Human Dimensions of Marine Fisheries: Using GIS to Illustrate Land-Sea Connections in the Northeast U.S. Herring, *Clupea harengus,* Fishery

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Introduction

The social and ecological interactions inherent to marine fisheries are a mystery for many who are not fishermen or members of fishing families. In areas where fishing takes place near the coast, there may be a general awareness and understanding of these interactions as fishing activities become part of the economic, social, and cultural landscape of the community.

Understanding offshore commercial fisheries, however, can be challenging for coastal and non coastal residents alike. Site visits to ports leave many questions unanswered. Vessels come and go along with trucks hauling catch (in many cases already processed, bagged, or packaged) away from ports.

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ABSTRACT—Geographic Information Systems can help improve ocean literacy and inform our understanding of the human dimensions of marine resource use. This paper describes a pilot project where GIS is used to illustrate the connections between fish stocks and the social, cultural, and economic components of the fishery on land. This method of presenting and merging qualitative and quantitative data represents a new approach to assist fishery managers, participants, policy-makers, and other stakeholders in visualizing an often confusing and poorly understood web of interactions. The Atlantic herring fishery serves as a case study and maps from this pilot project are presented and methods reviewed.

Additionally, while nearshore fisheries often supply local markets, larger scale commercial fisheries that commonly fish offshore often cater to markets outside local and even regional boundaries. Distance as well as increased vessel size and mobility present challenges for understanding the interactions between fishers, other fishery participants, and fishing grounds. Given the increased specialization of the fishing industry, one might have a general understanding of one fishery but the social, economic, and ecological connections in another may not be obvious.

Not only do fishing methods differ between fisheries, but the distribution, processing, and marketing of commercial marine resources also varies significantly. Certain fisheries are better understood than others. For example, coastal residents of Maine and elsewhere in New England are likely to have a general understanding of how and where lobsters, *Homarus americanus*, are caught and will certainly be able to recognize the species.

This familiarity is due in part to the fishery's visibility. Lobsters are predominantly caught close to shore and multicolored buoys commonly dot inlets and coastal waters. Owner-operated vessels are moored in harbors and go out daily to check and empty traps. Traps are ubiquitous—stacked in backyards, on piers, and even used as coffee tables in summer homes. And, of course, live and cooked lobsters and lobster products are widely available at the local fishmonger and restaurants.

Social and ecological interactions in most fisheries are much less obvious to fishery stakeholders. Fisheries in the northeastern United States such as herring, *Clupea harengus*; squid, *Loligo vulgaris;* monkfish, *Lophius americanus;* cod, *Gadus morhua;* and other groundfish species are examples of this disconnect. Some fisheries have few participants and are highly localized, landing their catch in a limited number of ports, while others have thousands of participants scattered along the coastline with catch being distributed throughout the region. While one species might be processed, packed, distributed, and consumed locally, another might be frozen and shipped abroad for international consumption. Understanding these land-sea linkages and social networks is essential to understanding the human component of the ecosystem as well as comprehending how changes in the condition of the resource or regulations might impact coastal communities and other stakeholders in the short term and over time.

Mapping Socio-Ecological Marine Connections

Analysis of economic and social impacts of fishery regulations is required by the National Environmental Policy Act and by the Magnuson-Stevens Fishery Conservation and Management Act, with the latter emphasizing the need to understand the history of the fishery and impacts on fishing communities (National Standard 8). Each fishery management plan or amendment to a plan must include a description of the potentially "affected human environment." Ideally, this information is used as a baseline against which sociocultural and economic changes experienced by stakeholder groups and relevant communities can be measured over time.

A common criticism of these documents is that they are too long, complicated, and inaccessible to the average fishery stakeholder. A recent Federal court decision in a challenge to Amendment 13 of the Northeast Multispecies Fishery Management Plan found that while the content of the document met legal requirements, it was less successful at "disclosing information in terms intelligible to interested members of the public, public servants, and legislators."[1] The total length of this document was over 1,500 pages with the "affected human environment" section of the document comprising over 350 pages (NEFMC, 2003).

Formal analysis of fishing activities is generally limited to either at-sea activities or the economic impacts of regulatory changes on fishing businesses. Only recently have research efforts focused on the social and cultural impacts on fishermen, their families, and other fisheries stakeholders such as coastal communities. Traditionally, the types of data about fishery participants available in government databases have focused on vessels and landings.

Socio-cultural data is only now beginning to be acquired. One example of this is the baseline demographic data on coastal communities now being collected to better document social change over time (Federal Register, 1998). Rarely, however, is there a connection drawn between the marine resource and coastal stakeholders at any scale to evaluate how environmental or regulatory changes might impact a region. One notable effort to address this gap is the development of an economic impact model capable of predicting multiplier effects of proposed fishery management actions on subregions in the northeast United States (Steinback and Thunberg, 2006).

GIS and the Human Dimensions of Marine Ecosystems

The use of Geographic Information Systems (GIS) in fisheries science and decision-making has occurred slower than in other fields of resource management (Isaak and Hubert, 1997; Meaden, 2000; St. Martin, 2004). However, recently applications have begun to grow exponentially and GIS is increasingly being used as a tool for understanding marine ecosystems (Meaden and Do Chi, 1996; Meaden, 1996; Valavanis, 2002; Fisher and Rahel, 2004). Increased peer-reviewed publications, numerous sessions at fisheries conferences dedicated to the subject, and, in 2005, the third international symposium on GIS in fisheries science are all testimony to the increasing interest in this subject area. A review of these publications and conference proceedings, however, shows that much of the work carried out to date has been focused on the biological and oceanographic aspects of marine ecosystems.

In marine applications, GIS usage by social scientists has generally lagged that of physical scientists, leading to a fundamental disconnect between the disciplines with respect to GIS applications. While biologists, ecologists, oceanographers, and the like are moving from the static representation of data to dynamic GIS-based modeling of the environment, social scientists are still attempting to find the best methods of displaying data in a static and yet meaningful manner. This is likely an important reason for the lack of efforts to visualize land-sea connections, and more communication may be necessary between the disciplines to find the best way of incorporating static socioeconomic data into the dynamic models being developed by physical scientists. At the same time, and more importantly, social scientists must press onward and develop more dynamic representations of the diverse socioeconomic data available.

There has been some progress along these lines in nonmarine applications, especially in regional science literature. Goodchild and Haining (2004) note that GIS and spatial data analysis were once separate fields of research, but they have converged over time. While this may be encouraging, applications are typically statistical in nature, like those embraced by practitioners of the physical sciences.

What is needed is a method of incorporating within these statistical exercises the wealth of data available from community profiles. Further, there are implications for the types of questions asked and data collected when completing community profiles. Recognizing that GIS is capable of displaying data of both quantitative and qualitative varieties, as long as the data are collected in a systematic manner and can be related to a geographic place, community profiles should be structured in a manner facilitating the use of GIS as a representational tool.

Participatory GIS applications dealing with marine resources typically focus on such exercises as mapping fishing grounds and fishermen's perceptions of the physical characteristics of the marine environment. While these are useful and may help guide fishery management by identifying the concerns of resource users, they are nonetheless focused on the sea. What we envision is a similar display of information about the fishing communities on land and their connection to marine resources. Only through an understanding of these linkages can we protect marine resources while also understanding the impact of protective management measures on fishing communities and other stakeholders.

GIS has been used to study a wide range of topics pertinent to fisheries and their management. Topics frequently encountered in the literature include habitat assessment and management, aquaculture and mariculture site selection, mapping oceanographic features, and population dynamics. Under the latter category are found such applications as abundance and spatial distribution mapping, as well as movement tracking, such as sightings of right whales, *Balaenidae eubalaena,* or migration patterns of yellowtail flounder, *Limanda ferruginea*. The growing number of tagging projects and increased funding for habitat mapping reflects the increasing prevalence of these applications. Applications of GIS for understanding the human dimensions of marine ecosystems, however, have only begun to evolve.

[1]Oceana v. Evans, Civil Action No. 04–0811, D.D.C. 9 March, 2005, p. 42.

Table 1.—Current applications of GIS in marine fisheries.

Category	Study types	Data sources	Examples
Remote sensing	Marine productivity hotspots	Airborne sensors	Karthik et al., 2005
	Aquaculture site selection	Space-based sensors	Valavanis et al., 2004
	Population dynamics	Radar	Pérez et al., 2003a
		Underwater sensors	
		Aerial photography	
Spatial visualization	Macro:	FAO statistics	FAO, 2003, 2004, 2005
	World fisheries		Watson, 2004
	Consumption by country		
	Production by country		
	Regional:	Permit data	St. Martin, 2004
	Permitted vessel by county	Landings data	Brody et al., 2003
	Registered vessels by size	Census data	Olson, 2003
	Landed value by county	Vessel logbooks	NE Reg. Cod Tagging Prog. (text footnote 2)
	Poverty rates by county	Tag returns/reports	Edwards et al., 2001
	Fishing effort by state	Location databases	Walden et al., 2001
	Value by place		Caddy and Carocci, 1999
	Landings by port		Kemp and Meaden, 2002
	Fishing activity		
	Effects of closures on behavior		
	Fish movement tracking		
	Stakeholder conflict mapping		
Participatory GIS	Delineation of fishing grounds	Surveys	Scholz et al., 2004
	Local ecological knowledge	Interviews	St. Martin, 2001
			Macnab, 2002
			Anuchiracheeva et al., 2003
			Close, 2003
			Close and Hall, 2006

GIS applications can be broadly grouped into three varieties: remote sensing of phenomena or patterns from afar, the spatial representation of data, and participatory GIS, which involves asking stakeholders their opinions as to the location of activities. Table 1 presents some examples of the types of studies within each of these categories.

Remote sensing may be defined as the acquisition of data about an object or phenomenon from afar. Airborne or space-based sensors, radar, aerial photography, and underwater sensors have all been used in remote sensing of marine phenomena, such as the identification of marine productivity hotspots (Valavanis et al., 2004), aquaculture site selection (Perez et al., 2003a; Perez et al, 2003b; Karthik, et al., 2005), or the tracking of species for studies of population dynamics. Simpson (1992) and Butler et al. (1998) provide useful introductions to the technical aspect of remote sensing in fisheries. There are relatively few applications attempting to integrate remote sensing into social science (Liverman et al., 1998; Hall et al., 2001). Of those that have focused on land-based activities, there are none to our knowledge that have focused on fisheries.

Another method used to track species movement has been the use of implanted tags, which are then returned by the person catching the tagged fish. The person provides information about where the fish was caught, and this information can be entered into a GIS. One initiative using this technique is the Northeast Regional Cod Tagging Program[2], which began in March 2003 and has tagged over 100,000 fish. This technique falls under the broad category of spatial representation of data, which has been the primary use of GIS in marine fisheries.

To date GIS has not become an integral part of the fisheries management process, though some maps have been produced for this purpose and demonstrate the utility and power of this medium to visually depict human interactions with different fisheries. Examples include using vessel trip report and census data to map total landings by place, total catch value by place, fishing activity by state, poverty rates by county, registered fishing vessels by size, landed value by county, or permitted vessels by county (Caddy and Carocci, 1999; Kemp and Meaden, 2002; Olson, 2003).

In economics, efforts have included the use of GIS coupled with economic models to predict the behavior of fishing fleets. Not only can catch locations be mapped but economic models help predict behavior changes of fleets faced with different area restrictions on their fishing activities (specifically groundfish fleets on both the U.S. east and west coast) (PMCC/Ecotrust, 2003; Walden et al., 2001). They have also been used to understand the economic impacts of area closures (Edwards et al., 2001).

On a macro level, GIS maps have been used to present global trends in fisheries, presenting information that helps illustrate distribution issues and access issues related to the world's fisheries (FAO, 2003, 2004, 2005; Watson, 2004; Watson, et al., 2004). These applications have a heavy focus on what occurs at sea without much attention paid to how these activities interact with land based activities or onshore activities. Land areas are usually presented as a colorless mass separated from the ocean with a black line. St. Martin (2006) (Fig. 1)

[2]http://codresearch.org/

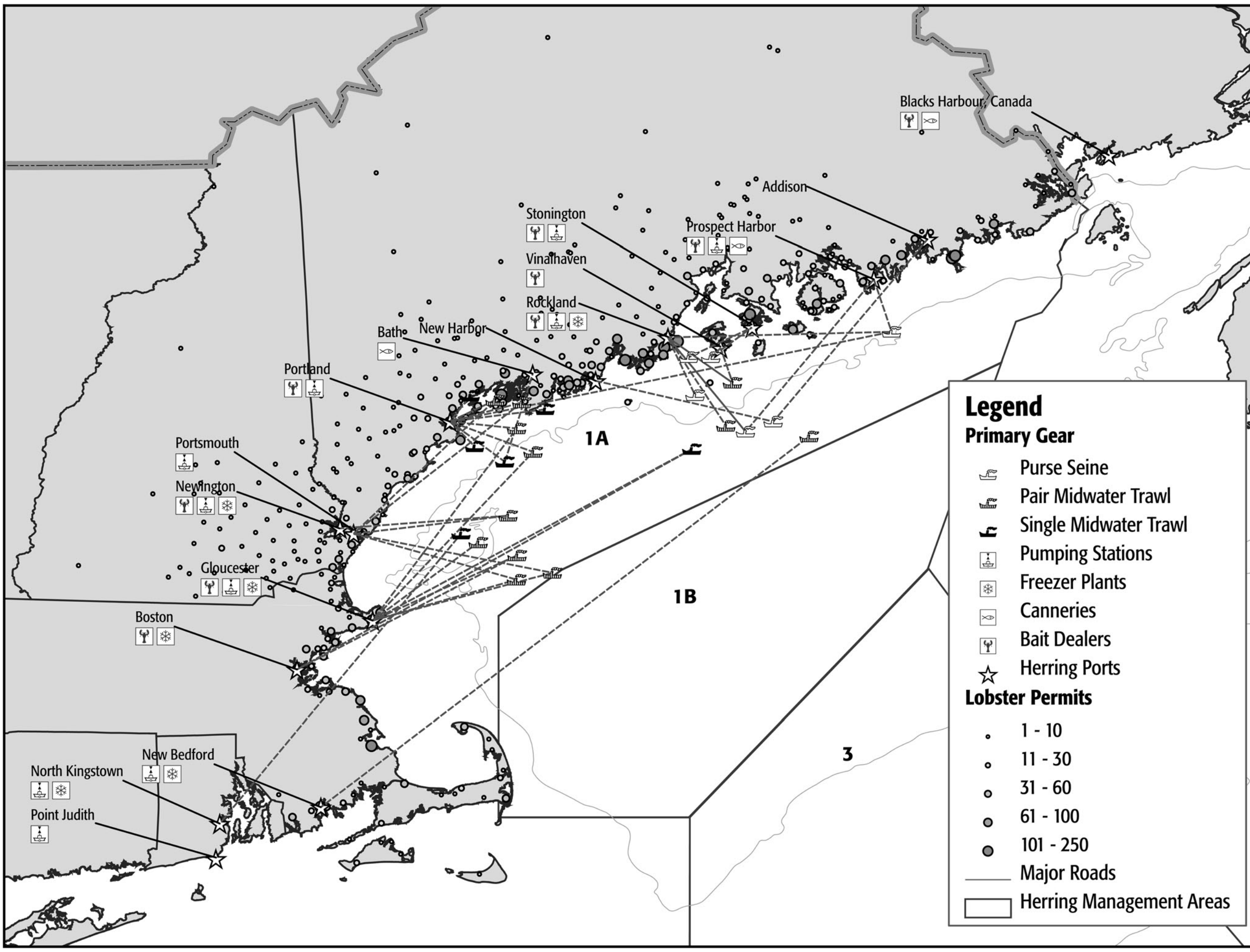

Figure 1.— Herring Management Area 1A summer/fall activity, 2000–03.

notes that the maps of fishing effort typically employed by NMFS and the regional fisheries management councils indicate where the vessels went when absent from shore, but the communities from which particular boats originate are not shown.

The use of surveys and interviews of local users of a resource to identify the spatial extent of an area or phenomenon is a technique used in participatory GIS. In marine fisheries, these studies have typically focused on the delineation of fishing grounds and the mapping of local ecological knowledge (Macnab, 2002; Anuchiracheeva et al, 2003; Scholz et al., 2004; Brody et al., 2005). St. Martin (2001) maps fisheries in terms of the perceptions of participants and scales of operation, noting that this reveals the landscapes of fishing communities and leads to suggestions for area-based management which has the potential to facilitate community development. Weiner et al. (2002) also note the important role that community participation can play in the development of GIS application, while Close (2003) and Close and Hall (2006) offer technical advice for integrating local knowledge and GIS for fisheries management.

Herring Fishery Pilot Project

The studies by St. Martin (2001) and Macnab (2002) are similar in spirit to the work presented herein. The herring fishery pilot project presented below attempts to merge two of the broad areas of GIS applications discussed above by including within a common framework of data collected by government agencies and the knowledge of the fisheries possessed by resource users. The herring fishery offers a new way of illustrating land-sea connections and demonstrates that a hybrid approach to GIS incorporating both qualitative and quantitative data can be an important tool for understanding the links between marine resources and human communities.

The impetus for this pilot project was the development of an Affected Human Environment Statement for Amendment 1 to the Atlantic Herring Fishery Management Plan prepared by the New England Fishery Management Council.

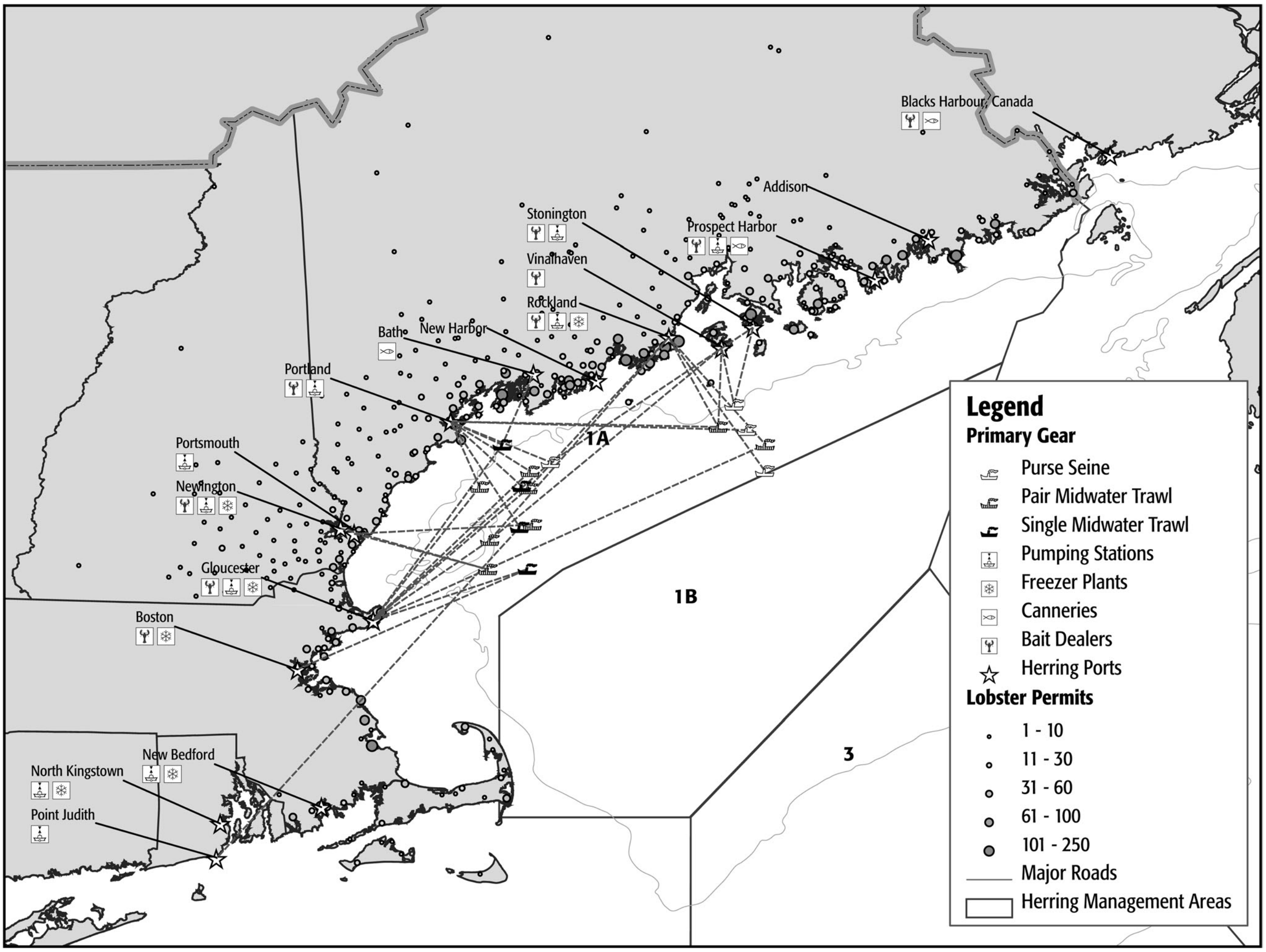

Figure 2.—Herring Management Area 1A winter/spring activity, 2000–03.

Currently[3], the herring fishery is an open access fishery managed by quotas and divided into four separate areas (1A, 1B, 2, 3) each with its own total allowable catch (TAC). Key measures in the Amendment are limiting access to the fishery and the creation of a seasonal purse seine/fixed gear only area in the northern part of Area 1A.

Implementation of these measures will impact current and future access to the fishery, and the distribution of potential catches among stakeholders. Given this, the primary purpose of the GIS-based analysis was to identify and illustrate the linkages between herring stocks in management Area 1A and fishery stakeholders in New England. This information will serve as a baseline from which to predict changes and impacts to stakeholders and to analyze future changes to the fishery. The maps produced focus on fishing effort in Area 1A, which is the prime location for the summer fishery that supplies the bait markets for the American lobster fishery and the herring cannery[4] in the region. Area 1A is also the only herring management area where the TAC is consistently attained.

Figures 1 and 2 illustrate the herring fishery in terms of geographic distribution, gear type, processing types, and key ports. Data for these maps were obtained from various sources. Herring landings were provided by the State of Maine, while vessel trip reports indicating catch, gear type, and fishing location came from NMFS databases. The number of lobster permits in each town in Maine, New Hampshire, and Massachusetts was provided by the respective state, and it was included to identify individuals who could be most impacted by changes in the availability of herring. Major roads were included to indicate possible trucking routes for the distribution of herring to more remote coastal areas. The locations of primary herring

[3]Amendment 1 to the Herring FMP is currently being reviewed by the National Marine Fisheries Service and will likely go into effect in 2007.

[4]Currently the herring cannery in Prospect Harbor, Maine, is the only facility of its kind in the region.

ports and support facilities (pumping stations, freezer plants, canneries, and bait dealers) located at or near those ports also appear on the maps.

The maps were created using the ArcView 8.3 GIS system. As the fishery undergoes seasonal changes, separate maps were generated for the winter/spring (December–May) and summer/fall (June–November) seasons. Total landings for each vessel were summed over the 2000–2003 period to determine the primary vessels within the fishery, and 34 vessels accounted for 99.5% of the landings during this period. To ensure that these vessels represented regular participants in the fishery, an additional requirement was that the vessels made at least 20 trips within the combined management areas during the period. For each of these 34 vessels, the primary gear used during each season in each management area was identified, as well as the port where they unloaded the largest percentage of their catch during the winter/spring and summer/fall seasons.

The maps are meant to be illustrative in nature, rather than a specific representation of fishing activity at any particular point in time. That said, the location of each vessel on the map was chosen to minimize the distance between the trip locations reported in the vessel logs and the port where the vessel unloaded the largest percentage of its catch. However, the locations should not be construed as indicating any vessel's particular fishing pattern.

Having created a point for each vessel, lines were drawn to each port where the vessel landed herring while fishing in that management area during that particular season. Again for clarity of presentation, a vessel had to have landed at least 10% of its catch in a particular port for a line to be drawn to that port. Then, the map symbol for each vessel was changed to indicate its primary fishing gear (single midwater trawl, pair midwater trawl, or purse seine).

Ideally, these maps provide the reader with a one page snapshot of the land-sea connections related to the herring harvested from Management Area 1A. Key communities related to this fishery are mapped and are shown with icons next to them indicating what herring-related infrastructure existed in that location. For example, both figures show that Gloucester, Massachusetts; Newington, New Hampshire; and Rockland, Maine have pumping stations, bait dealers, and freezer plants. Dots show concentrations of lobster permit holders in New England states with Maine clearly having the greatest number and consequently the greatest dependency on herring as a source of bait. The maps identify three primary destinations for herring from Area 1A—lobster dealers/bait dealers, sardine canneries, and freezer plants.

The maps show the connection between vessels and ports. The maps also depict the distribution of gear types used in different regions. For example, purse seine vessels are largely linked to more northern ports (such as Rockland and Prospect Harbor, Maine) while pair and midwater trawlers are concentrated in southern ports and linked to ports with processing and freezing facilities.

Clearly, these maps are an oversimplification of the herring fishery, but they provide the reader with a point of departure to explore social, economic, and ecological aspects of the fishery. Coupling maps with descriptions of the ports, communities, businesses, and other stakeholders should help to contextualize them. Future web-based improvements could be aimed at presenting this information in a more user-friendly way allowing users to explore the maps by clicking on icons of particular interest to them.

Conclusion

Research and analysis for fishery management plans is usually grouped into three areas: biological, social, and economic. Typically, information in each area is independently analyzed, presenting an artificial disaggregation of related information. Improving our understanding of social, economic, and ecological marine connections is critical to linking people to the marine environment and understanding the role of humans and human communities in ecosystem-based management. Single-species management has made these separations even more pronounced in that analyses are only related to one species or a group of species.

Fisheries management can benefit from an improved ability to visualize these connections, as social and economic impacts of regulatory changes can then be more quickly analyzed and accessible to a wider audience. GIS maps can show a scale of information otherwise inaccessible along with layers of information illuminating social and ecological networks that are poorly understood. Interactive web-based tools should increase the usefulness of this approach as these will allow for increased layering, options, and better integration of qualitative and quantitative data.

In addition, while it is increasingly difficult to make sense of long text-based reports on impacts and changes to a fishery, maps like this one could be used as "visual baselines" to measure changes in a fishery over time. The benefit is that much could be gleaned by simply comparing or overlaying maps from two different time periods. By making these maps web based and interactive, quantitative information could be accessed alongside qualitative data. For example, clicking on a key port icon could link the viewer to the community profile for that port that would include sociocultural and economic information for that location. Text-based information related to the Affected Human Environment of this fishery could also be linked to each icon. Such information might include site visits, structured and unstructured interviews with fishery participants, existing literature, census data, and web links. Over time, even photos and video could become illustrative elements of these interactive documents. For the purposes of the Affected Human Environment statement for Amendment 1, demographic profiles of key port communities; descriptions of each of the processing plants, canneries, and bait dealers; and information on the different gear types associated with this fishery were provided for readers to gain a deeper understanding of the stakeholders involved in this fishery.

While GIS can be a powerful analytical tool, it is unable to escape data limitations. GIS maps are only as good as the information that fuels them. While this approach worked well for the herring fishery, it may need to be adapted to work for other fisheries with different characteristics. For example, applying this method for a fishery like the northeast groundfish fishery may be complicated as the large number of vessels participating in the fishery are increasingly being managed though several different access privileges (i.e. days-at-sea, special access, and sector quotas). The large number of vessels involved may present challenges for this approach, as some aggregation of vessels by size class, gear type, or homeport will be necessary for the maps to be intelligible.

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