PART II

Science in Action: Working Examples of Marine GIS

CHAPTER 5

The OCEAN Framework—Modeling the Linkages between Marine Ecology, Fishing Economy, and Coastal Communities

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Abstract

Many of the most vexing problems and challenges of marine resource management and conservation turn on the interaction of human activities and communities with the marine environment. In the case of fisheries, recent management measures, such as habitat protection, fishing restrictions, and alternative area usages, are precipitated by fisheries declines and ecosystem-based management mandates, and require an integrated understanding of the resource and its users. Analytically, this challenge reduces to the need to link—through data and analysis—ocean ecosystems and human communities. In addition to the physical, geological and biological data collected and compiled by scientists to understand the ocean floors and water column, any analysis seeking to link the ocean environment to fishing activities and coastal communities must also include information on use patterns, economic statistics, and human behavior. With fisheries, essentially, the question becomes "where in the ocean are the resources, the fleets that harvest them, and the communities that depend on them?"

The Ocean Communities "3E" Analysis (OCEAN) is a suite of geographic information systems, databases, and analyses designed to answer this question. Using the case of the West Coast groundfish fishery, we illustrate how multiple, heterogeneous datasets can be linked and interpreted for marine management applications, notably area-based management. OCEAN operates at an intermediate, regional scale, with explicit consideration of the socioeconomic impacts of management measures on coastal communities. The system can be queried from within any one data layer, for example, to find particular vessels or gear groups fishing in a habitat of

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interest, which we illustrate with trawl fishery in the coral and sponge habitat of the Monterey Bay National Marine Sanctuary. Information can be manipulated both in database formats and map-based user interfaces, and results are plotted on maps.

Introduction

The oceans are the "final frontier" of science, a vast, largely uncharted expanse of the Earth's surface that poses innumerable challenges to mapping and exploration. No less formidable are the challenges to science and policy arising from human uses of the oceans for activities such as oil and gas extraction, transportation and shipping, commercial and recreational fishing, and recreational uses. Increasingly, these uses impact ecosystem health and functions, often with deleterious effects on marine environments and organisms from climate change, pollution, habitat degradation, and extinction.

In this chapter, we focus on fisheries and the potential for geographic information systems (GIS), spatial analysis, and new software tools to support the management and conservation of marine resources. Specifically, we address the potential of GIS for integrating socioeconomic information into models and tools used for managing marine resources. The Ocean Communities "3E" Analysis (OCEAN) framework is so called because it facilitates the consideration of ecological, economic and equity considerations in marine resource management. In particular, OCEAN is a geographic information system and database that links the economic behavior of fishing fleets with habitat and other oceanographic data, and relates them to coastal communities.

Globally, it is estimated that 47% of the world's fish stocks are fully exploited, and another 28% are either overexploited or so significantly depleted that they require drastic and long-term reductions in fishing pressure (FAO, 2002). The United States, with 11 million km^2 (4.5 million mi^2), has the largest Exclusive Economic Zone (EEZ) of any nation (NRC, 1998), and is the fourth-largest producer of capture fisheries, after China, Peru, and Japan (FAO, 2002). In 2000, U.S. fisheries produced 4.7 million tons of fish (FAO, 2002), the vast majority of which comes from the abundant waters of the Northeast Pacific.

In the Pacific Northwest of the United States, many fisheries are quite healthy, with Alaska groundfish and salmon accounting for the majority of Alaska landings, which averaged 2.5 million tons in recent years (NMFS, 1999). Farther south, however, off the coasts of Washington, Oregon, and California, several salmon stocks have been listed as endangered, and the groundfish fishery—a complex of 89 different species of flatfish, roundfish and rockfish, nine of which are considered overfished and the status of most of the others is unknown—was declared a federal disaster (PFMC, 2002).

The management of these and other U.S. fisheries is regulated by the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). The Act requires the eight regional councils charged with managing fisheries in the U.S. EEZ to not only to develop and execute fishery management plans that generate optimal yields while preventing overfishing (National Standard 1, MSFCMA, 1996), but to do so in ways that protect the marine environment (particularly habitats that are considered essential for fish at various life stages) and consider the socioeconomic impacts of management decisions on fishing communities (National Standard 8, MSFCMA, 1996). On a political level, this dual mandate of environmental conservation and community economic viability is the backdrop for many contentious policy issues, including marine protected areas, reduced harvest quotas, and disagreement over the siting of aquaculture facilities (for overviews of these issues see, respectively: NRC, 2001; Weber, 2002; and Naylor et al., 2003). Each of these and other marine resource management issues entail policy decisions based on scientific assessments that link marine ecology, fishing economy, and coastal communities. In this chapter, we focus on the analytical challenges of making these linkages, and novel GIS tools developed for this purpose.

Data Sources, Data Limitations and Ways to Overcome Them

Many of the data used to build OCEAN are relatively readily available. Typically, physical, geological, and biological data describing the ocean floors and water column have the best spatial resolution. We obtained bathymetry and other data on oceanographic characteristics from the National Oceanic and Atmospheric Administration (NOAA), the United States Geological Survey (USGS), as well as from state agencies such as the California Department of Fish and Game. The continental shelf in our study area has been the subject of considerable habitat mapping efforts, such as the USGS habitat GIS for the Monterey Bay National Marine Sanctuary (Wong and Eittreim, 2001; Greene et al., this volume). Using known habitat associations for various fish species, as well as the depth constraints on particular types of fishing gear, habitat data can also be used to relate fishing effort to particular ocean areas.

Serious data limitations emerge when considering the human aspects of the marine environment. One of the main limitations of fishery management today is that many routine data collection efforts are outpaced by evolving analytical needs. Emerging issues such as ecosystem-based management, Essential Fish Habitat (EFH) or spatiotemporal zoning reduce, analytically, to the need to link areas of the ocean where commercial and recreational fishing activities take place with the human communities that depend on the resulting landings, tourism economy, or other marine-related businesses. With fisheries, essentially, the question becomes “where in the ocean are the resources, the fleets that harvest them, and the communities that depend on them?"

Fish, Fleets and Fishing Communities

Although a plethora of data are routinely collected that document these three dimensions—fishery resources, fishing fleets, and coastal communities—they are not usually considered in an integrated, spatially explicit format. Rather than devising an entirely new data collection effort, OCEAN illustrates that existing data sources can be mined and interpreted in spatially explicit ways. Consider, in turn, the three dimensions of fishery management, resources, fleets and communities.

In terms of the fishery resource, little is known about the distribution of fish in the sea. Historically, fishery science has focused on estimating the biomass of stocks targeted in fisheries, developing several different schools of thought and models for inferring the volume of fish in the sea from samples and surveys (Smith, 1994). While these are generally considered to be the best available science for estimating the current status of a stock, the rate of removal due to fishing, or the abundance needed to sustain the stock in the future, a recent National Academy Study also cautioned that current stock assessment models may not be adequate for precautionary management as required by the Magnuson-Stevens Act (NRC, 1998).

This disconnect between current stock assessments and the information collected for them is borne out, for example, by the MSFCMA mandate to protect Essential Fish Habitat for species at their different life stages. To do this, fishery managers need to know where, both geographically and biologically, species spend their various life stages. The same dataset used for stock assessments provides an important starting point for this inquiry. Scientists employed by NOAA Fisheries conduct periodic trawl surveys, focusing on species that are commercially harvested. These surveys can be interpreted spatially to generate associations of species and biogeographic regions (see Monaco et al., this volume). Since the trawl surveys adhere to a strict sampling protocol, they essentially suggest where in the ocean scientific vessels are likely to encounter the various species and various life stages. Furthermore, the trawl surveys have been found to overlap well with fishing locations as reported in trawl logbooks (Fox and Starr, 1996), so it seems reasonable to use them to generate probability surfaces of where fishing vessels are likely to encounter the species they record in their landing tickets. In this chapter, we present another use of this same dataset. Adapting techniques developed by Monaco et al. (this volume), we use the West Coast fisheries survey data to infer spatial distributions of various marine organisms, both to constrain a model of fishing behavior and to infer distributions of non-targeted, but habitat-forming invertebrates.

The fact that we are discussing a *model* of fishing behavior is indicative of information challenges in the second dimension of marine resource management, the fleets. Although the logbooks and landing receipts generated by both commercial and recreational fishing vessels are integral to data collection efforts for fisheries management on the West Coast, they provide remarkably little information as to where they catch fish. To date, only a handful of U.S. fisheries employ electronic vessel monitoring systems (VMS) or on-board fisheries observers (NRC, 2000), and the Pacific Northwest is no exception. There is also little comprehensive observer coverage that would provide another fishery-independent source of location data. Where vessels fish is increasingly important for management issues designed to protect Essential Fish Habitat, conserve marine biodiversity and ecosystems, or to facilitate the rebuilding of overfished stocks.

Again, existing datasets provide a solution to this quandary, albeit imperfect. For more than 20 years, fishing vessels have filled out logbooks and landing receipts, with varying degrees of accuracy as to the geographic provenance of the catch. The quality of location-specific data on fishing activities varies significantly across fisheries. If vessels are required to record fishing locations at all, these tend to be reported in large statistical areas. In some fisheries and states on the West Coast, logbook and landings data are spatially coded in blocks that range from 5 to 30 nautical miles at the sides.[1] Even at the finest available resolution, however, the recorded data are too coarse to allow meaningful inferences about, for example, the interaction of fishing gear and sensitive habitat. Airamé (this volume) and elsewhere in this section detail a process that entailed using fishers' knowledge to generate maps of fishing effort at a much smaller scale (1 n.m.) for a marine reserves planning process in Southern California.

While this scale cannot realistically be attained along the entire coast, the logbook and landings data can be spatially interpreted to make them considerably more useful for marine management applications by relating them with other data sources in a GIS. For most marine management issues, an intermediary scale between point locations and regional generalization is indicated. For example, in the context of the MSFCMA mandate to protect Essential Fish Habitat, resource managers are interested in the extent and intensity of fishing activity on various habitat types, as well as the interaction of fishing gear with marine habitats. In order to assess the potential damage to benthic habitats from gear interactions, managers have to know where and how intensely fishing effort is distributed. We discuss this in more detail later, but the basic rationale is to constrain the landing receipts and logbooks with other data, notably on species-habitat associations and inferences on the likely distance a particular fishing vessel will travel for a reported trip.

Finally, the human dimension of fisheries, notably fishing communities, is central to marine resource management, yet relatively sparsely documented. In many parts of the West Coast, fisheries are an important part of the economic base and cultural fabric of communities, and any management measure that affects the amount or extent of fishing in an area will tend to have local impacts on employment and income. In addition to National Standard 1 of the MSFCMA, various federal and state laws and regulations also require that managers take these effects into consideration, yet available data are often problematic. For example, census data are recorded at the county level, which can make it difficult to distinguish coastal communities from inland areas. Similarly, most employment statistics tend to lump fishing activities with forestry and agricultural employment, thus making it hard to differentiate effects on the fishery sector. Since these statistics also tend to be based on unemployment insurance data, they may significantly under-report small fishing businesses that are exempt from paying unemployment insurance.

In OCEAN, weused an existing regional econimc model to approximate the effects of alternative management measures, the Fisheries Economic Assessment Model (FEAM) (Jensen, 1996). The FEAM belongs to a class of regional input-output models that treat the economic activity in a region as a set of interconnected sectors (Hewings, 1985). Each dollar generated in one sector has a "multiplier effect" because it generates economic activity in other sectors. For example, fish are landed and the vessel is paid a price per pound for its catch. Out of this ex-vesselrevenue, crew shares, maintenance and moorage costs and other expenses are paid, which in turn generate personal income, and revenues for the port district and other marine-related businesses.

The FEAM estimates these effects for the two primary sectors affected by fishing activity, i.e., harvesters (fishers and their families) and processors. We summarized these model outputs in a set of Excel spreadsheets, which we integrated into OCEAN. This allowed us to consider the income impacts of changes in landings in a port resulting from particular management scenarios. A key limitation of the FEAM analysis is that it is static in nature and only provides an incomplete snapshot in time. It is based on the landings and revenues generated by the fishing fleet, but remains silent on alternative sources of revenues in coastal communities such as tourism. Unlike other regional input-output models, FEAM is not designed to assess employment effects.

Furthermore, there are a host of considerations over and beyond economic impacts that are of importance to coastal communities and managers, but are not yet routinely assessed. For example, the lifestyle aspects of fishing communities are important (The H. John Heinz III Center for Science Economics and the Environment, 2000), as are concerns about the social and cultural resilience of ports and towns in response to the structural changes in the fishery (Langton-Pollock, 2004). Researchers have been using qualitative approaches to profile fishing communities on the West Coast (see, for example: Gilden, 1999; Pomeroy and Dalton, 2003; Package and Sepez, 2004), which are, in principle, compatible with GIS tools (Airamé, this volume; Scholz et al., 2004). By way of addressing these concerns, and to lay the groundwork for more in-depth analysis of coastal communities in future applications of OCEAN, we incorporated census statistics as well as qualitative information derived from port visits and interviews.

The Ocean Communities "3E" Analysis (OCEAN) Approach

Conceptually, OCEAN is a multi-layered information system comprising geographic and other data in a set of linked, "smart" maps. It is rooted in the growing literature of marine GIS that are being developed to address a host of oceanographic, coastal, and fisheries issues and problems (Kruse et al., 2001; Breman, 2002; Valavanis, 2002; Green and King, 2003). OCEAN is essentially a meta-analytical tool for combining a range of data, using a relational database architecture and spatial analysis as the common currency.

Analytically, the OCEAN approach is centered on the spatial association of multiple, heterogeneous datasets. This kind of analysis has been used in other marine applications of GIS, for example, to assess the location of fishery efforts close to shore (Caddy and Carocci, 1999), or to detect trends in global fishery statistics (Watson and Pauly, 2001; Watson et al., this volume). The OCEAN approach operates at an intermediate, regional scale, with explicit consideration of the socioeconomic impacts in coastal communities. The system can be queried from within any one data layer, for example, to find particular vessels or gear groups fishing in a habitat of interest, or to generate the ex-vessel revenues associated with a particular species or gear type. Information can be manipulated both in database formats and map-based user interfaces, and results are plotted on maps.

The centerpiece of this approach is the modeling of data that are already available in spatially explicit formats, and combining them with other, newly spatially interpreted information. The challenge is to organize and standardize data from diverse sources, recorded in diverse formats, and of varying quality, and to integrate them into a single framework. We began work on OCEAN by reviewing existing sources of data pertaining to fish populations, fishing activities and coastal communities, and compiling them into a single relational database. Where necessary, we built new models to spatially interpret data (further detailed in this chapter), especially those pertaining to the distribution of fishing effort. Combining bathymetry and habitat information with fishing effort and species distributions then formed the basis for analyzing where vessels fish, stratified by gear type and target species. To this we added a regional economic model for assessing the relative socioeconomic impacts of different management scenarios on coastal communities. The result is a set of smart maps that are linked through a relational database, and that allow the user to investigate jointly ecological, economic, and social questions; Figure 5.1 shows a schematic of OCEAN.

Modeling Fishing Effort, or Where in the Ocean are the Vessels?

By way of illustrating a central piece of spatial modeling involved in OCEAN, we discuss here the methods developed for interpreting existing landing records spatially in order to arrive at distributions of fishing effort. Effort maps are central for estimating the amount and degree of interaction between fishing gears and marine habitats, or for estimating the relative economic cost to fishing businesses of spatiotemporal closures of the fishing grounds, e.g., for temporary or permanent marine reserves.

We use the West Coast groundfish fishery off the coasts of Washington, Oregon, and California as an example, since it illustrates several linked management issues that center on the relationship between fishing and habitat. Managers are involved in processes to identify EFH areas and reduce by-catch of overfished species, both of which may lead to area restrictions on trawl, pot and line gear. Current management measures include large rockfish conservation areas on the continental shelf within which targeting of groundfish is prohibited to facilitate the rebuilding of several overfished stocks of rockfish. Five national marine sanctuaries off the coast of California and Washington

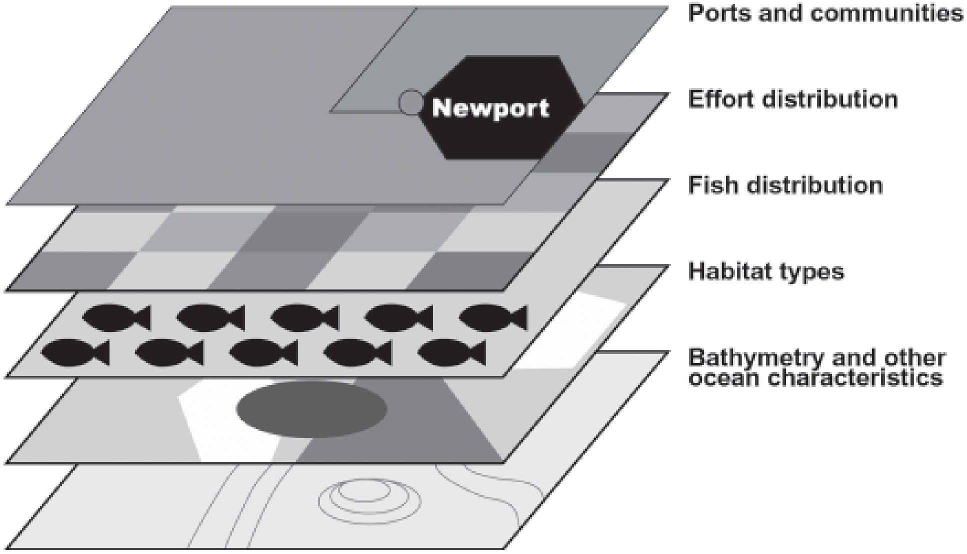


Figure 5.1. Linking smart maps in OCEAN.

are undergoing periodic management plan review processes that may result in changing regulations in some sanctuary waters.

There are several important aspects to the West Coast groundfish fishery. The fleet consists of around two thousand vessels that target groundfish using both fixed and mobile gear. Fixed gear includes hook and line formats such as benthic longlines, as well as pots and traps. Mobile gear refers to gear that is trawled through the water, typically on or just off the bottom. Although only a small (and, since a recent vessel buyback, shrinking) fraction of the fleet, the now roughly one hundred trawlers on the coast (2004) account for nearly 90% of all groundfish landed. All sectors of the fishery are required to report their landings, in the form of receipts filled out at the processor or buying station in the landing port. These landing receipts contain little geographical information, since the only spatial reference is to one of several large, statistical areas off the coast, requiring considerable creativity for making inferences about the spatial distribution of the fixed gear fleet.

For the trawl sector, however, there is a second data source, on which we focus in this chapter. Vessels submit federally mandated logbooks to fish and wildlife management agencies in the three coastal states, which in turn process and forward them to a regional database (Sampson and Crone, 1997), the Pacific Fisheries Information Network (PacFIN). The logbooks include vessel identifiers;[1] landing port and home ports; the date, location (set points and block number), number of tows and duration of each tow; species caught; gear used; and the amount landed (both hailed and adjusted by landing receipts). From the latitude and longitude recorded for the set points it is relatively straightforward to map the distribution of trawl effort. We summarized fishing effort in terms of tow duration, tow intensity (number of tows), and landings by the 10-min (approximately 20-km) statistical blocks used in the logbooks.

More accurately, what can be mapped from the trawl logbooks is the distribution of set points, since the haul points are not transcribed into PacFIN. This, and the fact that only the tow duration, but not the direction of each tow is recorded, introduces considerable uncertainty into the spatial interpretation of the logbook records. Since trawl vessels are capable of covering considerable distances, with each tow potentially covering dozens of kilometers, any maps based purely on the logbooks likely misrepresent the actual distribution of fishing effort and catch.

We therefore developed one model for spatially interpreting landing receipts—the only source of location information, at a coastwide scale, for the fixed gear fleet—and two additional methods for determining trawl activity: (1) one extracting and mapping the information as it is recorded in the logbooks, and (2) a constrained random direction model.

Interpreting Landing Receipts

The OCEAN landing receipts (also known as "fish tickets") model essentially consists of a sequence of steps, programmed in ArcInfo, which successively constrain each landing record and subsequently apportion catch and revenue to equal area analysis units (9-km by 9-km blocks) based on probability of fishing activity in an area. In contrast to multivariate analysis used in terrestrial applications, which generally predicts what happens in a particular location (e.g., Hargrove and

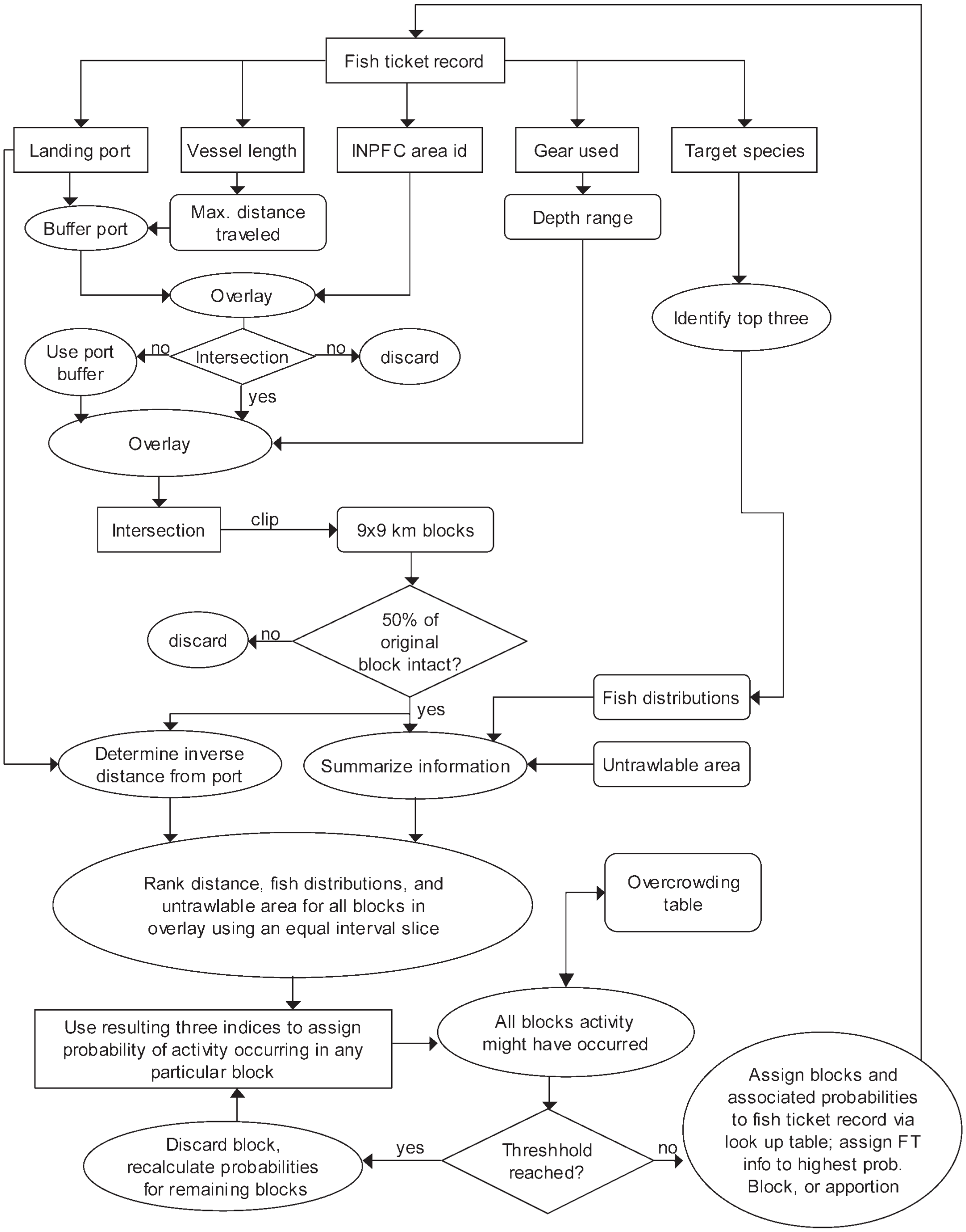


Figure 5.2. Flow chart for fish ticket model (Ecotrust)

Hoffman, 2000), we try to predict the location for known entities. The following steps characterize this process; Figure 5.2 shows a flow chart of the model:

1) Each PacFIN record contains information on the gear used, species caught, landing port, vessel information, and one of 12 statistical management areas where the catch originated;

2) Impose a maximum range from the landing port that a vessel is likely to have fished, given its length and gear type used—this is currently derived from expert witness testimonies, pending more formal studies of fishing behavior on the West Coast;

3) Impose depth restrictions on fishing gear used and target species—there are limits to the depth from which West Coast trawlers can haul their nets, or in what depth various fixed gear types are used; similarly, different species of fish have known ranges of bathymetric associations;

4) Compare this to the species distribution densities derived from the fishery-independent surveys—some areas are associated with higher frequencies of the target species in question, making it more likely that a fishing vessel would have gone there for its catch;

5) Within that maximum range, weight the species density clusters inversely by distance from port—this is a "friction of distance" idea: because travel is costly, vessels tend to fish closer to port even if they are slightly less likely to encounter the target species;

6) Impose habitat restrictions on fishing gear used—trawlers do not operate in high relief areas, while these same areas tend to be frequented differentially by vessels using hook and line gear;

7) Apportion pounds caught and associated revenue from fish tickets. This can be done either deterministically, associating the entire catch and revenues with the block that has the highest likelihood of fishing having occurred there; or probabilistically, apportioning catch and revenues to fishing blocks within the maximum range based on probabilities derived from distance from port, targeted species densities, habitat restrictions and previous activity.

8) Repeat for all records and map the resulting distribution of fishing activity; in principle, this can be normalized by number of records associated with an area, or—in the case of trawlers—number and duration of tows made there, to provide a measure of effort.

The maps resulting from this algorithm are probability surfaces of the distribution of fishing effort and the associated catches and revenues (see Fig. 5.3). The results shown here are derived from an earlier, deterministic version of the model. We discuss the probabilistic model and its sensitivity to various assumptions in another publication (Scholz et al., 2004). In general, however, the model is most sensitive to assumptions about the maximum range of vessels from port and about the associations of gear types with particular habitats, as well as to the weight given to the overcrowding parameter. We are in the process of

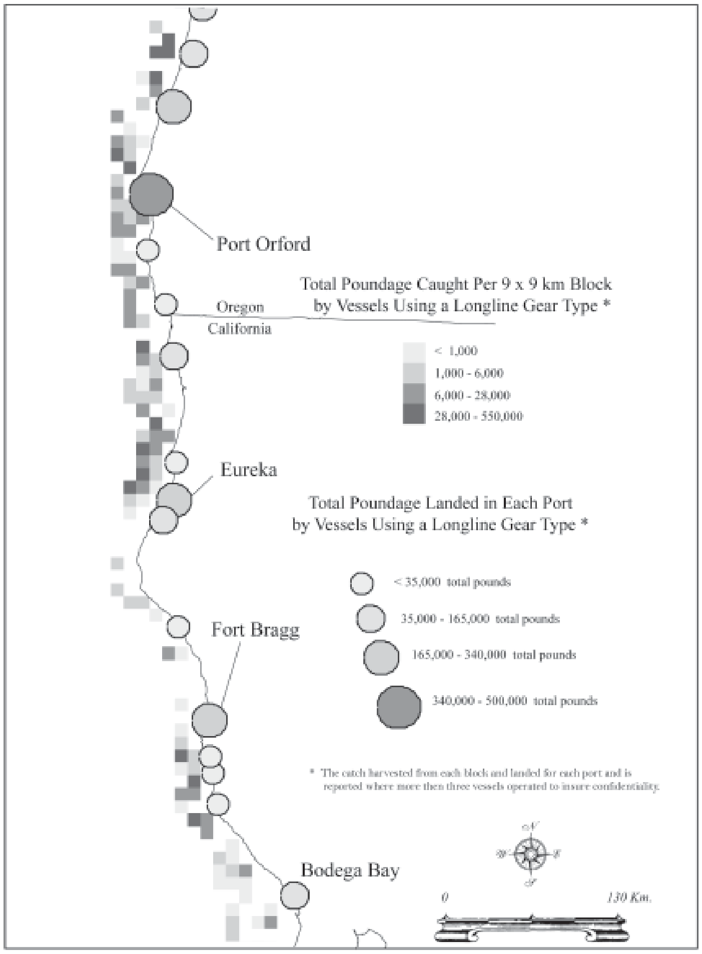


Figure 5.3. Probability distribution of fishing effort. Estimated pounds caught and landed summarized for all longline gear, southern Oregon and northern California, 2000.

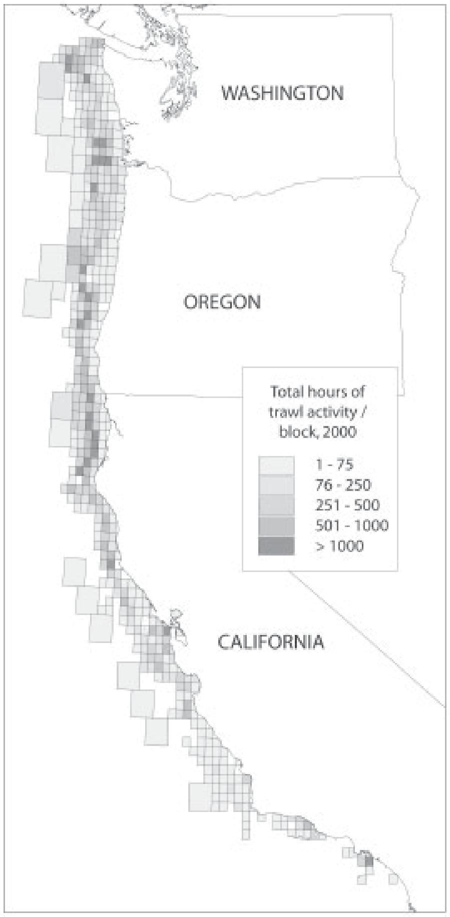
validating the model with fishermen along the coast, and eliciting additional information for further refining this approach.

Mapping the Trawl Logbooks

Fish tickets are available for all fisheries and all fleets on the West Coast. In addition, the trawl fleet, like several other fisheries, is also required to fill out and submit logbooks that record fishing locations. Typically, these logs record the latitude and longitude of the set points of individual tows, as well as the duration of each tow. It is relatively straightforward to map the resulting distribution of set points, and associate catches and revenues with them.

We determined the duration of each tow using database procedures. Essentially, we assigned the tow duration recorded in the logbooks to the block into which the recorded latitude and longitude of the set point fell. This generated a new set of records based on information about the duration of each tow (in hours); x, y location of set point; block id; and gear used—as recorded in the logbook data. Species information is omitted as multiple species are recorded for each tow. This newly created record set is then used to determine the cumulative

Figure 5.4. Trawl activity off the West Coast.



number of tows and cumulative tow duration for each block, generating a measure of trawl effort per area (Fig. 5.4).

Figure 5.4 illustrates the extent of trawl activity off the West Coast in terms of hours per unit area. It is somewhat problematic to associate trawl duration with the block in which the coordinates of the set points fall, since trawl vessels routinely cover distances larger than the 10 n.m. (roughly 20 km, the length of each block), or a set point might have fallen on the corner of a block. These confounders not withstanding , it should be apparent that some areas of the EEZ are more heavily trawled than others, since tow duration is directly related to bottom contact. Given the limitations of the logbooks as recorded, however, it would not suffice to simply overlay a nautical chart and expect to be able to identify the areas where tow activity occurs. The random direction model discussed in the next section is an attempt to remedy the uncertainty involved in interpreting logbooks.

A Constrained Random Direction Model for Trawl Vessels

Using the set points and additional information extraneous to the logbooks, we developed a model that generates a set of possible directions a vessel might have traveled. Based on the unique tows identified from the logbooks, we extract from each record the x and y-coordinates of each set point for each vessel, tow-date, and trip combination. We then derive a tow distance by multiplying the (recorded) tow duration by a constant speed. In our model, we assumed an average speed of 3 knots.[1] This was derived from interviews with expert witnesses, all participants in the West Coast groundfish fishery. It is likely an upper limit for actual tow speeds, which are influenced by local variables such as weather, depth at which the tow occurs, and the experience of the skipper.

The tow distance is then added to the set point's "y" location to get a secondary y-coordinate. The start point and secondary "y" coordinate (associated with the "x" coordinate) are used to create a vertical line representing distance the vessel would have covered while trawling at the constant speed of 3 kt. from the recorded set point. Since the logbook record contains no information about the direction traveled, this line is then copied and rotated 360° in 11.5° increments (for a total of 32 such increments, or possible directions) around the start point of the tow. Each rotated line is put into a comprehensive data layer. The resulting data layer represents 32 lines radiating from the tow start point each 11.5° apart (Fig. 5.5). This data layer is then converted to a raster model.

Given what we know about trawling, in particular that vessels tend to avoid rocks and other obstructions to avoid gear entanglements, it is possible to reduce the number of possible towpaths. Specifically, we excluded areas that we identified as "untrawlable," adapting a method for interpreting the NMFS trawl survey data (Zimmermann, 2002). Trawl and non-trawl fisheries are, by and large, mutually exclusive in that trawl gear is not used on high-relief substrates and many of the

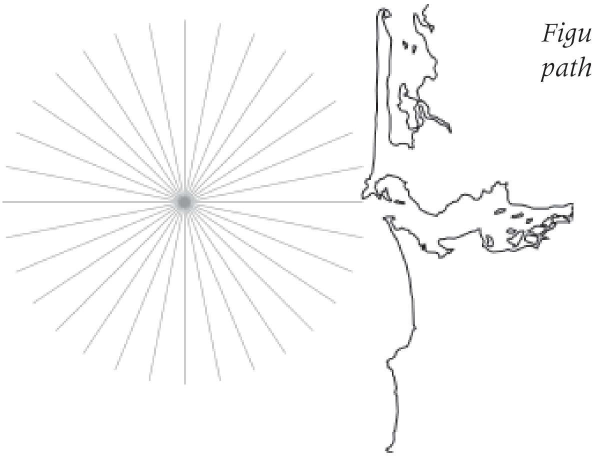


Figure 5.5. Possible tow paths from set point.

non-trawl gear types target species that live in rocky habitats. Interviews with expert witnesses confirmed this; our technique effectively designates around 80-90% of the fishing grounds as trawlable.

The data derived in the previous steps are overlaid with untrawlable areas and bathymetry. If any given tow line intersects untrawlable areas, which—for the purposes of constraining direction—includes regulated areas and non-marine areas (islands, mainland), that line is removed from the analysis (Fig. 5.6; see page XX). If all lines fall within untrawlable areas, the record is removed from the analysis. The total number of records removed from the analysis are tracked.

We further constrained these tow paths by factoring in the slope of the terrain, using bathymetry information. Considering the slope (rise over run) of each tow line remaining, any line with a slope greater than 1% is removed from the analysis. This is again based on expert testimonials, and may be a conservative constraint. If all lines have a slope greater than 1%, then the line with the lowest slope is selected as the most likely tow line. Otherwise a random function is applied to determine the tow line. All other lines are removed from the data layer and the resulting line is copied into a master tow-lines dataset. This further reduces the number of potential tow paths originating from each set point (Fig. 5.7; see page XX).

Of the remaining potential tow paths, we then picked one at random for each set point and summarized the information from the logbook record by area. Once all tow lines have been delineated, these are overlaid with a grid, and total distance towed is then summarized for each block (Fig. 5.8). These are properly interpreted as probabilistic estimates of trawl activity—essentially a density map of possible tow tracks—rather than a literal map of where trawling takes place.

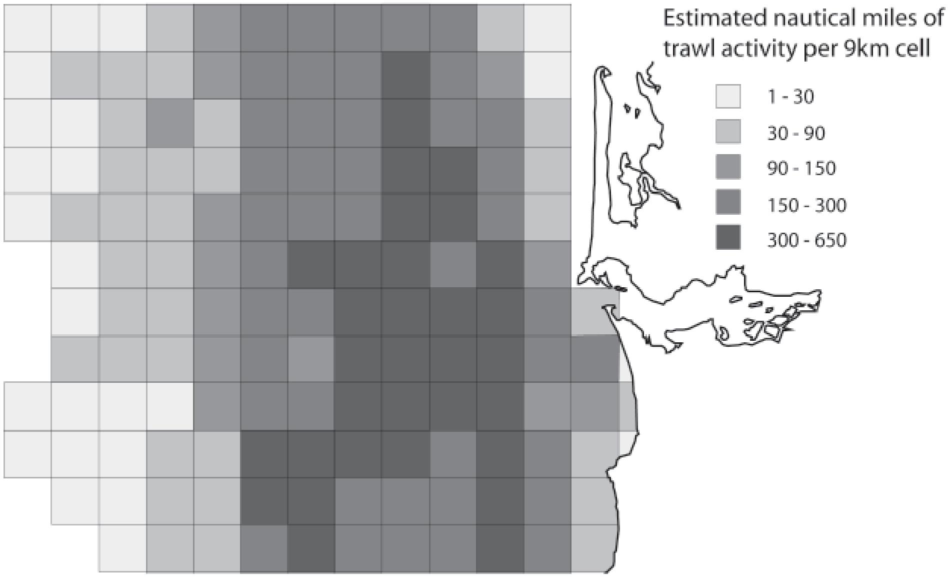


Figure 5.8. Estimated miles of trawl activity.

Repeating this procedure for each year of data generates a time series of effort distribution maps—a kind of movie—that illustrates the changes in fishing effort over time in terms of pounds-landed associated with each fishing block. The trawl effort distribution also details the species caught per block, and pounds landed per port. Applying average prices for each species (another data set available from PacFIN), it is possible to derive the revenues generated per block. We normalized the catch per area by tow duration and number of tows, thus deriving a measure of catch per effort and area.

The technique for interpreting trawl set points outlined in the above steps could be further improved. Specifically, the treatment of tow speed and terrain constraints (trawlable incline) could be improved by using a range of speeds and slops, as well as conducting further expert consultations. Also, the constraints on tow directions could be improved with more detailed habitat information than the trawlable/untrawlable distinction used to date. Finally, there is emerging research using a more detailed set of logbooks to suggest that the trawl fleets on different parts of the coast exhibits patterns of predominant directions, which would help further constrain the model.

OCEAN Applications to Marine Resource Management

Once fishing activities are modeled geospatially, it is possible to tell complex stories and to investigate issues that span marine ecosystems, economic activities, and coastal communities. Consider, for example, some of the issues faced by the managers of the three central California national marine sanctuaries (NMS)—Cordell Bank, Gulf of the Farallones, and Monterey Bay—in the context of the Joint Management Plan Review (JMPR) process they are undergoing. Together, they cover 7,000 mi^2 (approximately 18,200 km^2) of ocean and occupy almost one third of the state's coastline (Fig. 5.9). Like the other ten NMS in U.S. waters, the three central California sanctuaries were designated to protect natural and cultural resources, while encouraging multiple uses of sanctuary waters, including fishing and shipping. Historically, the regulatory authority over fishing activities in federal waters resides with NOAA Fisheries (formerly the National Marine Fisheries Service), while the sanctuaries are administered by NOAA Oceans.

With emerging concerns over ecosystem-based management, habitat impacts of fishing, and Essential Fish Habitat, the line between fishery management and ecosystem conservation are beginning to blur. Given their size, any management measure that the sanctuaries consider to protect the marine resources in their charge are likely to have socioeconomic impacts on the fishing fleet operating in, and coastal communities adjacent to, the sanctuaries. Similarly, existing fishery regulations are already affecting commercial and recreational fishermen

Figure 5.9. Map of three central California sanctuaries and the Exclusive Economic Zone.

operating in sanctuary waters and cannot be ignored in the sanctuaries' JMPR process.

In partnership with the sanctuaries, we are using the OCEAN framework to build an integrated database and GIS for profiling fishing activities in and communities adjacent to sanctuary waters. This provides the socioeconomic baseline information for a variety of management measures that the sanctuaries and the various stakeholder groups participating in the process will be considering. Since this is still a work in progress, and without wanting to prejudice these deliberations, we present here a hypothetical example based on concerns about interactions between fishing gears and sensitive marine habitats in the three central California sanctuaries.

Within the sanctuaries lie areas with some of the highest coral and sponge concentrations on the West Coast, notably along the Monterey Canyon break (Morgan et al., 2005). Corals create important habitat for marine fishes, providing shelter, nursery and feeding areas, including for some of the rockfish species that are currently considered overfished, or in danger of being overfished, on the West Coast. While it is well established that various fishing gears touch or otherwise interact with benthic substrates and any structures on it (NRC, 2002; Morgan and Chuenpagdee, 2003), the specific interactions between fishing gear and coral aggregations have not yet received wide-spread management attention on the West Coast.

A first step in assessing the extent of the potential interactions, and the effects on coral distributions, is to plot the distribution of fishing effort and that of corals, and to overlay the resulting maps. Figures 5.10a-d (see page XXX) illustrate the results from this analysis for the area of the three central California sanctuaries.

As should be apparent from Figure 5.10a, some of the highest volumes of trawl-caught groundfish comes from areas of high coral aggregations, e.g., the block due west of Moss Landing, or an area approximately 40 mi. (75 km) off Bodega Bay. Not surprisingly, these areas also coincide with the largest numbers of tows per unit area (Fig. 5.10b) and thus presumably the most bottom contact. That is not to say, however, that there is necessarily habitat damage from this trawl activity. There are several complicating factors. One is that the trawl logbooks from which this information is derived only contain the set points of individual tows, and so the actual footprint of the fishing activity may not overlap as directly as suggested by these maps. Further investigation, ideally using fishermen's local knowledge of the fishing grounds and independent observer data (that also record the amount of invertebrates caught incidentally) is needed for a comprehensive assessment.

Figures 5.10c and 5.10d illustrate another important aspect of the sanctuaries. Both in terms of miles towed and tow duration—two important measures of fishing intensity—the sanctuaries appear to be very important for the local fishing fleets. The possibility that the set points overstate this effect, and actual activity could be taking place just outside sanctuary boundaries, notwithstanding, these maps have important implications for the JMPR process and fishery management in the area more generally. Given the relative importance of the sanctuary waters as fishing grounds, any management measures restricting fishing in sanctuary waters is likely to have significant impacts on the economic viability of fishing vessels and the ports adjacent to the sanctuaries where they land their catch.

This issue is further complicated by recent rockfish conservation areas implemented on large sections of the continental shelf by NOAA Fisheries starting in 2002. Designed to aid the rebuilding of several overfished rockfish species, the closure areas prohibit the targeting of groundfish and have forced the fleet to relocate farther inshore and offshore, likely altering the spatial pattern of the resulting fishing footprint in sanctuary waters. With some of the rebuilding plans measured in decades rather than seasons, these closures may well become a permanent feature on the West Coast, and require careful consideration in the sanctuaries management process. As part of the socioeconomic analysis for the sanctuaries, we are assessing the actual and potential future effects of this shift in spatial behavior, and anticipate that the nexus of issues around gear impacts and area-based management measures will take center stage in the JMPR process and subsequent marine management processes.

Using the OCEAN framework, these and other questions can be explored, mapped and analyzed, and inform the decision-making process for marine management. The example of the sanctuaries, as well as other potential applications on the West Coast, demonstrate the utility of marine GIS for integrating socioeconomic concerns and issues into the policy process. Whether at the regional scale or at smaller, local scales as elaborated in the other chapters in Part II of this book, such integrated systems greatly enhance, and—to the extent that fishermen and other stakeholders participate in the creation of the spatial information—even help smooth out otherwise contentious marine management processes.

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Notes

1 Technically, distance on water is measured in nautical miles (n.m.). One n.m. is the angular distance of 1 min of arc on the Earth's surface. One min of latitude equals 1 n.m., and degrees of latitude are 60 n.m. apart. At the equator, 1 n.m. equals 1,852 m. The distance between degrees of longitude is not constant, since they converge at the poles.

2 The logbooks contain actual vessel identifiers, which in our case were fictionalized to maintain confidentiality. There are also several other constraints on which data are made available to researchers, and how they can be displayed.

3 A "knot" (kt.) is a nautical measure of speed, and equals 1 n.m. per hr. Modern fishing vessels travel at up to 10 kt. (roughly 20 km/h), and trawl tow speeds vary, depending on bathymetry, from 1.5 to 4 kt. (approximately 3 to 8 km/h).

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