_u	**1.0-2.0**	**1.0-2.0**	**0.5-1.0**	**0.2-0.6**	**0.2-0.6**
Basin, Soft, Canyon Wall	Bsc_u	**1.0-2.0**	**1.0-2.0**	**0.5-1.0**	**0.2-0.6**	**0.2-0.6**
Basin, Soft, Gully	Bsg	**1.0-2.0**	**1.0-2.0**	**0.5-1.0**	**0.2-0.6**	**0.2-0.6**
Basin, Soft, Gully floor	Bsg/f_u	**1.0-2.0**	**1.0-2.0**	**0.5-1.0**	**0.2-0.6**	**0.2-0.6**
Continental Rise, Biogenic		**3.5-10.5**	**3.5-10.5**	**2.0-8.0**	**0.0-3.0**	**0.0-3.0**
Continental Rise, Hard, Canyon Wall	Ahc	**2.5-3.0**	**2.5-3.0**	**1.0-2.0**	**0.5-1.0**	**0.5-1.0**
Continental Rise, Hard, Exposure	Ahe	**2.5-3.0**	**2.5-3.0**	**1.0-2.0**	**0.5-1.0**	**0.5-1.0**
Continental Rise, Soft	As_u	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Continental Rise, Soft, Canyon Floor	Asc/f_u	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Continental Rise, Soft, Canyon	Asc_u	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Continental Rise, Soft, Gully	Asg	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**
Continental Rise, Soft, Landslide	Asl	**1.0-2.0**	**0.5.1.5**	**0.3-1.0**	**0.2-0.6**	**0.1-0.3**

4 DISCUSSION AND CONCLUSIONS

This analysis is a first attempt to quantify the sensitivity of bottom habitats to and recovery of bottom habitats from the impacts of different types of fishing gear that occur along the US west coast. The analysis was based on major literature reviews, particularly Johnson (2002) but also Watling and Norse (1998), Auster and Langton (1999), Dayton et al. (2002), National Research Council (2002), and Morgan and Chuenpagdee (2003). The resulting sensitivity and recovery values are presented in Tables 4 and 5. The intention is for these values, or values modified based on additional information and/or analysis, to be used in the Bayesian modeling process to identify fishing impacts and ways of preventing, minimizing or mitigating those impacts. Before proceeding to the modeling process, however, several topics warrant discussion.

First, it may be useful to discuss Tables 4 and 5 from the perspective of what this analysis does and does not aim to be. The values in all cells are given as ranges. As discussed, the ranges represent plus or minus one standard error around the mean for all values given. The magnitude of each range reflects the amount of uncertainty in a statistical sense, which is affected in large measure by the number of studies incorporated into each mean. For those gear-by-habitat combinations for which there were few studies, the ranges are generally greater compared to those that had relatively large "n" values; see Table 3 for statistics for each gear-by-habitat combination for which empirical data were available. The values presented in Tables 4 and 5 are adequate for use in the Bayesian modeling process, but they should not be pressed too far quantitatively.

This caveat is based on the paucity of empirical data for the overall analysis, but also the fact that an arbitrary scale of 0 to 3 was used to standardize the various metrics reported in the literature (Annex 1). Researchers have used a wide range of metrics to try to assess gear impacts, and the various ecological processes that determine EFH characteristics are not well understood. Hence, the present analysis should not be interpreted as a direct quantification of gear impacts that can be used to infer, for example, functional habitat characteristics related to EFH. The relative effects of gear types on some functional habitat characteristics may well be reflected in the ranges of values given in Tables 4 and 5, but they do not represent a direct quantification of any particular impact on habitat function. The relationship of EFH to various habitat characteristics is complicated and not well understood quantitatively.

Secondly, it was noted in the Introduction section that the literature consists largely of research in other areas. There is therefore a need to determine how studies in other parts of the world relate to impacts on habitats from fishing gears used on the Pacific coast. Only two studies from the Pacific were found that had useful information for the present analysis (see first two entries in Table A1.2). In order to develop a more complete picture of potential impacts, studies from other areas must be relied upon. This raises the question of how inferences can and/or should be drawn from studies in other areas. This is essentially a question of applicability that is relevant to all of the sciences: How representative are the findings from one study of situations in other areas or at other times?

All the major reviews on the impacts of fishing gear on fish habitat address this issue directly or implicitly. For example, the extensive international review and assessment of the impacts of trawling and dredging on seafloor habitats (National Research Council 2002) found that (p. 20): "The extensive primary literature and many review articles… reveal several generalities about the response of seafloor communities to trawling and dredging." In another review, Morgan and Chuenpagdee (2003) ranked gear types by their relative impacts based on the scientific literature as well as surveys of those involved in the research and management of fisheries. With respect to the utility of their findings to others, they state (p. v): "The methods demonstrated here can be applied to specific fishery management councils to catalyze both regional and national conversations on how to manage truly sustainable ecosystems for fishing and other societal values." Auster and Langton (1999) have taken what might be considered a first step towards a general theory of gear impacts based on habitat complexity, fishing intensity, and ecological theory. Their analysis essentially takes a global perspective based on the overall literature.

Three major facts support this kind of reasoning: (1) many of the same gear types are used in many different geographic areas of the world, (2) seafloor habitats worldwide have a variety of ecological similarities, particularly as related to water depth and substrate characteristics, and (3) many harvested species have broad geographic ranges. Therefore, it seems quite reasonable to infer impacts from studies in other areas so long as they are based on similar gear x habitat combinations. The present analysis considered only studies that involved gear types used on the west coast and the major habitat types that occur there.

Another topic that warrants discussion is the disparity between the number of sensitivity (n=89) and recovery (n=41) studies (see summary in Table 3). Clearly, most of the research has been done on short-term impacts (sensitivity) and there is a need to better understand how habitats recover from different types of impacts in order to better quantify the long-term and cumulative impacts of fishing gear. However, the overall trends for both sensitivity and recovery values relative to gear and habitat types were similar. Most studies showed that all habitat types were most sensitive (greatest short-term impact) to dredges, followed by trawls, then pots and traps (Table 3). A similar relative ranking occurred for recovery times. This does not negate the need for a better quantitative understanding of the recovery process but it does suggest that the recovery times are related to the level of the initial impacts.

A related topic that was not considered in the present analysis is the issue of fishing intensity, or frequency of disturbance of the bottom by fishing gear. Where available, relevant comments were recorded in the literature summary tables in Annex 1. However, there was no consideration of these data in the formulation of the sensitivity and recovery values in the impact tables. Two major reviews developed conceptual models incorporating fishing intensity to their assessment of gear impacts. Auster and Langton (1999) related "level of fishing effort" to changes in habitat characteristics, particularly habitat complexity. The National Research Council 2002 related "frequency of fishing disturbance" and "frequency of natural disturbance" to their overall effect on benthic communities in different kinds of substrates. These kinds of analyses recognize the fact that fishing intensity is an important consideration regardless of how gear impacts are assessed.

A final topic to consider for future research is the possibility of refining the substrate categories, which at present include only "soft," "hard" and "biogenic." For example, the impacts of fishing gear generally are very different when comparing mobile sands and stable muds with some biogenic structure, both being classified as "soft" sediments in the present analysis. It might, for example, be useful to incorporate information such as water depth and potential frequency of natural disturbance (e.g. storm waves). Even if the existing literature was not adequate for a quantification of the differences, ecological theory and/or conceptual models (National Research Council 2002, p. 23) would allow a semi-quantitative assessment.

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ANNEX 1: LITERATURE SUMMARIES

DRAFT 6 - Table A1.1. Summary of references on impacts of **ALL GEAR TYPES** on **ESTUARINE HABITATS**

Reference	Location	Megahabitat	Water Depth	Substrate Type	Macrohabitat	Habitat Code	Sensitivity Level	Sensitivity Comments	Recovery Time (years)	Recovery Comments	Study Design & Sampling Methods	Study Design & Gear Comments
Otter Trawls x Soft Sediment												
Gibbs et al. 1980	New South Wales, Australia	Estuarine	"shallow" estuary	Soft Sediment; sand, 0-30% mud	n/a	n/a	0, 0, 0, 0 (avg=0.0)	minor disturbance of sand; no significant differences between fished and control sites in any community characteristics measured	0, 0, 0, 0 (avg=0.0)	(no detrimental impact)	Smith-McIntyre grab samples	10-m otter trawl with 1 x 0.5 m boards and chain spiders; before & after seasonal prawn trawling and repeated experimental trawling for 1 wk
Smith et al. 1985	Long Island Sound, NY	Estuarine	?	Soft Sediment; sand, mud	n/a	n/a	1, 1, 0, 1 (avg=0.8)	tracks in sediment 1 to 6" deep; attraction of predators; suspension of epibenthos	0.1	tracks "naturalized" by tidal currents after ??; lobster burrow alterations "easily" repaired by lobsters	diver observations	otter trawl with 6' doors, 30-60' scissors, 60-110' extended wing nets, 3/8" chain footrope
Brylinsky et al. 1994	Bay of Fundy, NS	Estuarine	0 to 10+ m; intertidal (6 to 8 m tidal range)	Soft Sediment; mud (silt)	n/a	n/a	1, 1, 1, 1 (avg=1.0)	5 cm deep x 30 cm wide tracks in sediment; decrease in nematodes and diatoms; no effect on polychaetes	0.4	furrows 2 to 7 mo; 4 to 6 wk for nematodes; 1 mo for diatoms - quick recovery expected because of frequent natural distur-bance by storms and ice	core (?) samples of seabed	otter trawl, 18 m trawl, 220 kg doors, 29 cm rollers; experimental tows
DeAlteris et al. 1999	Narragansett Bay, RI	Estuarine	0 to 10+ m; 14 m	Soft Sediment; mud (also see sand)	n/a	n/a	1, 1, 1, 1 (avg=1.0)	otter trawl door tracks (5 to 10 cm) and berms (10 to 20 cm) formed	0.4	hand dug scars persisted >60 da	side scan sonar	otter trawl; observations with side scan sonar of otter trawl door tracks; divers monitored hand dug scars
DeAlteris et al. 1999	Narragansett Bay, RI	Estuarine	0 to 10+ m; 7 m	Soft Sediment; sand with sand waves (also see mud)	n/a	n/a	1, 0, 0, 0 (avg=0.3)	no tracks observed (but see mud)	0.2	hand dug scars recovered in 1 to 4 da	side scan sonar	otter trawl; sand in shallow areas eroded daily, gear impacts may be inconsequential
Cahoon et al. 2001	Pamlico River Estuary, North Carolina	Estuarine	?	Soft Sediment; (no grain size given)	n/a	n/a	0	"…no significant or consistent effect …on any of the soft-sediment organisms we studied."	0	(no effects)	replicate Ponar grabs in six areas, before and after trawling, and in areas known to be affected by shrimp and crab trawling and others unfished	"shrimp and crab trawl" rigged as used in commercial fishery
							Mean = 0.5 Std Err = 0.19 n=6		**Mean = 0.2 Std Err = 0.07 n=6**			
Beam Trawls x Soft Sediment												
Hall-Spencer et al. 1999	Gulf of Venice	Estuarine	25 m	Soft Sediment; sand and mud	n/a	n/a	1, 1, 3, 2 (avg=1.8)	decreased # of large, slow-moving epifauna (scallops, sea cucumbers), inc. # scavengers	(not studied)	none	video surveys 1 and 15 hr post trawling	3-m Rapido (toothed beam) trawl; five passes across study area
							Mean = 1.8 Std Err = n=1		**Mean = Std Err = n = 0**			
Otter Trawls x Biogenic, Macrophytes												
Futch and Beaumariage 1965; Meyer et al. 1991; Tabb 1958	Florida	Estuarine	0 to 10+ m; "shallow"	Biogenic; seagrass (*Thalassia*) *beds;* (sediment??)	n/a	n/a	0, 0, 0, 0 (avg=0.0)	removed some leaves and algae; no change in shoot density, blade number and length, or below ground biomass	0, 0, 0, 0 (avg=0.0)	(no detrimental impact)	?	"Tarpon Springs" & "St. Petersburg" shrimp roller trawls with 4.5 to 8 in rollers; 75 kg roller trawl with steel rollers
							Mean = 0.0 Std Err = n = 1		**Mean = 0.0 Std Err = n = 1**			
New Bedford/Scallop Dredges x Soft Sediment												
Eleftheriou & Robertson 1992	Loch Ewe, Scotland	Estuarine	5 m	Soft Sediment; sand	n/a	n/a	2, 1, 1, 1 (avg=1.3)	shallow furrows by teeth; no changes in infauna; crustaceans and sea stars increased; urchins, scallops, razor clams and other epifauna damaged or removed	(not studied)	?	photographic obser.; grab samples of epifauna and large infauna; samples taken before and after dredging	scallop dredge, 1.2 m wide with nine 12-cm long teeth, no chain bag; 25 tows in one area over 9-da period
Watliing et al. 2001	Damariscotta River, Maine	Estuarine	15 m	Soft Sediment; silty sand	n/a	n/a	1, 1, 2, 1 (avg=1.3)	tilled sediment to 9 cm; trenches 2 cm deep; decearse in fines and org. cont at surf, inc. at 5-9 cm; decreased macrofauna	0.5	sediments similar after 4 - 6 mo; no differences in macrofauna after 6 mo.	sediment samples collected before, immediately after, and 4 - 6 months after dredging	New Bedford style, 2 m wide with chain sweeps, no cutterbar; "intensive" experimental dredging at one site
							Mean = 1.3 Std Err = 0.0 n = 2		**Mean = 0.5 Std Err = n = 1**			
Hydraulic/Suction Dredges x Soft Sediment												

Kyte et al. 1975	Maine	Estuarine	intertidal	Soft Sediment; mud	n/a	n/a	0, 0, 0, 1 (avg=0.3)	turbidity plumes, limited effects on infauna	0.5	rapid recruitment of benthic organisms	water samples and sediment/benthos (cores?); sampled prior to dredging, during, and after 10 mo.	escalator dredge
Peterson et al. 1987	Back Sound, North Carolina	Estuarine	<10 m	Soft Sediment; sand	n/a	n/a	0	no significant impacts for any metric measured	0	(no impacts)	measured clam recruitment, scallop densities, macrofaunal benthos; control and treatment, up to 4 yr post-exp	hydraulic-like clam harvester
Hall et al. 1990	sea loch, Ireland	Estuarine	7 m	Soft Sediment; fine sand	n/a	n/a	3	trenches 0.25 m deep, some holes 0.6 m deep immediately after dredging; 60% reduction in infauna density, 24% loss of species	0.2	all dredge-caused sediment features gone after 40 da; infaunal recovery within 40 da; quick recovery probably because of winter storms in area	diver observations; sediment/benthos samples before, after, and 40 da after	suction dredging for razor clams; experimental dredging for 5 hr to simulate commercial fishing
Wynberg & Branch 1994	Langebaan Lagoon, South Africa	Estuarine	intertidal	Soft Sediment; sand	n/a	n/a	2	up to 75% decreases in some metrics for micro-, meio-, and macrofauna	1.5	recovery of bacteria within weeks, meiofauna 4 mos, macrofauna still some diffs after 18 mos	sample micro-, meio-, and macrofauna up to 18 mos post-exp	experimental fishing with suction dredge used for prawns, replicate sites and controls
Maier et al. 1995	South Carolina	Estuarine	intertidal creeks	Soft Sediment; muddy sand	n/a	n/a	0, 0, 0, 0 (avg=0.0)	short-term turbidity plumes; no significant changes in dominant tax or abundances	0, 0, 0, 0 (avg=0.0)	(no measured impact)	turbidity levels and benthic infauna (cores?); samples before, during, and 2 wk after dredging	mechanical escalator dredge
Kaiser et al. 1996	southeastern England	Estuarine	intertidal	Soft Sediment; muddy sand	n/a	n/a	1, 1, 2, 2 (avg=1.5)	large amounts of sand re-suspension; sig diffs in total infaunal numbers	0.6	"complete recovery" of sediments and benthos after 7 mo	sediment/benchos samples (cores?) taken before, 3 hr after, and 7 mo after in impacted area and control site	suction dredging for manila clams; experimental dredging to simulate commercial fishing
Hall & Harding 1997	Auchencairn Bay, Scotland	Estuarine	intertidal	Soft Sediment; sand	n/a	n/a	2	up to about 50% decrease in some macrofaunal metrics	0.2	approached full recovery within 56 da	sampled macrofauna for up to 56 da post-exp	experimental fishing for cockles with hydraulic suction (and mechani-cal/tractor - see below) in replicate plots and control areas
							Mean = 1.3 Std Err = 0.44 n = 7		**Mean = 0.4 Std Err=0.20 n = 7**			
New Bedford/Scallop Dredges x Biogenic, Macrophytes												
Fonseca et al. 1984	Beaufort, North Carolina	Estuarine	intertidal, shallow subtidal	Biogenic; Soft Sediment; eelgrass beds in muddy sand	n/a	n/a	3, 3, 3, 2 (avg=2.8)	sig decreases in eelgrass biomass and shoot density at both sites, with reduction to ~0 at 30 times site	(not studied)	(no long-term sampling)	sampling of eelgrass	hand-operated scallop dredge, 0.65 m wide, 13 kg, no teeth; experimental dredging at two sites with diff intensity: 0, 15, 30 tows
							Mean = 2.8 Std Err = n = 1		**Mean = Std Err = n =**			
Hydraulic/Suction Dredges x Biogenic, Macrophytes												
Godcharles 1971	Tampa Bay, Florida	Estuarine	?	Biogenic, Soft Sediment; seagrasses, algae, sand	n/a	n/a	3, 3, 3, 2 (avg=2.8)	trenches 5 in deep; all vegetation in path uprooted leaving bare sand	1.5	trenches persisted 1 - 86 da; some sediments still altered after 500 da; authors recommended complete prohitbition of dredging in seagrasses with algae	diver observations	escalator dredge; experimental
Peterson et al. 1987	Back Sound, North Carolina	Estuarine	<10 m	Biogenic; eelgrass and shoalgrass	n/a	n/a	3	seagrass density decreased by 65% in some areas; decreased bay scallop densities	5	seagrass density still 35% lower after 4 yr	measured seagrass damage, clam recruitment, macrofaunal benthos; control and treatment, up to 4 yr post-exp	hydraulic-like clam harvester
Orth 1998	Chincoteague Bay, Virginia	Estuarine	?	Biogenic; Soft Sediment; seagrass beds	n/a	n/a	3, 3, 3, 3 (avg=3.0)	circular "scars" with loss of >50% seagrass cover	5	re-growth minimal after 2 yr; authors estimated 5 or more yr for recovery	diver observations	escalator dredge
							Mean = 2.9 Std Err = 0.07 n = 3		**Mean = 3.8 Std Err = 1.17 n = 3**			
Oyster Dredges/Mechanical Dredges x Biogenic, Oyster Reefs												

Langan 1998	Piscataqua River, New Hampshire and Maine	Estuarine	<10 m	Biogenic; Hard; oyster reef	n/a	n/a	0, 0, 0, 0 (avg=0.0)	temporary turbidity plume; no sig diffs in infauna; oyster size larger in un-dredged area; (no exam of reef structure?)	0, 0, 0, 0 (avg=0.0)	(no serious impacts)	water samples and sediment/benthos and oyster samples in fished (ME) and unfished (NH) areas of same oyster reef	oyster dredge, 30 in wide, 60 lbs, 2-in teeth, chain mesh bag; fished (ME) vs unfished (NH) areas of same oyster reef sampled
Lenihan and Peterson 1998	Neuse River, North Carolina	Estuarine	3 - 6 m	Biogenic; Hard; oyster reef	n/a	n/a	3, 3, 2, 3 (avg=2.8)	reduction in reef height by about 30 cm in dredged areas	(not studied)	(no long-term sampling)	measured reef height and ?	oyster dredge; experimental dredging; compared dredged and un-dredged reefs
Powell et al. 2001	Delaware Bay, New Jersey	Estuarine	< 10 m	Biogenic; Hard; oyster reef	n/a	n/a	0	no significant impacts for any metric measured	0	(no impacts)	repicate dredge samples taken up to several months after exp dredgeing; measured several oyster metrics (no non-oyter metrics)	exp dredging with commercial oyster dredges; 4 sites, 2 exp & 2 control
							mean = 0.9 Std Err = 0.93 n = 3		**Mean = 0.0 Std Err = 0.0 n = 2**			
<u>Hand/Mechanical x Soft Sediment</u>												
Peterson et al. 1987	Back Sound, North Carolina	Estuarine	<10 m	Soft Sediment; sand	n/a	n/a	0	no significant impacts for any metric measured	0	(no impacts)	measured clam recruitment, macrofaunal benthos; control and treatment, up to 4 yr post-exp	Hand/clam rake
Wynberg & Branch 1994	Langebaan Lagoon, South Africa	Estuarine	intertidal	Soft Sediment; sand	n/a	n/a	2	up to 75% decreases in some metrics for micro-, meio-, and macrofauna	1.5	recovery of bacteria within weeks, meiofauna 4 mos, macrofauna still some diffs after 18 mos	sample micro-, meio-, and macrofauna up to 18 mos post-exp	experimental fishing with hand rake (and suction pump - see above) used for prawns, replicate sites and controls
Brown & Wilson 1997	Lowes Cove, Maine	Estuarine	intertidal	Soft Sediment; mud	n/a	n/a	2	up to about 50% decrease in some macrofaunal metrics	(not studied)	(not designed to study recovery)	sampled macrofauna in un-dug, low intensity, and high intensity areas over 2.5 mo period	experimental fishing with clam rake at low and high intensities over 2.5 mo period
Hall & Harding 1997	Auchencairn Bay, Scotland	Estuarine	intertidal	Soft Sediment; sand	n/a	n/a	2	up to about 50% decrease in some macrofaunal metrics	0.2	approached full recovery within 56 da	sampled macrofauna for up to 56 da post-exp	experimental fishing for cockles with tractor (mechanical) dredge (and hydraulic suction- see above) in replicate plots and control areas
							mean = 1.5 Std Err = 0.50 n = 4		**Mean = 0.9 Std Err=0.53 n = 3**			
<u>Hand/Mechanical x Biogenic, Macrophpytes</u>												
Peterson et al. 1983	North Carolina	Estuarine	<10 m	Biogenic; eelgrass and shoalgrass	n/a	n/a	3	bull rake removed 89% of shoots and 83% roots; pea digger 55% and 37%	(not studied)	(no long-term sampling)	measured seagrass damage only	Hand/mechanical; clam raking with bull rakes and pea digger rakes
Peterson et al. 1987	Back Sound, North Carolina	Estuarine	<10 m	Biogenic; eelgrass and shoalgrass	n/a	n/a	1	seagrass density decreased by 25%; no effects on other metrics	1	full recovery of seagrasses within 1 yr	measured seagrass damage, clam recruitment, macrofaunal benthos; control and treatment, up to 4 yr post-exp	Hand/clam rake
							Mean = 2.0 Std Err=1.00 n = 2		**Mean = 1.0 Std Err = n = 1**			

DRAFT 6 - Table A1.2. Summary of references on impacts of **TRAWLS** on **SHELF HABITATS**

Reference	Location	Megahabitat	Water Depth	Substrate Type	Macrohabitat	Habitat Code	Sensitivity Level	Sensitivity Comments	Recovery Time (years)	Recovery Comments	Study Design & Sampling Methods
								Otter Trawls x Soft Sediment			
Engel & Kvitek 1998	**central California**	**Shelf**	**180 m**	**Soft Sediment; mud, sand, gravel**	**n/a**	**Ss_u**	**1, 1, 2, 1 (avg=1.3)**	**higher densities of all dom epifauna in lightly fished areas; some invert prey spp higher in heavily fished areas**	**(not studied)**	**(short-term study)**	**still and video; grab samples; fish stomachs**
High 1998	**Pacific NW USA**	**Shelf**	**?**	**Soft Sediment; "various"**	**n/a**	**Ss_u**	**1**	**trawl marks visible; benthic fauna and rocks dislodged**	**(not studied)**	**(short-term study)**	**diver observations**
Gibbs et al. 1980	New South Wales, Australia	Shelf	10 m	Soft Sediment; sand	n/a	PC 915	0, 0, 0, 0 (avg=0)	infauna at low densities but no difference detected pre- and post-trawl	0, 0, 0, 0 (avg=0)	(short-term study)	grab samples of infauna pre- and post-trawl; underwater observations
Harris & Poiner 1991	Gulf of Carpentaria, Australia	Shelf	17-21 m	Soft Sediment; mud	n/a	Ss_u	2, 1, 2, 2 (avg=1.8)	>50% reduction in total fish abundances, but some spp inc, some decreased little	(not studied)	**This study attempted to show persisten differences due to continued trawling, which might be relevant for some management decisions.**	comparison of 1964 and 1985/86 data on demersal fish
Mayer et al. 1991	Gulf of Maine, Maine	Shelf	20 m	Soft Sediment; mud	n/a	Ss_u	1, 0, 0, 1 (avg=0.5)	furrows in sediments several cm deep; no sig diffs in infauna inside and out	0, 0, 0, 0 (avg=0.0)	(no sig effects; short-term study)	sediment/benthos, cores; sampled inside and outside trawl track before and 1 da after
Rumohr & Krost 1991	Western Baltic Sea	Shelf	?	Soft Sediment; sand	n/a	Ss_u	1	observed shell damage to ocean quahogs	(not studied)	(short-term study)	samples of bivalves
Prena et al. 1996	Grand Banks, Canda	Shelf	?	Soft Sediment; sand	n/a	Ss_u	1, 2, 1 (avg=1.3)	25% decrease in epifauna biomass in trawled area; some damage to brittle stars and urchins; no effect on molluscs	1	(assumed "recovery" within 1 yr or minor effects)	sampled infauna, epifauna (sled) and observations
Schwinghamer et al. 1998 (physical effects); Prena et al. 1999 & Kenching-ton et al. 2001 (biological effects)	Grand Banks, New Foundland	Shelf	120-146 m	Soft Sediment; fine and medium sand	n/a	Ss_u	1, 1, 1, 2 (avg=1.3)	trawl marks visible, trawling smoothed the bottom, less hummocky; sig diffs in various epifauna characteristics	1	trawl marks gone after 1 yr;"little long-term effects on infauna"; (persistent?) decreases in sand dol-lars, brittle stars, crabs, urchins after trawling;	video observations, epibenthic sled, grabs; multiple samples over 3 yr period
Tuck et al. 1998	Scottish Sea, Scotland	Shelf	30-40 m	Soft Sediment; mud	n/a	Ss_u	1, 1, 1, 1 (avg=1.0)	species richness sig higher after 16 mo and throughout recovery 18 mo in fished areas; abundance higher then lower in fished areas	1	(minor sig but complex effects)	"biological surveys" of infauna, sampled after 5, 10, 16 mo after initiation of trawling, then 6, 12, 18 mo after end of trawling in fished and unfished areas
Fridd et al. 1999	North Sea	Shelf	55-80 m	Soft Sediment; mud, sand	n/a	Ss_u	1, 0, 1, 1 (avg=0.8)	heavy fishing decreased some taxa, but increased some opportunistic taxa - study started with a priori predictions and tested them by taxa	(not studied)	(study not directly designed to assess recovery, but did suggest persistence of benthos even with heavy trawling)	grab sampling over 27 yr period in fished areas
Bergman & Van Santbrink 2000	North Sea	Shelf	30 -50 m	Soft Sediment; sand, silty sand	n/a	Ss_u	1, 1, 1, 2 (avg=1.3)	mortality of various taxa ranged from 0 to 52%, with average about ~20%	(not studied)	(short-term study)	grab or corer(?); sampled before tow and within 2 days after
Hansson et al. 2000	Sweden	Shelf	75-90 m	Soft Sediment; clay	n/a	PC 915	1, 1, 1 (avg=1.0)	differential responses by taxa, but some decrease in most	(not studied)	(short-term study)	grab sampling before and 5-9 mo after trawling in area closed to fishing for 6 yr
McConnaughey, et al. 2000	eastern Bering Sea, Alaska	Shelf	44-52 m	Soft Sediment; sand	n/a	Ss_u	1	epifauna less abundant and less diverse in fished; infauna with mixed responses, some less	(not studied)	(study designed to fished vs unfished areas)	sampled epifauna with 34 m otter trawl
Moran & Stephenson 2000	northwest Australia	Shelf		Soft Sediment; sand(?)	n/a	Ss_u	2, 2, 2, 2 (avg=2.0)	benthic densities decreased exponentially with # tows, 4 tows=50% reduction	(not studied)	(short-term study)	video camera on sled; multiple samples over several days(?)

Sanchez et al. 2000	Catalan coast, Spain	Shelf	30-40 m	Soft Sediment; mud	n/a	Ss_u	1, 1, 0, 1 (avg=0.8)	minor sig diffs in some infaunal characteristics; furrows visible in side scan images	0	(minor sig effects; short-term study)	benthos, van Veen grab, side scan sonar; sampled over time after trawling (hrs): 0, 24, 102, 150
Drabsch et al. 2001	South Australia	Shelf	20 m	Soft Sediment; fine silt, sand	n/a	Ss_u	1, 1, 2, 2 (avg=1.5)	28% loss of epifauna; some infauna losses; board marks on seabed	(not studied)	(short-term study)	grab or corer(?); sampled before tows and within 3 wks after
							Mean = 1.1 **Std Err = 0.12** **n = 16**		**Mean = 0.6** **Std Err = 0.25** **n = 5**		
Beam Trawls x Soft Sediment											
de Groot and Apeldoorn 1971	southern North Sea	Shelf	20 m	Soft Sediment; sand	n/a	Ss_u	2, 2, 2 (avg=2.0)	sessile organisms (e.g. hydroids, tube worms, bivalves, echinoids) badly damaged; mobile epifauna not affected	(not studied)	(short-term study)	diver observations
de Groot 1984	North Sea	Shelf	?	Soft Sediment; sand	n/a	Ss_u	2, 2, 1 (avg=1.7)	trawling removed "high numbers" of hydroids	(not studied)	(short-term study)	diver observations
Margetts & Bridger 1971	English Channel	Shelf	22 m	Soft Sediment; sand, mud/sand	n/a	Ss_u	1, 1, 1, 1 (avg=1.0)	left 15 mm deep furrows and smoothed bottom roughness in some areas	(not studied)	(short-term study)	underwater video; obs of physical effects only
Fonteyne 2000	Goote Bank, Belgium and Netherlands	Shelf	20-30 m	Soft Sediment; sand, silt	n/a	Ss_u	1, 1, 1, 1 (avg=1.0)	shallow furrows, sediment hardness affected	(not studied)	(short-term study)	side scan sonar, sediment physical measurements; made up to 52 hr after trawling
Bergman et al. 1990, Bergman & Hup 1992	North Sea	Shelf	30 m	Soft Sediment; sand	n/a	PC 915	1, 1, 2, 3 (avg=1.8)	up to 65% decrease in some epi and tube dwelling taxa, but no effect on many, some increased	(not studied)	(short-term study)	grab and trawl sampling of epifauna; sampled before and up to 16 hr after
Philippart 1998	North Sea	Shelf	variable	Soft Sediment	n/a	PC 915	1, 1, 2, 1 (avg=1.3)	beam trawl much more effective at catching large epifauna, up to 10x for some	(not studied)	(not designed to determine recovery level)	analyzed bycatch data as fishery changed trawl types
Kaiser & Spencer 1996, Kaiser et al. 1996, 1998, 1999	Irish Sea	Shelf	12-35 m	Soft Sediment; sand, sand with gravel and shell	n/a	Ss_u	1, 2, 2 (avg=1.7)	up to 54% reduction in species numbers and abundances in some areas; losses of epi- and infauna	0.5	differences between sites detectable only up to 6 mo	bottom sampling and observations over time (sampling schedule??)
Santbrink & Bergman 1994	North Sea, Netherlands	Shelf	?	Soft Sediment; very fine sand	n/a	Ss_u	2, 2, 2 (avg=2.0)	mortality of various taxa ranged from 4 to ~100%: echinoderms low, larger molluscs 12-85%, epifaunal crustaceans 30-74%, most annelids unaffected; fish scavengers attracted	(not studied)	(short-term study)	infauna sampling; compared before and after trawling
Jennings et al. 2001a, b	eastern North Sea	Shelf	40-75 m	Soft Sediment; mud to sand	n/a	Ss_u	2	in one area fishing intensity sig neg correlated with infaunal prod & biomass ("dramatic reductions"), no sig with epifauna; no sig correl in second area	(not studied)	(not designed to determine recovery level)	sampled epifauna with small beam trawl, infauna with anchor dredge
Jennings et al. 2002	central North Sea	Shelf	50-75 m	Soft Sediment; sandy, muddy sand	n/a	Ss_u	0	no sig relation between production of small infauna, esp polychaetes (assumed to be fish prey items)	(not studied)	(not designed to determine recovery level)	sampled infauna at nine sites with replicate NIOZ corer
Schratzberger et al. 2002a	North Sea	Shelf	39 and 59 m	Soft Sediment; muddy sand	na	Ss_u	1	some changes in meiofaunal community structure; no sig effects on diversity or biomass	0	(recovery assumed fast because only minor impacts)	sampled meiofauna with corer from 1 to 392 days post-exp trawling

Schratzberger et al. 2002b	North Sea	Shelf	59 m	Soft Sediment; mud, muddy sand	n/a	Ss_u	1, 0, 0, 1 (avg=0.5)	minor decreases at some sites attributed to trawling	(not studied)	(short-term study)	core sampling before and after trawling, meiofauna only
							Mean = 1.3 **Std Err = 0.19** **n = 12**		**Mean = 0.3** **Std Err = 0.25** **n = 2**		
Shrimp Trawls x Soft Sediment											
Ball et al. 1999	Western Irish Sea	Shelf	75 m	Soft Sediment; mud	n/a	Ss_u	1, 1, 2, 1 (avg=1.3)	fewer spp & abundances, and dominance by opportunists in fished area; many more spp & larger individuals of some taxa in unfished area	(not studied)	**This study attempted to show persisten differences due to continued trawling, which might be relevant for some management decisions.**	benthos, grab; sampled before and 24 hr after trawling at fished site
							Mean = 1.3 **Std Err =** **n = 1**		**Mean =** **Std Err =** **n =**		
Otter Trawls x Hard Bottom											
Auster et al. 1996; Lindholm et al. 1999	Gulf of Maine, Maine	Shelf	94 m	Hard; Boulder	n/a	She	3, 3, 3, 3 (avg=3.0)	abundances of several taxa "greatly reduced" or completely absent; boulders apparently moved	(not studied)	(not designed to determine recovery level)	submersible observation in 1987 and 1993, after 6 yr of trawling by large gear
							Mean = 3.0 **Std Err =** **n = 1**		**Mean =** **Std Err =** **n =**		
Beam Trawls x Hard Bottom											
Kaiser & Spencer 1994	Irish Sea	Shelf	32 m	Hard; Gravel, Cobble	n/a	She	2	density of epifauna reduced by 50%	(not studied)	(not designed to determine recovery level)	diver observations
							Mean=2.0 **Std Err =** **n = 1**		**Mean =** **Std Err =** **n =**		
Otter Trawls x Biogenic, Sponges											
Van Dolah et al. 1987	Atlantic, Georgia	Shelf	20 m	Biogenic; sponges and octocorals; Hard; gravel, cobble	n/a		2, 2, 3, 2 (avg=2.3)	heavy damage to barrel sponges, slight damage to corals	1	all epifauna recovered after 12 months	diver observations
Freese 2001	Gulf of Alaska	Shelf	~200 m	Biogenic; sponges	n/a		2	30% sponges badly damaged, 16% reduction in abundance; boulders moved and furrows in bottom	1.5	after 1 yr: 21% less sponges in trawl tracks, little recovery evident	submersible surveys immediately after trawling and 1 yr post
							Mean = 2.2 **Std Err = 0.15** **n =2**		**Mean = 1.3** **Std Err = 0.25** **n = 2**		
Otter Trawls x Biogenic, Corals											
Van Dolah et al. 1987	Atlantic, Georgia	Shelf	20 m	Biogenic; sponges and octocorals; Hard; gravel, cobble	n/a		1	heavy damage to barrel sponges, slight damage to corals	1	all epifauna recovered after 12 months	diver observations
							Mean = 1.0 **Std Err =** **n = 1**		**Mean = 1.0** **Std Err =** **n = 1**		
Otter Trawls x Biogenic, Mussels											
Magorrian 1995	Strangford Lough, Northern Ireland	Shelf	?	Biogenic; mussel beds (*Modiolus*)	n/a		1	mussel beds disconnected by trawling, reductions in epifauna	(not studied)	(short-term study)	side scan sonar
							Mean = 1.0 **Std Err =** **n =1**		**Mean =** **Std Err =** **n =**		
Otter Trawls x Biogenic, Macrophytes											
Guillen et al. 1994	Western Mediterranean	Shelf	?	Biogenic; seagrass meadow (*Posidonia*)	n/a		2	monitored seagrass densities	3	seagrass density had increased 6-fold afte 3 years	noted 45% loss of seagrass meadows due to trawling

	Mean = 2.0 **Std Err =** **n = 1**		**Mean = 3.0** **Std Err =** **n = 1**		

Study Design & Gear Comments
compared lightly and heavily fished areas
?
otter trawl; area trawled repeatedly for one week
otter trawls used for prawns; compared before data after 20 yr of fishing
otter trawl, 18 m footrope, 90 kg doors, with tickler chains; one tow
otter trawl; experimental trawling
otter trawl; experimental trawling 12 times annually for 3 yr
otter trawl, Engel 145 with 1250 kg oval doors, 46 cm rockhopper gear; many experimental tows in area closed to fishing for 1 - 2 yr
otter trawl, no net, with rock hopper gear; experimental trawling in area closed to fishing for 30 yr, 1 tow per mo for 16 mo
otter trawls used for prawns; compared 27-yr series of data during light, mod, heavy fishing
otter tawl, (size?); single experimental sweep
otter (shrimp) trawl, 14 m groundrope, 125 kg boards; experimental trawling (# tows, etc?)
studied different areas representing unfished (closed) and heavily fished with otter trawls
otter trawl, (size etc?); experimenal trawling of short-term (days) multiple tows

otter trawl, (size etc?); experimenal trawling of one or two tows at multiple sites
otter trawl; experimental trawling in non-fished area
beam trawl; site hauled once
beam trawl; observations of immediate effects of trawl
beam trawl, 9.1 m wide; experimental trawling
beam trawl, 4 m wide with tickler chain; experimental trawling
beam trawl, 12 m, 7000 kg with ticklers; repeated exp trawling to cover study site 3 times
beam trawl vs otter trawl
beam trawl, 4 m, 3.5 tonnes with chain matrix; experimental tows, 10-12 passes
beam trawl; experimental trawling
studied two areas, each with wide range of intensities of beam trawling
sampled nine sites representing 17.5-fold range of beam trawling intensities (from 0.35 to 6.14 times/yr disturbance)
sampled two sites after 25 experimental tows with beam trawl

beam trawl, 4 m beam, 80 mm mesh and chain matrix; experimental trawling to simulate "lightly fished"
shrimp bottom trawl; "heavily" fished site vs unfished for 50 yr site near shipwreck
otter trawls, etc; assumed "large" trawl gear effects by before/after obs, 1987 & 1993
beam trawls; 10 hauls with 4 m and 3 hauls with 2 m beam trawls, catches compared
otter trawl, roller-rigged; area trawled once
experimental trawl tows with Nor'eastern bottom trawl with 0.45 m rockhopper discs
otter trawl, roller-rigged; area trawled once
otter trawls; pre- and post-impact study
otter trawls; studied recovery of seagrasses after trawling stopped by artificial reefs

DRAFT 6 - Table A1.3. Summary of references on impacts of **DREDGES** on **SHELF HABITATS**

Reference	Location	Megahabitat	Water Depth	Substrate Type	Macrohabitat	Habitat Code	Sensitivity Level	Sensitivity Comments	Recovery Level	Recovery Comments	Study Design & Sampling Methods
New Bedford/Scallop Dredges x Soft Sediment											
Caddy 1968	Northumberland Strait, Gulf of St. Lawrence, Canada	Shelf	20 m	Soft Sediment; mud, sand	n/a	Ss_u	1, 0, 1, 1 (avg=0.8)	2 cm deep tracks, ridges, dislodged shells in dredge tracks	(not studied)	(short-term study)	diver observations
Butcher et al. 1981	Jervis Bay, New South Wales, Australia	Shelf	13 m	Soft Sediment; sand	n/a	Ss_u	1, 1, 1, 1 (avg=1.0)	smoothed sand ripples	(not studied)	(short-term study)	diver obs of physical effects only
Langton and Robinson 1990	Fippennies Ledge, Atlantic, Maine	Shelf	56-84 m	Soft Sediment; silty sand, some gravel and shell	n/a	Ss_u	1, 2, 2, 2 (avg=1.8)	sediment coarser after dredging; disruption of amphipod tube mats	1.5	scallops, burrowing anemones, tube polychaets decreased significantly after dredging (1 yr?)	submersible obs and photos; before and 1 yr after
Mayer et al. 1991	Atlantic, Maine	Shelf	8 m	Soft Sediment; mud with sand, shell	n/a	Ss_u	1, 2, 1, 1 (avg=1.3)	decrease in fines and org content at surface, increase at 5-9 cm depth; sediment diatoms disrupted, microbial biomass increased after dredging	(not studied)	(short-term study)	core samples; sampled before and 1 day after tow
Eleftheriou and Robertson 1992	Scotland	Shelf	5 m	Soft Sediment; sand	n/a	Ss_u	1, 1, 1 (avg=1.0)	numbers increased with increasing tows, biomass decreased; some polychaetes, urchins and sand eels affected most	(not studied)	(short-term study)	sampled benthic fauna at 1-5 da and 9 da
Black and Parry 1994, 1999	Port Phillip Bay, SE Australia	Shelf	15 m	Soft Sediment; muddy sand	n/a	Ss_u	1, 1, 0, 1 (avg=0.8)	sediment plume; smoothing of seafloor; disturbance up to 6 cm deep in sediments	(not studied)	(short-term study?)	diver observations (?); short-term (?)
Thrush et al. 1995	Mercury Bay, New Zealand	Shelf	24 m	Soft Sediment; coarse sand; "high energy site"	n/a	Ss_u	1, 1, 1, 1 (avg=1.0)	smoothed ripples and infaunal tubes, tracks 2-3 cm deep; reduced densities of common taxa and taxa richness; some community-level changes	0.5	partial recovery after 3 mo in benthic community and pops of some dominant taxa	diver obs and core samples; before and up to 3 mo after dredging
Auster et al. 1996	Stellwagen Bank, Atlantic, Massachusetts	Shelf	20-55 m	Soft Sediment; sand with ripples	n/a	Ss_u	1, 1, 1, 2 (avg=1.3)	sand ripples smoothed, dispersal of shell	1	physical effects only; ripples restored by storms, within 1 yr (?)	side scan sonar surveys
Currie and Parry 1996, 1999	Port Phillip Bay, SE Australia	Shelf	15 m	Soft Sediment; muddy sand	n/a	Ss_u	1, 1, 2, 1 (avg=1.3)	smoothed sand ripples and biogenic mounds; tracks up to 25 cm deep; sig decreases in several taxa; inc in some opportunistic taxa	0.8	tracks gone after 6 mo, ripples re-formed 5 da after dredging after a storm; biogenic mounds re-formed after 6 mo; most spp recovered within 6 mo, some not after 14 mo; annual recruitment 6 mo after exp caused non-sig diffs in most pops	diver obs (?); infauna sampling; monitored up to 14 mo post dredging
Kaiser et al. 1996a	Irish Sea	Shelf	?	Soft Sediment; ? sand, ? gravel	n/a	Ss_u	1, 1, 1 (avg=1.0)	reduced abundances of most species; impacts of both gears similar	(not studied)	(short-term study)	"benthic" samples
Bradshaw et al. 2000	Irish Sea	Shelf	25-40 m	Soft Sediment; sand, mud, gravel	n/a	Ss_u	2, 1, 3, 1 (avg=1.8)	(apparently pops of many common taxa had been decreased by "towed gear" fishing)	?	many epifaunal spp increased significantly in abundance… including brittle stars, a spider crab, scallops, hermit crabs, one sea star	diver obs; multiple surveys over 10 yr period (1989-1998) after area closed to fishing - a long-term, observational "recovery" study
Bradshaw et al. 2001	Irish Sea	Shelf	25-40 m	Soft Sediment; sand, mud, gravel	n/a	Ss_u	1, 1, 0, 1 (avg=0.8)	some diffs in taxa (see recovery notes) but no sig differences in spp richness among plots	?	after 3-9 yr, encrusting epibenthic taxa more common in dredged areas, upright taxa more common in undredged; no sig diffs or clear trends for infauna	diver obs, grab samples 2 times annually for 10 yr (?)

Bradshaw et al. 2002	Irish Sea	Shelf	?	Soft Sediment; sand, gravel	n/a	Ss_u	2, 1, 3, 1 (avg=1.8)	taxa that decreased over time: brittlestars, hydroids, bryozoans, barnacles; taxa that increased: large tunicates, crabs, shrimp, lobsters, whelks, seastars; length of fishing time rather than fishing intensity most important	?	recovery level estimated by comparing areas fished at different intensities, over long-term	compared recent benthic data from 7 sites exposed to different levels of fishing effort to data collected 50-60 yr earlier when scallop fishing was limited
Alves et al. 2003	eastern Atlantic, southern Portugal	Shelf	7-9 m	Soft Sediment	n/a	Ss_u	1.5	significant decreases in abundance, taxonomic richness, and biomass; most <50% ?	(not studied)	(short-term study)	before-after experimental dredge tows in different seasons; core and quadrat samples of meio- and macroinfauna
Gaspar et al. 2003	eastern Atlantic, southern Portugal	Shelf	5-12 m	Soft Sediment; sand, sandy mud	n/a	Ss_u	1	"damage and mortality relatively low"; scavengers attracted to site	(not studied)	(short-term study)	experimental tows with dredge; sampled immediately after and up to 24 hr after
Sullivan et al. 2003	Atlantic, New York Bight	Shelf	45-88 m	Soft Sediment; sand	n/a	Ss_u	0	no sig diffs in any areas	0	some short-term increase in juvenile fish recruits, but no diffs in other metrics (except those related to storm events)	underwater video surveys of seabed; suction sampling of infauna; beam trawl sampling of young-of-year flatfish
							Mean = 1.2 Std Err = 0.10 n = 16		**Mean = 0.8 Std Err = 0.25 n = 5**		
Hydraulic Dredges x Soft Sediment											
Meyer et al. 1981	Atlantic, New York	Shelf	11 m	Soft Sediment; silty sand	n/a	Ss_u	1, 0, 1, 1 (avg=0.8)	20 cm deep trenches formed; attracted predators preying on damaged and exposed infauna	0.1	within 24 hr predator numbers appeared back to normal; (no data on recovery of infauna)	diver observations
MacKenzie 1982	Atlantic, New Jersey	Shelf	37 m	Soft Sediment; fine to medium sand	n/a	Ss_u	0, 0, 0, 0 (avg=0)	no sig diffs in any areas	0	designed to estimate recovery by comparing areas with different fishing intensities; "no lasting effcts…"	sampled benthic infauna in areas with diff fishing levels: none, active for 2 yr, fished then abandoned (for ?? yr)
Medcof and Caddy 1971	Southern Nova Scotia	Shelf	7-12 m	Soft Sediment; sand, sand-mud	n/a	Ss_u	1, 1, 1, 1 (avg=1.0)	physical effects only; avg 20 cm deep furrows by hydraulic, 3-10 mechanical	(not studied)	(short-term study only)	diver and manned submersible observations
Murawski and Serchuk 1989	mid-Atantic, NJ-NY	Shelf	?	Soft Sediment; mud, sand, gravel	n/a	Ss_u	1, 1, 1, 1 (avg=1.0)	trenches cut, deeper by hydraulic dredge; sand dollars, crustaceans, worms "substantially disrupted"; attraction of sea stars, fish to trenches	(not studied)	(short-term study only); sand dollars appear to recover quickly	manned submersible observations
Pranovi and Giovanardi 1994	Venice Lagoon, Adriatic Sea, Italy	Shelf	1.5-2 m	Soft Sediment;	n/a	Ss_u	1, 1, 1, 1 (avg=1.0)	8-10 cm deep furrows; some sig decreases in infauna, non-sig in some areas	0.3	densities recovered in 2 mo, but not biomass	sediment/infauna samples by divers; sampled immediately after tows, 3-wk intervals for 2 mo
Tuck et al. 2000	Outer Hebrides, Scotland	Shelf	2-5 m	Soft Sediment; fine to medium sand; (tidal currents up to 3 knots in area)	n/a	Ss_u	1, 1, 1, 1 (avg=1.0)	sediment fluidized to 30 cm depth; sig decrease in infaunal spp richness and total abundances, polychaetes most affected	0.2	benthos "recovered completely" within 11 wks	core samples, diver observations, video; sampled before, during, and up to 11 wks after tows
							Mean = 0.8 Std Err = 0.16 n = 6		**Mean = 0.2 Std Err = 0.06 n = 4**		
New Bedford/Scallop Dredges x Hard											
Caddy 1973	Chaleur Bay, Gulf of St. Lawrence, Canada	Shelf	40-50 m	Hard (Mixed); sand over gravel, some boulders	n/a	She	3, 2, 2, 3 (avg=2.5)	rocks overturned, dislodged or plowed along bottom	(not studied)	(short-term study)	manned submersible observations

Collie et al. 1996, 1997	Georges Bank, Massachusetts	Shelf	?	Hard; gravel pavement	n/a	She	2, 0, 2, 1 (avg=1.3)	unfished areas with more epifauna, higher densities, species numbers and biomass of some infauna; different species composition also	(not studied)	best interpreted as study of chronic effects of different fishing intensities	observations and benthic samples; assessed cumulative impacts of scallop dredging by comparing fished to unfished sites
Veale et al. 2000	Irish Sea	Shelf	20-67 m	Hard (Mixed); sand overlain by pebbles, cobble, boulders, shell	n/a	She	1, 1, 2, 1 (avg=1.3)	decreases in spp diversity and total abundances with increasing fishing effort	(not studied)	best interpreted as study of chronic effects of different fishing intensities	compared bycatch from fishing grounds exposed to different fishing intensities
							Mean = 1.7 Sts Err = 0.40 n = 3				
New Bedford/Scallop Dredges x Biogenic, Shellfish											
Brown 1989	Strangford Lough, Northern Ireland	Shelf	?	Biogenic; mussel (*Modiolus*) beds	n/a		1	mussels are bycatch in dredges	?	concern that it would take "extended period" for recovery	compared benthic survey data from before and after initiation (8 yr) of scallop fishery
							Mean = 1.0 Std Err = n = 1		**Mean = Std Err = n =**		
New Bedford/Scallop Dredges x Biogenic, Macrophytes											
Hall-Spencer and Moore 2000	Clyde Sea, Scotland	Shelf	10-15 m	Biogenic (maerl); calcareous red algae, sand, mud, cobble, boulders	n/a		3, 3, 2, 3 (avg=2.8)	rocks overturned, dislodged or plowed along bottom; tracks still visible after 2.5 yr in some areas; damage to many taxa	5	epifauna most impacted, infauna less so; taxa with regular recruitment recovered most quickly; some large epifauna did not recover after 4 yr	video monitoring by divers 2-4 times per year for 4 yr
							Mean = 2.8 Std Err = n = 1		**Mean = 5 Std Err = n = 1**		

Study Design & Gear Comments
New Bedford scallop dredge, 2.4 m wide, 0.36 m height, chain sweep, no teeth; obs in fished area
toothed scallop dredge
New Bedford scallop dredge; obs made in area with "heavy commercial dredging"
New Bedford scallop dredge; one experimental tow
scallop dredge; several tows over same track for 9 days
toothed scallop dredge; experimental towing repeatedly over 3-da periood in area not fished for 3 yr
toothed scallop dredge; experimental dredging at 2 sites, one fished
New Bedford scallop dredge; experimental tows
toothed scallop dredge; experimental towing repeatedly over 3-da period in area not fished for 3 yr
scallop dredge and beam trawl, experimentally fished together; 10 tows of each
commercially dredged area closed to fishing in 1989
scallop dredge; experimental dredging in and out of closed area (since 1989), and control sites; 10 tows along each line every 2 mo for 5 yr

(studied area mostly impacted by scallop dredging; see Sampling Methods notes)
Portugese toothed clam dredge (similar impact to scallop dredge?)
"commercial dredge" (clam dredge as Alves et al 2003?)
pre- and post-impact (up to 1 yr) study of experimental scallop dredging (New Bedford style, 4.6 m) at multiple sites including some in closed areas
hydraulic dredge, 4 ft wide; experimental tows in surf clam bed
hydraulic dredge; active ocean quahog fishing areas
hydraulic dredges and toothed mechanical dredges; experimental tows
hydraulic and scallop dredges; experimental tows
hyrdaulic dredge, 2.7 m wide; experimental tows inside and outside commercial fishing areas
hydraulic dredge; experimental tows
New Bedford scallop dredge, 2.4 m wide, 0.36 m height, chain sweep, no teeth, 1300 lbs; obs in fished area

(studied area mostly impacted by scallop dredging; see Sampling Methods notes)
(studied area mostly impacted by scallop dredging; see Sampling Methods notes)
scallop dredging; reivew paper assessing survey data
toothed scallop dredge; experimental dredging in area fishec for 40 yr and unfished area

DRAFT 6 - Table A1.4. Summary of references on impacts of **MULTIPLE MOBILE GEARS** (DREDGES, TRAWLS, etc) on **SHELF HABITATS**

Reference	**Location**	**Megahabitat**	**Water Depth**	**Substrate Type**	**Macrohabitat**	**Habitat Code**	**Sensitivity Level**	**Sensitivity Comments**	**Recovery Time (years)**	**Recovery Comments**	**Study Design & Sampling Methods**	**Study Design & Gear Comments**
							Multiple gears (trawls+dredges) x Soft Sediment					
Hall et al. 1993	Turbot Bank, North Sea	Shelf	80 m	Soft Sediment; coarse sand	n/a	Ss_u	0, 0, 0, 1 (avg=0.3)	no sig differences in benthos, except associated with sediment characteristics	(not studied)	n/a	sampled along gradient of fishing intensity based on distance from shipwrecks; grab sampling	otter trawls and dredges mainly
Auster et al. 1996	Swans Island Cons Area; Gulf of Maine	Shelf	30-40 m	Soft Sediment; sand, shell, cobble	n/a	Ss_u	2, 1, 2, 2 (avg=1.8)	some epifauna and biogenic structure such as depressions and debris less common outside cons area	(not studied)	(sensitivity comments also relevant here, but no easy way to quantify?)	in vs. out of Cons. Area closed for 10 yr; ROV, video transects	otter trawls and dredges mainly
Auster et al. 1996	Stellwagen Bank, Massachusetts	Shelf	32-43 m	Soft Sediment; sand, shell	n/a	Ss_u	1, 1, 2, 1 (avg=1.3)	loss of some hydroids, algae, and shrimp by fishing gear	(not studied)	n/a	ROV observations	otter trawls and dredges mainly
Thrush et al. 1998	Hauraki Gulf, New Zealand	Shelf	17-35 m	Soft Sediment; mud, sand	n/a	Ss_u	2, 1, 2, 1 (avg=1.5)	various changes to infauna (spp #, densities), and density of large epifauna; overall 15-20% of differences attributed to fishing	(not studied)	n/a	sampled 18 sites over wide gradient of fishing intensity; sampled with video, corer, grab, dredge	otter trawls and dredges mainly?
Almeida et al. 2000	Closed Area II, Georges Bank, Massachusetts	Shelf	?	Soft Sediment; sand	n/a	Ss_u	1, 0, 1, 1 (avg=0.8)	some fish spp more abundant inside; scallops larger inside; sponges more abundant inside; other benthic characters similar	(not studied)	(sensitivity comments also relevant here, but no easy way to quantify?)	in vs out after 4.5 yr closed; sampling of seabed, fish, and observations	otter trawls and dredges mainly
Collie et al. 2000	Georges Bank, Massachusetts	Shelf	42-90 m	Soft Sediment; sand (also gravel, see below)	n/a	Ss_u	1.5	colonial epifauna "conspicuously less abundant" in fished areas	(not studied)	(not designed to assess recovery)	compared fished vs non-fished areas; analyzed video and still photos of seabed in both areas	trawls and scallop dredges
Kaiser et al. 2000b	Devon coast, England	Shelf	15-70 m	Soft Sediment; fine to coarse sand	n/a	Ss_u	2, 1, 2, 1 (avg=1.5)	sig differences in some epi- and infauna among areas related to fishing; higher biomass and abundances of hydroids, soft	(not studied)	(sensitivity comments also relevant here, but no easy way to quantify?)	compared areas of high, medium and low fishing intensity; sampled with grab, beam trawl, dredge	otter trawls and dredges mainly
							Mean = 1.2 **Std Err = 0.20** **n = 7**		**Mean =** **Std Err =** **n =**			
							Multiple gears (trawls+dredges) x Hard Bottom					
Valentine and Lough 1991	Georges Bank, Massachusetts	Shelf	?	Hard Bottom; gravel and sand	n/a	She	2, 1, 2, 2 (avg=1.8)	unfished areas with boulders had abundant epifauna; smoother bottom and sparse epifauna in fished areas	(not studied)	n/a	correlated impacts with evidence of gear impacts on seabed; side scan sonar and submersible observations	otter trawls and dredges mainly
Auster et al. 1996	Swans Island Cons Area; Gulf of Maine	Shelf	30-40 m	Hard Bottom; shell, cobble	n/a	She	2, 2, 2, 2 (avg=2.0)	some epifauna and biogenic structure such as depressions and debris less common outside cons area	(not studied)	(sensitivity comments also relevant here, but no easy way to quantify?)	in vs. out of Cons. Area closed for 10 yr; ROV, video transects	otter trawls and dredges mainly
Collie et al. 1997	Georges Bank, Massachusetts	Shelf	40-90 m	Hard Bottom; gravel, cobble	n/a	She	1, 0, 2, 2 (avg=1.3)	closed area had higher numbers, biomass and species richness; closed area also had more "bushy" organisms, giving more structure to bottom	(not studied)	(sensitivity comments also relevant here, but no easy way to quantify?)	in vs. out of area closed to fishing	scallop dredges, otter trawls
Collie et al. 2000	Georges Bank, Massachusetts	Shelf	42-90 m	Hard Bottom; gravel (also soft sediment, see	n/a	She	1	colonial epifauna "conspicuously less abundant" in fished areas	(not studied)	(not designed to assess recovery)	compared fished vs non-fished areas; analyzed video and still photos of seabed in both areas	trawls and scallop dredges
							Mean = 1.7 **Std Err = 0.16** **n = 4**		**Mean =** **Std Err =** **n =**			

DRAFT 6 - Table A1.5. Summary of references on impacts of **POTS AND TRAPS** on **SHELF HABITATS**

Reference	**Location**	**Megahabitat**	**Water Depth**	**Substrate Type**	**Macrohabitat**	**Habitat Code**	**Sensitivity Level**	**Sensitivity Comments**	**Recovery Time (years)**	**Recovery Comments**	**Study Design & Sampling Methods**	**Study Design & Gear Comments**
Pots and Traps x Biogenic, Shellfish												
Eno et al. 2001	Great Britain	Shelf	14-23 m	Biogenic; mud with sea pens	n/a		1, 0, 1, 1 (avg=0.8)	bending and uprooting of sea pens	0.1	sea pens recovered within 6 da	diver observations	experimental setting and retrieval of pots at one site
							Mean = 0.8 **SE =** **n = 1**		**Mean = 0.8** **SE = n** **= 1**			
Pots and Traps x Hard Bottom												
Eno et al. 2001	Great Britain	Shelf	14-23 m	limestone slabs, boulders	n/a	She	1, 0, 0, 1 (avg=0.5)	bending of sea pens	0, 0, 0 (avg=0.0)		diver observations	experimental setting and retrieval of three types of pots at one site
Eno et al. 2001	Great Britain	Shelf	14-23 m	rock	n/a	She	0, 0, 0, 0 (avg=0.0)	no damage	0, 0, 0, 0 (avg=0.0)	n/a	diver observations	experimental setting and retrieval of pots at five sites
							Mean = 0.3 **SE = 0.3** **n = 2**		**Mean = 0.0** **SE = 0 n =** **2**			

DRAFT 6 - Table A1.6. Summary of references on impacts of **TRAWLS** on **SLOPE HABITATS**

Reference	Location	Megahabitat	Water Depth	Substrate Type	Macrohabitat	Habitat Code	Sensitivity Level	Sensitivity Comments	Recovery Time (years)	Recovery Comments	Study Design & Sampling Methods	Study Design & Gear Comments
Otter Trawls x Soft Sediment												
Cryer et al. 2002	Western Bay of Plenty, New Zealand	Slope	205-595 m	Soft Sediment; mixed, mostly soft-bottoms	Slope, Soft Sediment	Fs_u	1	fishing intensity negatively correlated with species richness and density of 15 spp, but positively to 6 spp, mostly opportunistic scavengers; overall 11-40% of changes attributed to fishing	(not studied)	Not studied - rather, the relation of benthic invert communities to different intensities of fishing was studied	66 research trawls in areas with known different fishing intensities	otter trawls used to catch demersal fish and lobsters (scampi)
							Mean = 1.0 **Std Err =** **n = 1**		**Mean =** **Std Err =** **n =**			
Otter Trawls x Hard Bottom												
Otter Trawls x Biogenic, Sponges												
Freese et al. 1999	eastern Gulf of Alaska	Slope	206-274 m	Hard Bottom; pebble, cobble, boulders	Slope, Hard, Biogenic, Sponges		3	boulders displaced; large epifauna removed or damaged; sig decreases in sponges and anthozoans but not in motile invertebrates	(not studied)	(not studied)	8 tows; manned submersible observations and video along trawl path	Nor'eastern trawl rigged with rockhopper roller gear
Koslow et al. 2001	Pacific Ocean, southern Tasmania	Slope (seamounts)	660-1700 m	Mixed Hard Bottom; ranging from mud to rock	Slope, Hard, Biogenic, Sponges (and corals)		3	trawling had "effectively removed the reef aggregate" organisms	(not studied)	(not studied)	Differences between fished areas and unfished areas (MPA?) sampled; sampled seabed with Lewis dredge, photos along transects, droplines and traps;	trawls (otter?) for orange roughy fishery
							Mean = 3.0 **Std Err =0.0** **n = 2**		**Mean =** **Std Err =** **n =**			
Otter Trawls x Biogenic, Corals												
Koslow et al. 2001	Pacific Ocean, southern Tasmania	Slope (seamounts)	660-1700 m	Mixed Hard Bottom; ranging from mud to rock	Slope, Hard, Biogenic, Corals (and sponges)		3	trawling had "effectively removed the reef aggregate" organisms; large bycatches of corals noted early on in fishery by fishermen	(not studied)	(not studied)	Differences between fished areas and unfished areas (MPA?) sampled; sampled seabed with Lewis dredge, photos along transects, droplines and traps;	trawls (otter?) for orange roughy fishery
Krieger 2002	Gulf of Alaska	Slope	260, 365 m	Hard Bottom; pebble, cobble, boulders	Slope, Hard, Biogenic, Corals		3	moved boulders, broken corals common in trawl path	> 7	5 of 13 large coral colonies still missing >95% of branches; 27% of corals in path detached; no young corals had re-populated the trawled area	manned submersible observations and video in 1997, 7 years after a 1990 otter trawl tow	Nor'eastern trawl rigged with rockhopper roller gear, 998 kg doors, ~15 m spread; trawl had removed large quantities of deepwater corals