PACIFIC COAST GROUNDFISH FISHERY MANAGEMENT PLAN

FOR THE CALIFORNIA, OREGON, AND WASHINGTON GROUNDFISH FISHERY

APPENDIX C PART 1

Description of Impacts Model for Groundfish Essential Fish Habitat

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1.0 INTRODUCTION

In response to a court directive and settlement agreement to complete new National Environmental Policy Act (NEPA) analyses for Amendment 11 to the Pacific Coast Groundfish fishery management plan (FMP), the NOAA Fisheries developed an Essential Fish Habitat (EFH) Designation and Minimization of Adverse Impacts Environmental Impact Statement (EIS). Council action based on this EIS led to the Groundfish FMP being amended with new EFH provisions.

This document is adapted from the *Risk Assessment for the Pacific Groundfish FMP* prepared by MRAG Americas, Inc.; National Marine Fisheries Service (NMFS) Northwest Fisheries Science Center, FRAM Division; NMFS Northwest Regional Office; and TerraLogic GIS, Inc. The Risk Assessment describes the EFH Model used to identify and describe EFH, an Impacts Model developed to evaluate anthropogenic impacts to EFH, and a data gaps analysis.

Developing these components of the Risk Assessment was intended to answer the following fundamental questions:

- What areas could qualify as essential pursuant to section 303(a)(7) of the Magnuson-Stevens Act (MSA)?
- Given past inputs (anthropogenic and environmental), what is the probability that the condition of Pacific coast groundfish habitat has been degraded to an extent that function has been impaired?
- Given foreseeable inputs (anthropogenic and environmental) and regulatory regimes, how are trends in Pacific coast groundfish habitat expected to respond? What areas are at risk of impaired function and of particular concern?
- How might trends in habitat function be affected by altering anthropogenic inputs and regulatory regimes?
- What types of fisheries management alternatives could be applied to mitigate the effects of fishing on habitat? What are the likely impacts to habitat of specific fisheries management alternatives?
- What are the scientific limitations of assessing habitat?

The data analysis undertaken to address these questions has included spatial and temporal analysis of the distribution of habitat types, distribution of fish species, habitat use by fish, sensitivities of habitat to perturbations, and the dynamics of fishing effort.

The three parts of the Risk Assessment referenced above have been adapted as parts of the appendices to the Groundfish FMP. The description of the Impacts Model comprises this document, part of Appendix C to the Groundfish FMP.

The Risk Assessment proceeded along three major tracks; data consolidation and infrastructure development, proof of concept, and assessment modeling and review. The results of these efforts are discussed in Appendix B.

Five main types of data were available for the risk assessment; habitat use, habitat characteristics, fishing effects, nonfishing effects, and existing habitat protection. These data feed into the analytical parts of the decision-making framework, which the development team termed the Comprehensive Risk Assessment, reflecting the integrated use of the best scientific information available in the development of guidance for the policy development process.

Many of these data types can be analyzed and presented in GIS maps and overlays to indicate where the most important and vulnerable habitats are distributed in relation to the activities that may be impacting them (fishing and nonfishing).

Thorough and responsible analysis of these data, however, involves substantially more than creating maps and spatial overlays in the GIS. To represent better the processes that make a particular piece of habitat more or less "essential" for managed species, and the risks posed to that habitat by fishing and nonfishing activities, the development team created a sophisticated modeling framework. As mentioned above, two models were developed; the EFH Model and the Impacts Model. While these components are clearly integrated, it was more practical to develop the models separately due to the complex and wide-ranging scope of the issues they address.

The first step in the process was the identification and description of EFH. The second step is an assessment of the risk to EFH from both fishing and nonfishing activities, which if fully developed, could assist the Council in developing measures to prevent, mitigate, or minimize, to the extent practicable, the adverse effects of fishing and fishing gear on EFH. As stressed above, the Impacts Model forms only part of this process. It was envisioned that all of the data elements from the data consolidation phase might feed into the Impacts Model. However, in practice this has proved to be not possible at this stage.

The Council's Scientific and Statistic Committee (SSC) reviewed the Impacts Model and concluded it was not sufficiently developed to support the development and evaluation of alternatives for the EFH environmental impact statement that served as the basis for Council decision-making in amending the Groundfish FMP to incorporate new EFH-related material.

The Comprehensive Risk Assessment is, of necessity, a part quantitative and part qualitative procedure supporting EFH-related actions. It is hoped that in the future it will be possible to gather the necessary data and information to allow further development of the Impacts Model so that it can integrate these other data sources into an overarching quantitative model for the risk analysis. Pending future review, these improvements could allow the Impacts Model to be used in support of future Council decision-making.

2.0 DATA CONSOLIDATION FOR IMPACT ASSESSMENT

2.1 The Effects of Fishing

2.1.1 Fishing Gear

The Pacific States Marine Fisheries Commission (PSMFC) prepared a document that describes the fishing gear used on the West Coast of the United States (excluding Alaska) and which components of those gears might affect structural habitat features (Appendix 8 to the Risk Assessment). This gear description is one part of a fishing gear impact analysis, which requires an understanding of the gears used, how gear affects habitat, the amount and distribution of fishing effort, and the sensitivity and resiliency of various habitat types.

The fishing gears report describes the types of fishing gear used on the West Coast in potential groundfish EFH and the parts of the gear that might impact structural habitat features. It includes gear used by fishermen targeting groundfish as well as gear used to target other species.

Many different types of fishing gear are used to capture groundfish in commercial, tribal, and recreational fisheries. Groundfish are caught with trawl nets, gillnets, longline, troll, jig, rod and reel, vertical hook and line, pots (also called traps), and other gear (e.g., spears, throw nets). Table 1 summarizes the gear used by each of these sectors.

Most fishing gear types used to target non-groundfish species (such as salmon, shrimp, prawns, scallops, crabs, sea urchins, sea cucumbers, California halibut, Pacific halibut, herring, market squid, tunas, and other coastal pelagic and highly migratory species) are similar to gear used to target groundfish. These gear types include trawls, trolls, traps or pots, longlines, hook and line, jig, set net, and trammel nets. Other gear that may be used includes seine nets, brush weirs, and mechanical collecting methods used to harvest kelp and sea urchins.

Gear types in the PacFIN database are listed on the PSMFC web site. Gear used for salmon net pen aquaculture and Washington and California kelp harvest are not included in the analysis of the effects of fishing gear, but are described under the nonfishing effects section of the EFH EIS. A list of authorized gear types for the West Coast is at 50CFR 660.322.

Table 1. Gear Types Used in the West Coast Groundfish Fisheries.[1]

	Trawl and Other Net	Longline, Pot, Hook and Line	Other
Limited Entry Fishery (commercial)	Bottom trawl Mid-water trawl Whiting trawl Scottish seine	Pot Longline	
Open Access Fishery Directed Fishery (commercial)	Set gillnet Sculpin trawl	Pot Longline Vertical hook/line Rod/reel Troll/dinglebar Jig Drifted (fly gear) Stick	
Open Access Fishery Incidental Fishery (commercial)	Exempted trawl (pink shrimp, spot and ridgeback prawn, CA halibut, sea cucumber) Setnet Driftnet Purse seine (round haul net)	Pot (Dungeness crab, CA sheephead, spot prawn) Longline Rod/reel Troll	Dive (spear) Dive (with hook and line) Poke pole
Tribal	as above	As above	As above
Recreational	Dip net, Throw net (within 3 miles)	Hook and line methods Pots (within 3 miles) (from shore, private boat, commercial passenger vessel	Dive (spear)

2.1.2 Fishing Gear Impacts: West Coast Perspective

At its meeting on February 19-20, 2003, the Groundfish Habitat Technical Review Committee (GHTRC) reviewed the proposed risk assessment framework and recommended that PSMFC contract for development of a West Coast perspective on fishing gear impacts.

There are several literature reviews of the effects of fishing gears on habitat, but these rarely contain information specific to the West Coast and there is no clear direction on how information from other areas should be applied there. There is a general lack of West Coast-specific studies and the GHTRC identified the need to determine specifically how to make inferences from studies that occurred in other parts of the world. A new review was therefore undertaken as part of this risk assessment and the results are presented in Appendix 10 to the Risk Assessment.

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. Those for which useful studies were found include eight gear types; otter trawls, beam trawls, shrimp trawls, New Bedford/scallop dredges, hydraulic dredges, oyster dredges, pots, and hand/mechanical harvesting. Only two studies bearing directly on West Coast gear types were found to be useful. Hence, research from areas other than the Pacific coast provided most of the information on which the analysis was based.

[1] Adapted from Goen and Hastie (2002). Most fishing gear used to target non-groundfish species (such as salmon, shrimp, prawns, scallops, crabs, sea urchins, sea cucumbers, California and Pacific Halibut, herring, market squid, tunas, and other coastal pelagic and highly migratory species) are similar to those used to target groundfish. These gears include trawls, trolls, traps or pots, longlines, hook and line, jig, set net, and trammel nets. Other gear that may be used includes seine nets, brush weirs, and mechanical collecting methods used to harvest kelp and sea urchins.

Presently there is very little quantitative information describing the relationship between habitat type, structure, and function and the productivity of managed fish species. Hence impacts on habitat that cause adverse effects are hard to quantify. For purposes of the analysis, consistent with NMFS EFH Final Rule, adverse effects of fishing gear are defined as "direct or indirect physical, chemical, or biological alterations of the waters or substrate and loss of, or injury to, benthic organisms, prey species and their habitat, and other ecosystem components, if such modifications reduce the quality and/or quantity of EFH" (50 CFR part 600.810).

Changes in the quantity of EFH can be measured, if there are time series of sufficient length. However, linking these changes to specific, fishing or nonfishing actions can be difficult due to the scale of the available data on intensity (e.g., fishing effort). Measuring the quality of EFH is presently an inexact science and relies substantially on relative and often qualitative metrics rather than absolute and quantitative metrics.

2.1.3 Fishing Effort

2.1.3.1 Commercial Trawl Logbooks

West coast commercial trawling effort has been recorded in logbooks and provided to state fisheries managers since at least the 1980s. These logbook entries include the starting point of the trawl, either by latitude/longitude or by logbook block number, the tow duration, the gear used, and the estimated weight of the catch for several species or species groups. PSMFC created and maintains a comprehensive database (PacFIN) for commercial fishing data, which includes West Coast trawl logbook data starting in 1987. Commonly, the commercial trawling data are summarized geographically by logbook blocks, which are primarily 10-minute latitude/longitude cells. Trawl logbook data from PacFIN are available on a tow-by-tow basis starting from 1987. (For the EFH assessment data through 2002 was used.)

The data can be summarized in a multitude of ways, both temporally and spatially. The specific logbook data summaries developed as input for the Impacts Model are described in Sections 3.5.2.1 and 3.3. The logbook data are coastwide; however, prior to 1997, position data for trawls off California were provided by logbook block only, not by precise haul location. In addition, prior to 1998, the date specification was limited to year, rather than full date. This removes the potential to analyze seasonal patterns of effort. Finally, the gear types in the PacFIN database are more general categories than the detailed gear types in would suggest. The gear type identifiers in the logbook data are: groundfish trawl, midwater trawl, roller trawl, flatfish trawl, and other trawl. The number of records by gear type in the PacFIN database is shown in Table 2.

Table 2. Use of different gear types recorded in the PacFIN database (1987-2002).

Gear type	Number of tows (percent of tows)
groundfish trawl	363,709 (54.4%)
flatfish trawl	138,856 (20.8%)
roller trawl	126,478 (18.9%)
midwater trawl	33,157 (5.0%)
other trawl	3,674 (0.5%)
no gear given	2,173 (0.3%)

2.1.3.2 Non-trawl Gear in the PacFIN Database

Effort data for the non-trawl commercial fishery (hook and line, longline, pot/trap) are also available per vessel (fake ID), recorded by port-based fish tickets. Data available in the PacFIN database include year and port where catch was landed, type of gear used, vessel length, species landed, prices and revenues, and the eight International North Pacific Fisheries Commission (INPFC) areas.

As part of their Groundfish Fleet Restructuring Information and Analysis Project (www.ecotrust.org/gfr), Ecotrust, Inc. has developed a predictive model to further resolve catch and effort data to levels consistent with the commercial trawl data (Ecotrust 2003). Using this predictive model, fishing activity is assigned to a specific 9 km block, summarized by 9 km block for the following gear groups; hook and line, longline, pot and trap, trawl, and other gear. GIS data resulting from this model were provided for two years, 2000 and 1997.

2.1.3.3 Data From Fishermen's Focus Groups

Another project, initiated as part of the EFH risk analysis, sought to collect fishing effort information retroactively directly from fishermen through focus groups. The project was initiated on the recommendation of the TRC to ground truth the Ecotrust product described above. The data collected covered current and historical fishing areas defined by the fishermen and fishing intensity for groundfish trawl and fixed gear fisheries within those areas. Due to funding constraints, this project was only undertaken for a small section of the coast sufficient to complete groundtruthing of the Ecotrust product. The results are presented in Appendix 11 to the Risk Assessment.

The methodology for collecting this type of information was tested on a single NOAA nautical chart, number 18520, covering the area offshore of Oregon between the Columbia River and Yaquina Bay. Focus group participants drew polygons on the chart indicating known fishing areas for three eras: 1986-1999, 2000-2002, and 2003. In addition, they provided information on fishing intensity, including average number of boats in a polygon per day, as well as some indication of typical units of fishing, (such as average tows per boat and average tows per hour), which varied by gear type. Participants were generally quite comfortable drawing the boundary lines on the maps, but not very comfortable with estimating fishing intensity (i.e., effort). After the focus group sessions, the data were converted to GIS format using a heads-up digitizing approach.

2.1.3.4 Using Available Commercial Fishing Effort Data

All three sources of commercial fishing effort data have their strengths and weaknesses. The logbook data are extensive, both spatially and temporally, and are acknowledged to be the most comprehensive source of information on trawl effort currently available (SSC Groundfish Sub-committee review of Impacts Model, February 2004[2]). However, these data only include information on trawl gear. The Ecotrust model and the focus group project both provide information on fixed gear. However, the Ecotrust model is predictive and quantifies revenue and catch, rather than effort. The focus group information is limited in spatial extent to a small section of the coast.

Appendix 12 to the Risk Assessment provides a first order of comparison and validation of the three data sets described above. The focus group information was compared both to trawl logbook data and the Ecotrust model for spatial coincidence and consistency in estimates of the area impacted by fishing.

[2] Exhibit C.6.c, Attachment 1, Briefing Book for April 2004 Council meeting.

Intensity measures were not compared at this stage—fishing effort was compared as a simple presence/absence variable.

The focus group polygons for bottom trawl fishing showed good spatial consistency with trawl logbook data, particularly when overlaid with the trawl set point locations. Unfortunately, the spatial coincidence and the consistency of fishing area estimates between focus group and Ecotrust results was fairly low for fixed gear types. Based on a review of this analysis, the SSC Groundfish Subcommittee recommended against using the Ecotrust model output in the impacts model.[3] In addition, the SSC review endorsed the use of the focus group approach for collecting coastwide fixed gear information. However, because the focus group information is limited to a small portion of the coast, it has not been included in the current version of the impacts model.

2.1.3.5 Recreational Fishery

The recreational fishery sector comprises the commercial passenger fishing vessel (CPFV) fleet (charters), private fishing vessels, and other miscellaneous fishing activities. Appendix 13 to the Risk Assessment provides a summary of available information on recreational fishing effort.

The Marine Recreational Fishery Statistics Survey (MRFSS) is a nationwide survey conducted since 1979, (with the exception of 1990-2) that collects information on all elements of the recreational fishery. Information is elicited through telephone surveys and port interviews, and is collected on mode of fishing (e.g., charter, pier), catch information, distance from shore, and catch reference area. The questionnaire also makes provision for information on gear type use (see http://www.psmfc.org/recfin/). As expected, with a questionnaire of this nature, spatial resolution of the catch reference area is relatively poor. It has therefore not been possible to incorporate these data into the Impacts Model at this stage.

The California Department of Fish and Game also collects species information on CPFV fishing that is apparently available at a 10 nm by 10 nm resolution from 1936 through 1997.

2.2 Effects of Nonfishing Activities on Groundfish Habitat

2.2.1 Description of Nonfishing Impacts

In 2003, NOAA Fisheries prepared a detailed description of nonfishing impacts to EFH and recommended conservation measures (Appendix 14 to the Risk Assessment). The document is organized by activities that may potentially impact EFH occurring in four discreet ecosystems: upland, riverine, estuarine, and coastal/marine systems.

Nonfishing activities have the potential to adversely affect the quantity or quality of EFH-designated areas in riverine, estuarine, and marine systems. Broad categories of such activities include but are not limited to mining, dredging, fill, impoundment, discharge, water diversions, thermal additions, actions that contribute to non-point source pollution and sedimentation, introduction of potentially hazardous materials, introduction of exotic species, and the conversion of aquatic habitat that may eliminate, diminish, or disrupt the functions of EFH. For each activity, known and potential adverse impacts to EFH are described in the review document. The descriptions explain the mechanisms or processes that may cause the adverse effects and how these may affect habitat function. The review also provides proactive conservation measures designed to minimize or avoid the adverse effects of these nonfishing gear activities on Pacific Coast EFH.

[3] Exhibit C.6.c, Attachment 1, Briefing Book for April 2004 Council meeting.

2.2.2 Spatial Data on Nonfishing Impacts

An initial survey of available nonfishing impact spatial data undertaken in the fall of 2003. Although the DEIS for the Gulf of Mexico EFH Project was used as a model, the 2003 Draft document *Nonfishing Impacts to Essential Fish Habitat and Recommended Conservation Measures* and a phone conversation between TerraLogic, MRAG Americas, and the NMFS Project Manager served to focus efforts for the West Coast. A list of individuals to contact was generated during this conversation and served as the starting point for the collection effort.

To date, over 70 individuals at NMFS, USEPA, USACOE, MMS, USGS, Washington DNR, Washington DOE, Oregon DEQ, California Fish and Game as well as several private and non-profit organizations have been contacted (Appendix 15 to the Risk Assessment). The individuals on this list were identified during the calling effort with each phone call generating additional names to contact. The survey followed the resulting path. The list of collected West Coast nonfishing impact data includes dredge disposal sites, shoreline hardening, marinas, land use land cover, oil and gas lease locations, Pacific cable information, etc. (Table 3).

In addition to the collection of available data, this process has yielded the added benefit of identifying numerous data gaps relevant to nonfishing impacts. While the generation of these various data sets is well beyond the scope and scale of this effort, it is hoped that this work will lead to additional initiatives that will start to tackle these gaps.

The greatest challenge to this data collection effort has been the lack of centralized spatial data storage at the agency level. Although many individuals were contacted, identifying the right individual is critical or a potentially useful dataset may be overlooked. In addition, data incorporating nonfishing impacts often reside with the states. If data are located in Oregon, equivalent data must be located for Washington and California. If available, data developed independently by state agencies are often collected at different scales or degrees of accuracy. Stitching together these disparate data into a unified, coherent database will require reconciling data sets to make them usable in a coast wide database. This reconciliation of data will be possible for some data sets and impossible for others.

Due to the nature of the available data (varied spatial scales, lack of completeness, etc.) and the large data gaps identified, nonfishing impacts are not incorporated into the Impacts Model at this time. In essence, there is presently no common currency in which to express the impacts of both fishing and nonfishing activities and thereby consider their effects on a comparable scale. However, this collection of the best available data provides important information for the comprehensive risk assessment and hence policy development. While some of the data are not currently in a GIS format, they can be converted if time and resources allow. Once the data all reside in a GIS, they can be used for data visualization and simple overlay analysis with other data sets as well as model output. This process will enable decision makers to take into account nonfishing impacts into the policy process to the extent that the available data allow.

Table 3. West coast nonfishing impact data.

	Data Collected	Geographic Extent	Limitations
Upland			
Agricultural/Nursery Runoff	USGS LULC (1993)	WA, OR, CA	NOTE: 2003 Coastal Land Use/Land Cover is currently available for California but will not be available for Oregon and Washington until late summer/early fall 2004.
Silviculture/Timber Harvest	USGS LULC (1993)	WA, OR, CA	
Pesticide Application	USGS LULC (1993)	WA, OR, CA	
Urban/Suburban Development	USGS LULC (1993)	WA, OR, CA	
Road Building and Maintenance			
Riverine			
Mineral Mining			
Sand and Gravel Mining			
Organic Debris Removal			
Inorganic Debris Removal			
Dam Operation	Dam Locations	WA, OR, CA	Point data.
Commercial and Domestic Water Use			
Estuarine			
Dredging			
Disposal of Dredged Material	USACE	WA	Grays Harbor only.
Fill Material			
Vessel Operations/ Transportation/Navigation			
Introduction of Exotic Species			
Pile Driving			
Pile Removal			
Overwater Structures	Marinas	WA ,CA	Point Locations.
Flood Control/Shoreline Protection	Shoreline Hardening	WA, CA	Washington shoreline segments are based on geologic features and then assigned an attribute indicating percent hardening. Do not delineate exact extent of hardened shoreline.
Water Control Structures			
Log Transfer Facilities/ In-Water Log Storage			
Utility Line/Cables/Pipeline Installation	Cable Locations	OR, CA	

	Data Collected	Geographic Extent	Limitations
Commercial Utilization of Habitat	Aquaculture	WA, OR, CA	Data contain areas that are approved/certified for harvest, but do not show actual active aquaculture areas.
Coastal and Marine			
Point Source Discharge			
Fish Processing Waste - Shoreside and Vessel Operation			
Water Intake Structure/ Discharge Plumes	Water Intake	CA	
Oil/Gas Exploration/ Development/Production	Lease Locations	CA	
Habitat Restoration/ Enhancement			
Marine Mining			
Persistent Organic Pollutants			

3.0 ASSESSMENT OF IMPACTS

3.1 Guidance from the EFH Final Rule

The EFH Final Rule (50 CFR 600.815(a)(2)(ii)) provides regulations and guidance on the implementation of the EFH provisions of the Magnuson-Stevens Act. It includes information on the types of information that can be used for developing alternatives that mitigate fishing impacts on EFH. The guidelines advocate using information in a risk-averse fashion to ensure adequate protection of habitat for all species in the management units.

The EFH Final Rule establishes a threshold for determining which fishing activities warrant analysis to address the adverse effects of fishing on EFH:

> Councils must act to prevent, mitigate, or minimize any adverse effects from fishing, to the extent practicable, if there is evidence that a fishing activity adversely affects EFH in a manner that is more than minimal and not temporary in nature, based on the evaluation conducted pursuant to paragraph (a)(2)(i) of this section and/or the cumulative impacts analysis conducted pursuant to paragraph (a)(5) of this section.

As discussed in the preamble to the EFH Final Rule at 67 FR 2354, management action is warranted to regulate fishing activities that reduce the capacity of EFH to support managed species, not fishing activities that result in inconsequential changes to the habitat. The “minimal and temporary” standard in the regulations, therefore, is meant to help determine which fishing activities, individually and cumulatively, cause inconsequential effects to EFH.

In this context, temporary effects are those that are limited in duration and that allow the particular environment to recover without measurable impact. The following types of factors should be considered when determining if an impact is temporary:

- The <u>duration</u> of the impact
- The <u>frequency</u> of the impact

Minimal effects are those that may result in relatively small changes in the affected environment and insignificant changes in ecological functions. Whether an impact is minimal will depend on a number of factors:

- The <u>intensity</u> of the impact at the specific site being affected
- The <u>spatial extent</u> of the impact relative to the availability of the habitat type affected
- The <u>sensitivity/vulnerability</u> of the habitat to the impact
- The <u>habitat functions</u> that may be altered by the impact (e.g., shelter from predators)
- The <u>timing</u> of the impact relative to when the species or life stages need the habitat

The measurement of impacts to EFH caused by fishing gears is clearly a complex process requiring substantial amounts of information. The narrative below describes some of the relationships between the factors listed in the EFH Final Rule, the types of data we have available and the types of impacts assessment tools that could be derived from these in more detail. However, it is worth noting at the outset that there remain two major limitations in our understanding of the process by which fishing and nonfishing activities can impact EFH: the first is the relationship between fishing effort and habitat modification (i.e., how much modification of the habitat occurs for a given unit of fishing effort), and the second is the relationship between habitat modification and ecosystem productivity, more specifically the productivity of fish (i.e., how does a given amount of habitat modification impact the growth and/or reproductive success of fish). Presently there are very little data to fill either of these gaps. It was therefore necessary to find innovative ways of expressing the risk of impacts using the best information available.

3.2 Measuring Fishing Gear Impacts: Habitat Sensitivity and Recovery

In an effort to provide a quantitative measure of the degree of habitat modification resulting from a unit of fishing effort, two notional indices were developed: the Sensitivity Index and the Recovery Index. The Sensitivity Index provides a relative measure of the sensitivity of habitats to the action of fishing gears. The Recovery Index provides a measure of the time taken for a habitat to recover to a pre-impacted state. These indices were constructed based on available literature, much of which reports on the results of studies conducted on benthic habitats outside the West Coast region (see Appendix B to the Groundfish FMP). Information on the effects on pelagic habitats has not been pursued to date. The indices themselves are presented in Appendix C (Part 2) of the Groundfish FMP along with detail on the interpretive decisions made in their construction.

Development of the indices was accomplished in three phases, each building upon the preceding phase. Phase 1 consisted of defining levels of sensitivity and recovery based on information in the literature, and the identification of habitat types and gear types to be used in the analysis.

The Sensitivity Index is a matrix of fishing gears and habitats, with each cell scored using a four-level measure of the expected effect resulting from the potential interaction of the gear with the habitat. The sensitivity level may be based on an actual effect measured in a specific location, or inferences from experimental evidence, but when used in the Impacts Model, it is regarded as a predicted effect. When and where a specific interaction between gear and habitat has actually occurred depends on the fishing effort data (see above) and it is the combination of the fishing effort data and the sensitivity that determines the predicted impact.

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.

This predicted impact, however, is not static; fishing effort is variable over time, and impacted habitats may recover between impact events. When a habitat is subjected to an impact, the way in which it supports and benefits the groundfish that associate with it is changed. A combination of physical, chemical, and biological processes subsequent to the impact may then bring about a process of recovery of that habitat towards its pre-impacted state. However, exactly what is meant by a pre-impacted state is rather difficult to define, given the limited information on how specific habitats support specific life states of specific species. Nevertheless, there are studies in the literature that describe and have attempted to measure this process. Relevant studies are reviewed in Appendix C (Part 2) to the Groundfish FMP and have been used to develop the Recovery Index. This is measured in time and is used in the model to allow habitat potentially to recover its pre-impacted function, at some assumed rate, if it is not subjected to a further impact.

Approximately 30 gear types are used in West Coast fisheries. All of these were considered in the analysis initially, but studies have been done on only a few. Gear types therefore had to be summarized into five major gear types:

- Dredges: New Bedford Dredge; Hydraulic Clam Dredge; Oyster Dredge
- Trawls: Otter Trawl; Shrimp Trawl; Beam Trawl; Midwater Trawl
- Nets: Demersal Seine; Round Hall Seine; Gillnet; Trammel Net; Dip Net; Salmon Reef Net
- Traps & Pots: Pots
- Hook & Line[4]: Hook & Line; Bottom Longline; Pelagic Longline; Handline, Jig; Stick (Pipe); Rod & Reel; Vertical Hook & Line; Mooching

Similarly, there was insufficient information to distinguish, in terms of sensitivity and recovery, between all of the benthic habitat types identified in the GIS (about 47), and these therefore had to be summarized into just nine categories. These nine initially comprised biogenic, hard and soft substrates, each in estuarine, shelf, and slope megahabitats. However, based on information collected during the course of the study, it was later possible to subdivide the biogenic category into the following categories:

[4] The hook & line category is a combination of longline and recreational gear such as rod/reel. However, information in the literature regarding these gear types and their effects on EFH on the West Coast is lacking. Appendix 8 to the Risk Assessment discusses hook & line gear (e.g., rod/reel) used both commercially and recreationally only from the commercial perspective.

- in estuaries; macrophytes, shellfish,
- on the shelf; macrophytes, shellfish, sponges, and corals
- on the slope; sponges and corals

Phase 2 was a detailed review of the global literature (using major recent reviews), culminating in the construction of tables that summarize, on a study-by-study basis, the sensitivity levels and recovery times by gear type and habitat type, to the extent that these were available at the time of writing. Phase 3 was the construction of the sensitivity and recovery matrices themselves.

Using the literature summary tables from Phase 2, statistics were calculated for sensitivity levels and recovery times for various combinations of gear and habitat types. In the final draft index (Phase 3), ranges representing the mean + or - one standard error were determined for each gear-by-habitat combination for which empirical data were available. For others, ranges were derived using the empirical ranges combined with the relative rankings by gear and habitat types given above.

The general trends shown by this analysis when organizing habitats from most to least sensitive, and gears from most to least impacting, were similar to previous assessments. In terms of major habitats, biogenic habitats are more sensitive than hard bottoms (although the former may occur on the latter) and these are much more sensitive than soft bottoms.

In terms of the major gear types, dredges are most impacting, followed by bottom trawls, and these are much more impacting than nets,[5] which are more impacting than pots & traps and hook & line (including longlines).

Recovery times ranged mainly from zero to five years, although these may be much longer for slow growing biogenic habitat such as corals and sponges, and the overall trends by gear and habitat types were similar to the trends indicated by sensitivity levels.

While these indices provide a useful first step in the quantification of fishing gear effects on habitat, they have some obvious limitations at this stage. The sensitivity index provides a relative measure of the likely changes to habitat caused by interactions with various fishing gears. However, it is not explicit that the changes described in the index result from a single contact with the gear, nor what happens with subsequent contacts. The relationship between fishing effort and habitat change (impact) is likely to be complex and almost certainly non-linear. The process of recovery is similarly difficult to quantify. At this stage, however, we have no empirical data from which to develop such relationships. A first attempt is made, however, in the development of the Impacts Model, described below.

As previously mentioned, there is also no quantitative link between change in habitat structure and consequent change in its utility for managed species. For example, for a habitat/gear combination with a sensitivity level of 2, the index tells us that contact with the gear will cause substantial changes in the habitat, such as deep furrows on the bottom, with differences between impact and control sites being 25 to 50% in most metrics measured. What the index does not tell us, however, is what this change implies in terms of the functionality or utility of the habitat for the species that occupy it.

It is most often assumed that there will be some change in functionality and that that change is likely to be proportional to the physical change; i.e., in the case described above, there would be a 25 to 50% change in the utility of the habitat. However, as with fishing effort and impact, this relationship is also likely to be complex and non-linear. It is likely, for example, that changes in habitat will affect its utility

[5] Meaning here seine, gill, dip, trammel, and salmon reef nets.

differently for different species and life stages, depending on the function or functions it provides. The timing of the impact is also important. For example, impacts at spawning sites during the spawning season compared to different times of the year may have profoundly different effects on the spawning process. In addition, changes that are important at a small scale may be less important if we consider impacts across a wider spatial scale. Is it possible, for example, for some fraction of an area of habitat to be impacted and to remain in an impacted state without significantly affecting the overall utility of the whole area as habitat for managed species?

Finally, it has also been pointed out that while evidence suggests that most changes caused by fishing gears are likely to be detrimental to habitat function, it may be that for some habitats and some species, the function is not changed, or is even enhanced.

3.3 Fishing Effort

At the core of an analysis of the actual effects of fishing gear on specific areas of habitat is the need to understand where and when the gear comes into contact with the seabed. This requires detailed data on fishing locations and tracks of mobile gears on a haul-by-haul basis. Fishing effort could then be allocated, in terms of area effected, by individual habitat polygon. This would enable estimation of the impact of each gear to each unique habitat type. Knowledge of the footprint of the gear would begin to provide a common measure of fishing effort that would allow consideration of the cumulative effects of different gears operating in the same location.

However, in reality, there is a large degree of uncertainty in the spatial component of the fishing effort data. This uncertainty is particularly large for fixed gears, for which no detailed location information is available, other than home or landing port. Without this information, it is not possible to predict, with any reliability, even relative impacts between different locations. By contrast, the trawl logbook data provide set points on a haul by haul basis. This is substantially more useful, but still far from ideal, because the database does not record trawl end points, and certainly does not record actual trawl tracks. Nevertheless, the project team attempted to develop a quantitative model for bottom trawls to assist the Council in making management-related decisions.

Ideally, the trawl effort would be summarized by habitat polygons in order to estimate the impact to each unique habitat type. This is theoretically possible using trawl set points, but due to the lack of information about the actual trawl track, there remains a large degree of spatial uncertainty about the location of each tow.

For those tows starting in a particular polygon, a portion of them will end outside, and some fraction of those tows would take place outside of that polygon, in a neighboring polygon. The converse is also true, that some trawls starting outside the polygon will end inside. The importance of this effect will depend on a number of factors. These include polygon size, relative to the length of a tow and habitat type of the polygon and its neighbors, relative to the habitat type on which the fishermen are trying to fish. The appropriate scale would, therefore; (1) minimize overrun errors (unit of area should be large)[6] and (2) achieve a reasonable spatial resolution (unit of area should not be too large).

As indicated above, the first thought was to simply overlay trawl start points on a habitat map and using habitat polygons as the units of area. However, habitat polygons cover a wide range of different spatial scales; some are small relative to trawl hauls, making the overrun errors potentially significant. In

[6] In essence this means that we are assuming that the effects of tows starting inside the grid and ending outside are balanced by the effects of tows starting outside and ending inside.

addition, the assumption that the overlay would correctly match up a given trawl with a given piece of habitat needs detailed analysis. PacFIN does not contain end points of hauls, hence there is only a single point from which to estimate the location of the tow. Added to this, not all trawl positions in the database are genuine start points,[7] habitat data quality varies greatly, and the project team decided during the formulation of the EFH Model that such an overlay would not be valid for survey data and for commercial data it may be even less valid.

Therefore, the effort data is represented on a grid of dimensions of the order of two average trawl lengths, representing a reasonable compromise in terms of the optimal size. An average trawl tow length of 11.8 km was calculated from trawl set and haul point data provided by Marlene Bellman for several study sites off Oregon (Bellman and Heppell 2004). This would give a grid with square cells of side 23.6 km, or 12.74 nautical miles. A grid delineated by lines of latitude/longitude would be most consistent with the convention for reporting fisheries spatial data, despite the fact that a latitude/longitude grid cell is not square and cell size changes with latitude.[8] Using these criteria, a 15-minute latitude/longitude grid was initially chosen as the preferred size. However, this grid is larger than the 10-minute generally used to summarize logbook data, and causes difficulty when summarizing historical logbook data because the edge of the 15-minute grid is exactly at the center point of many of the trawl logbook blocks. We therefore relaxed the average tow length criterion and selected the 10-minute latitude/longitude grid for trawl effort data summaries. A 10-minute grid cell is approximately 18.5 km in the north/south direction, and 12.2 km in the east/west direction at 49° N. latitude and 15.7 km in the east/west direction at 32° N. latitude.

A 10-minute latitude/longitude grid was developed for the entire West Coast EEZ, and then subset to include only grid cells that overlap with existing GIS habitat layers, given only interactions between bottom trawls and benthic habitat are relevant to the modeling effort. The trawl set points were overlayed with the l0-minute grid to assign a grid cell to each data row. Trawl effort data summaries included the total number of tows and total duration by month for each grid cell for the five years for which there is complete date information, i.e., 1998-2002. Midwater trawls were excluded from the summary assuming that they do not impact bottom habitat. The monthly time step allows for seasonal analysis in the impacts model. In addition, the same data were summarized for the full logbook time series, 1987-2002, by year.

In order to provide habitat-specific information for the sensitivity and recovery elements of the Impacts Model, the merged EFH habitat data were overlayed with the grid cells. For each grid cell, we calculated the area occupied by each benthic habitat type and the total area of the grid cell, to provide the proportion of each cell occupied by each habitat type.

For cells along the edge of the habitat information, there were two types of special cases. First, the deepwater case is where there is potential fish habitat outside of the mapped area, and there is no mapped habitat information. In this case, all of the trawl start points in the cell and the area of the entire cell was used for calculating effective fishing effort. Second is the shoreward case, where the area outside of the mapped habitat area is upland, and therefore not an area where either fishing effort or EFH would occur. In this case, the area to which the fishing effort is applied is only the area of that grid cell that comprises potential EFH. An additional GIS overlay of the shoreline with the grid cells was performed in order to provide a list of cells along the shoreward edge of the habitat data.

[7] Prior to 1997, position data for trawls off California were provided by logbook block only, not by actual haul start point.

[8] Cells increase in size as you go from north to south in the study area.

3.4 Nonfishing Impacts: Sensitivity Index

There is information available on nonfishing impacts on the West Coast, but the spatial and temporal resolution of these data presently precludes a quantitative analysis. Different types of impacts can be overlaid in the GIS to show their spatial overlap, but it is not possible to develop a quantitative evaluation of the cumulative effects of fishing and nonfishing impacts on EFH at this time. We have, however, made a first attempt to develop a sensitivity index of nonfishing activities analogous to the sensitivity index for fishing activities.

The major information source for this analysis was the technical report *Nonfishing Impacts to Essential Fish Habitat and Recommended Conservation Measures* compiled by NMFS staff from the Alaska, Northwest, and Southeast Regional Offices (Hanson, *et al.* 2003). This report reviews the literature on the potential impacts of a wide range of nonfishing activities that occur on the Pacific coast, and is organized by general location of the activities: Upland, Riverine, Estuarine, and Coastal and Marine. It does not, however, provide any straightforward guidance for quantifying the impacts of each activity even in a relative manner. Hence, we needed to develop a set of rules for assigning overall relative impact levels for each activity as well as relative impacts by habitat, before the draft impact matrix could be derived.

Table 4 summarizes the rules used to assign overall impact levels to nonfishing activities. Three major points need to be made concerning the development of this table. First, a range of 0 to 3 was chosen to reflect uncertainties in assigning numbers to the impacts, in effect representing a low, medium, high view, as was taken for the fishing gear impacts assessment. The impacts of human activities of all kinds typically have a net effect that is dependent on the intensity of the activity. For example, the application of pesticides can have local effects ranging from non-detectable to catastrophic, depending on the amount and manner of application. Assigning a relative impact level independent of the intensity of the activity can only be pushed so far quantitatively. Secondly, the present analysis required consideration of impacts on "waters," "substrate," "benthic organisms, prey species and their habitat" with respect to potential effects on EFH (see above). Hence, the potential impact of each activity on all these environmental components was considered in developing the rules listed in Table 1. Finally, the present analysis required assessment of the initial impacts as well as the potential for recovery after the activity ceased. Therefore, the rules in Table 4 include direct, indirect, and recovery considerations.

Table 4. Levels of impacts (direct and indirect adverse effects and their descriptions) for nonfishing activities on EFH functions of bottom habitats.

	Direct and Indirect Effects
Level of Impact	**Description/Rules for Assigning Levels**
0	No detectable direct or indirect adverse effects on EFH functions would be expected.
1	Minor impacts that potentially only affect fish or benthos in short-term manner. Minor or no impacts on physical structure of habitat. Recovery of EFH functions likely in months to a few years if activity ceased.
2	Moderate impacts that potentially kill fish and benthos, and cause some changes in physical structure of habitat. Recovery of EFH functions likely within several years if activity ceased.
3	Major impacts that potentially kill fish and benthic fauna, and cause serious alterations in physical structure of habitat. Recovery of EFH functions not likely unless restoration efforts conducted, or will require many years if activity ceased.

Appendix C (Part 2) to the Groundfish FMP provides the draft index of adverse impacts for nonfishing activities. Each impact is given as a range to reflect uncertainty in the values. As an example of how the rules were applied, consider the upland activity Agricultural/Nursery Runoff which was assigned an impact level of 1. Runoff from such activities is typically regulated by the states so that various "best management practices" are encouraged or required to minimize impacts on receiving waters. Also, the impacts do not necessarily alter the physical habitat of receiving waters such that characteristics related to EFH are impaired. Finally, if such activities are ceased it is likely that many EFH functions will return in a relatively short time as the land returns to a more natural condition, or is actively restored. In contrast, consider Urban/Suburban Development which was assigned an impact level of 3. This activity ranges from low density residential developments to high density urban commercial development with complete replacement of natural ground cover by impervious surfaces. Compared to Agricultural/Nursery Runoff, there is typically much more impervious surface and accompanying runoff that can carry similarly harmful pollutants. And after such development occurs, it typically remains, causing long-term impacts. The removal of many kinds of urban developments requires active and expensive restoration efforts. This general approach was followed in assigning each nonfishing activity an impact level that reflects its potential impact on EFH relative to other nonfishing activities on a scale of 0 to 3.

The ranges given were based on the impact level for each activity, and a consideration of the general location (Upland, Riverine, etc.) where the activity normally occurs relative to the megahabitat (Estuarine, Shelf, Slope, etc.) potentially affected. Basically, each range given in Appendix C (Part 2) to the Groundfish FMP is the value for that activity plus or minus 50% for the megahabitat nearest the typical location of that activity. Each range is decreased by about 50% per megahabitat moving away from the activity. For example, Agricultural/Nursery Runoff was assigned a range of 0.5-1.5 (the value of 1, plus or minus 50%) for all Estuarine substrate x macrohabitats because these activities can occur adjacent to estuaries and would be expected to have their full impact in these habitats. The range was halved for each move from megahabitat to megahabitat proceeding offshore. Each nonfishing activity was assigned a range of impact levels for each megahabitat x substrate x macrohabitat in this manner.

3.5 The Impacts Model for Trawl Gear

3.5.1 Introduction

A Bayesian Network model for examining fishing impacts has been developed. This model provides a framework for the quantitative consideration of habitat status and the effects over time of different management regimes based on the available data. These data are, in essence, the sensitivity and recovery matrices and the fishing effort data.

The model provides a scientific method for assessing Pacific Coast groundfish habitat. While the presentation of information in the GIS can provide a first order indication of areas of habitat that may be under threat and in need of protection, a quantitative approach is needed to bring together information from a variety of sources to better understand the processes involved.

The methodology was implemented with the goal of answering the questions listed in the introduction for Pacific coast groundfish, to the extent possible. Limitations on answering these questions were encountered, particularly in regards to the availability of data for model parameterization.

As will be seen, additional work will need to be undertaken to investigate in detail how the sensitivity index and fishing effort data can best be used to evaluate impacts on a scale that has some relevance in an absolute sense to the status of the habitat, in terms of its functionality for managed species. With improved data, the utility of the impacts model for the management process could be substantially enhanced.

3.5.2 Impact Function

We seek a mathematical representation of the impact of fishing effort on a given portion of seabed. Impact is measured on a scale 0 to 1 and can be thought of as proportion impacted, with 0 representing a pristine state and 1 totally functionally destroyed.

A family of functions with suitable properties is provided by:

$$f(x) = \frac{1-(1-s)^x}{1+(1-s)^x}$$

where *x* is fishing effort measured on an appropriate scale (see below), and *s* is sensitivity measured on a scale $0 < s < 1$[9]. This function is a version of the generalized logistic function and can be written:

$$f(x) = \frac{1-e^{-\beta x}}{1+e^{-\beta x}} = \tanh\frac{\beta x}{2}$$

where $\beta = -\log(1-s)$ (so that $\beta > 0$).

It has the following properties, which make it suitable as a basis for modeling impact:

(a) $0 \le f(x) \le 1$

(b) $f(0) = 0$ and $\lim_{x\to\infty} f(x) = 1$

(c) $\lim_{x\to\infty} f'(x) = 0$ and $f'(0) = \frac{\beta}{2} = -\frac{1}{2}\log(1-s)$

Note that property (c) implies that the slope of the impact function for zero effort increases with sensitivity. In other words, the impact on pristine habitat increases more rapidly for greater sensitivity, as required.

3.5.2.1 Measurement Scale for Fishing Effort

For a given area, the basic measure of fishing effort for bottom trawls is estimated from logbook data as the total duration of all tows that start in the area during the period under consideration.

This measure suffers from a potential upward bias resulting from the inclusion of tows that start in the area but end outside it. A partial correction for this error is automatically provided by the exclusion of tows that start in neighboring areas. The extent of the bias also clearly depends on the magnitude of the area, smaller areas tending to produce greater errors. An area that is roughly a square with width equal to twice the mean tow length should produce a minimal error. This can be achieved by choosing units of the order of 15 minutes of latitude and longitude. This choice would result in a fairly low resolution grid for representing maps of fishing impacts. In the event, a 10 minute cell size was adopted, mainly for practical reasons (See Section 3.3).

The distribution of total duration (Figure 1) suggests that a log-scale may result in greater discriminating power. To allow for zero effort, log (*duration* + 1) was used.

[9] This is a simple conversion from the four point scale described in Section 2.1.2.

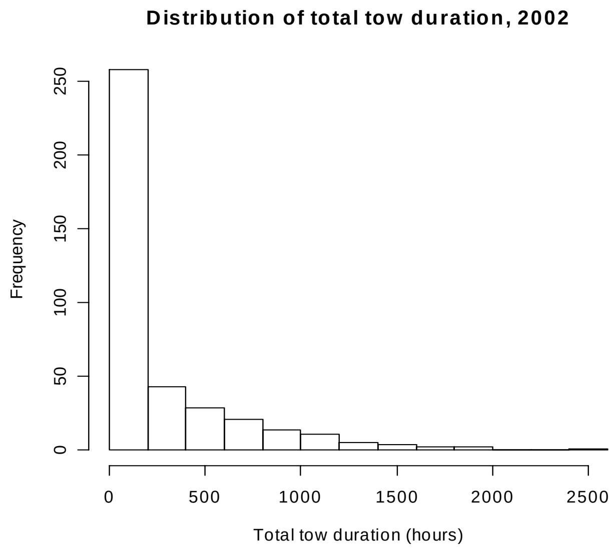

Figure 1. Distribution of total tow duration, 2002.

3.5.2.2 Modeling the Relative Impacts of Fishing Effort

There appears to be no sound empirical basis to relate a given quantum of fishing effort to a measurable impact on the habitat. Consequently, the aim of the present modeling exercise was limited to representing *relative* impacts. To allow some flexibility in calibrating impact with effort, a tuning constant k has been included in the scaling of effort, so the variable x in the impact function is effectively:

$$x = \frac{1}{k}\log_{10}\left(duration + 1\right)$$

A suitable value of this constant will depend on the range of values of the total duration, and hence on the period being modeled. For a period of one year, values in the range 0.1 to 0.5 seem reasonable. Figure 2 shows a family of impact functions for various sensitivity levels with the tuning constant fixed at k = 0.25. Figure 3 shows the same plot for a range of values.

Choosing the Tuning Constant

Suppose we are to compare n cells (or times).

Data: total durations **Error! Objects cannot be created from editing field codes.**

CEE values are **Error! Objects cannot be created from editing field codes.**

First set ymax = 0.95, say.

smin = lowest sensitivity among the n cells to be compared.

Calculate **Error! Objects cannot be created from editing field codes.**

Choose the scale factor k so that

Error! Objects cannot be created from editing field codes.

so that

Error! Objects cannot be created from editing field codes.

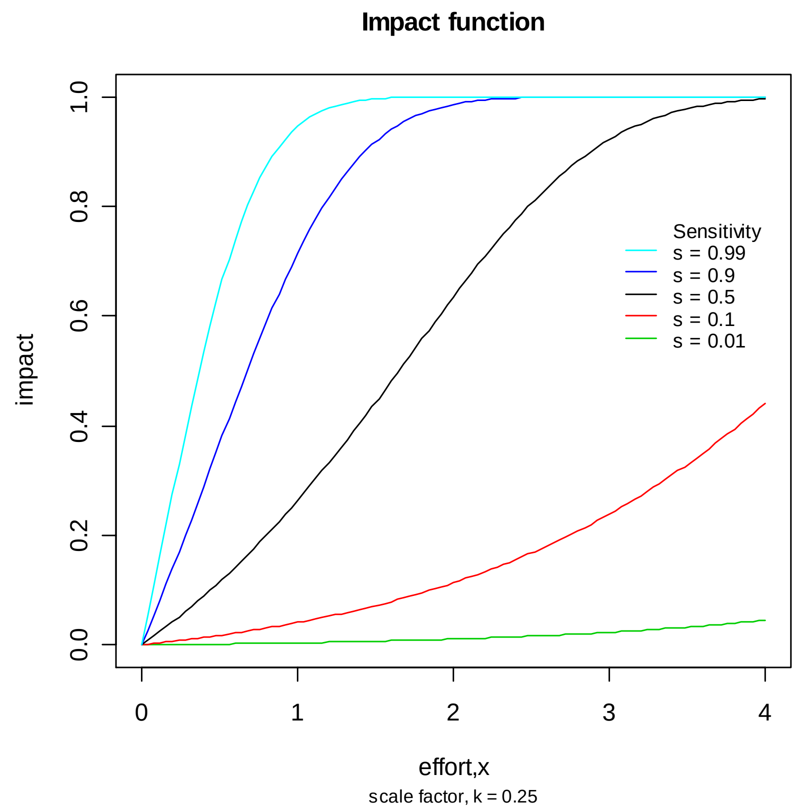

Figure 2. A family of impact functions for various sensitivity levels with the tuning constant fixed at *k* = 0.25.

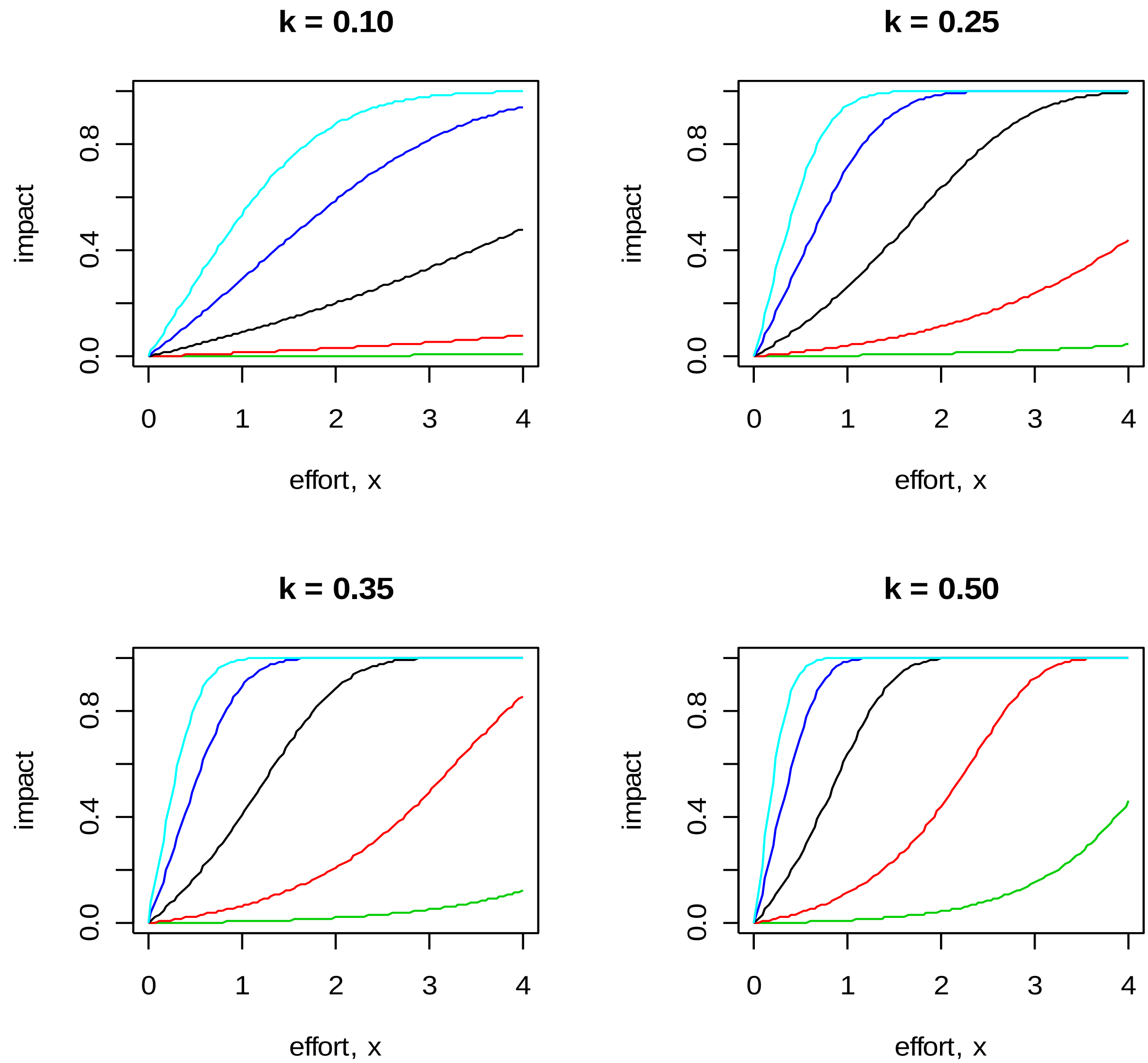

Figure 3. Figure 2 plotted for various levels of the tuning constant *k*.

3.5.2.3 Cumulative Effects of Fishing Impacts and Recovery

A convenient paradigm for concurrently modeling the cumulative effects of recurrent fishing activity and recovery is to imagine translations up and down the *x* scale, described above as $x = \frac{1}{k}\log_{10}\left(duration + 1\right)$. A recovery event moves down this scale, while extra fishing effort moves up. We can think of this *x*-scale as an indirect measure of impact, in the sense that in any time period, additions to *x* occur when there is new fishing effort; reductions on the *x*-scale correspond to recovery. Modeling in discrete time, we measure the net impact by first locating the appropriate position on the *x*-scale by adding new effort and accounting for recovery during the preceding time period. Only then do we calculate the actual impact from the function $f\left(x\right) = \frac{1-\left(1-s\right)^x}{1+\left(1-s\right)^x}$, where *s* is the sensitivity score ($0 < s < 1$). Thus the *x*-scale is a kind of proxy measure for impact—the scale on which we do out accounting for new fishing and recovery. We can call it the *cumulative equivalent effort (CEE).*

To account for recovery on the CEE scale, we need a maximum value from which to recover. This function is an idealized mathematical model and the limiting value of 1 (meaning the area is totally functionally destroyed) is attained only as effort $\to \infty$. We therefore define a notional maximum value $x_{\max}$ of CEE to be that value of *x* for which impact is some high impact value I^*, say 0.9 or 0.95: $f\left(x_{\max}\right) = I^*$. Inverting the impact function:

$$x_{\max} = \frac{\log\left[(1-I^*)/(1+I^*)\right]}{\log\left(1-s\right)}$$

When CEE is *x* = 0, the impact is zero, i.e., $f\left(0\right) = 0$. If *r* represents the mean recovery time (in years) for a given habitat type, we take this to mean that on the CEE scale, it takes *r* years to move from $x_{\max}$ back down to 0. In the event that the current impact, as measured on the CEE scale is some other value $x < x_{\max}$, then the recovery in one year is $\Delta x = \frac{1}{r}x_{\max}$, or in a period *T* years is $\Delta x = \frac{T}{r}x_{\max}$. (Note that *T* may be fractional, say half a year.) If it happens that $x - \Delta x < 0$ then we truncate at zero. If the current period is *t* and we are modeling impact every successive *T* years, we write the current cumulative net CEE as $x^{(t)}$, and denote the new fishing effort (on the *x*-scale) during the period *t-T* to *t* as $e^{(t-T,t)}$. We then have the recurrence relation:

$$x^{(t)} = \max\left(x^{(t-T)} - \frac{T}{r}x_{\max}, 0\right) + e^{(t-T,t)}.$$

This relationship forms the kernel of a dynamic Bayesian Network in which the actual impact at time *t* is estimated by substituting the above value $x^{(t)}$ of CEE into the impact function $f\left(x\right) = \frac{1-\left(1-s\right)^x}{1+\left(1-s\right)^x}$.

3.5.3 The Bayesian Network for the Impacts Model (Version 1)

A diagram of the Bayesian Network is given in Figure 4. For clarity, this shows only four time periods, but in principle any number of periods can be added to the model, provided they follow each other successively in time, such that the start of period t+1 immediately follows the end of period t. The model is for bottom trawl gears only, a separate version being required for each gear type.

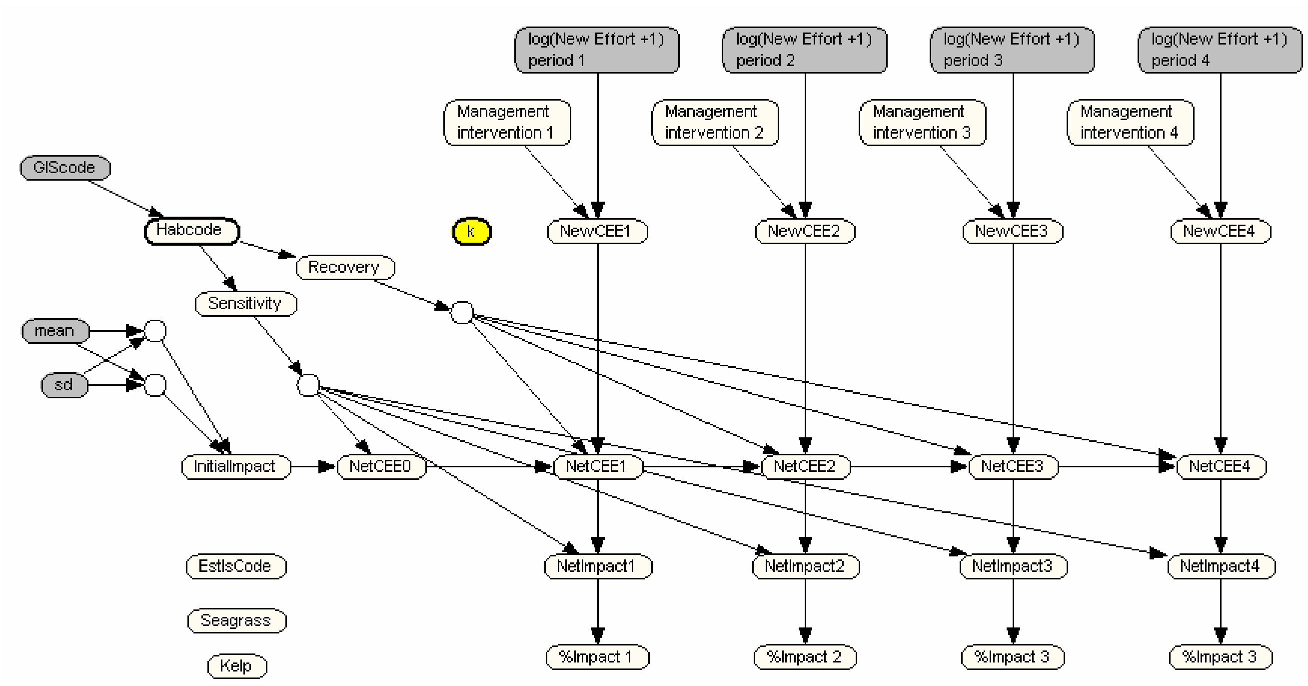

Figure 4. Bayesian Network to model relative spatial impacts of fishing gears over time.

The node labeled “GIScode” contains the habitat descriptor codes as used in the GIS. These are mapped onto the appropriate corresponding codes, in node “Habcode,” that are used in the sensitivity and recovery indices. Sensitivity and recovery values, as given for each combination of gear type and habitat in Appendix 10, are re-scaled to 0-1, as required by the impact function. These values are assumed constant over time.

Initial impact is modeled by a beta distribution to represent prior uncertainty in knowledge of the initial state of the habitat. This information can be entered either by specifying the two parameter values for the standard beta distribution, or by specifying the mean and variance. As an alternative to a probability distribution, an actual value can be entered. The initial impact value is converted to the CEE scale by the inverse of the impact function.

New effort for each period is entered as log(duration + 1) in the top node. This is modified by any management intervention and rescaled to the CEE scale. Net CEE is computed by accounting for recovery from the previous CEE. Net CEE is then converted to the impact scale and finally summarized in the % Impact node, by its expected value.

The entire process is replicated for each time period, resulting in a dynamic Bayesian network. Note that the time interval between successive periods is arbitrary; a feature which enables the modeling of seasonal effects.

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