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The connection between fisheries resources and spatial land use change: The case of two New England fish ports

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ABSTRACT

This study examined interactions between targeted fish populations, aspects of the fishing industry and land use changes along two ports in New England. By tracking changes in land uses over a two-decade period using parcel level data and geographic information system (GIS) tools, we examined the relationship of changes in species biomass, landings and other fishing industry variables to community spatial change. Using logistic regression models we assessed the impacts on essential infrastructure for continued fishing industry activity. Our findings have implications for land use policy that should accompany efforts being made to rehabilitate fish stocks; it should ensure that current marine infrastructure will remain in place to support the fishing industry if and when species rebound. Our models show that in New Bedford Harbor, the larger of the two ports, increasing scallop biomass (considered a long-term factor) is associated with the increase of marine-related land uses. In Provincetown Harbor, short-term factors, such as value and volume of fish landings as well as stock sizes, influence land use change. These findings suggest that the smaller port (Provincetown) is more vulnerable to market conditions and therefore in need of greater land use controls to prevent the conversion of marine-related uses. We propose some directions for further research and present the methodology used as one that can be applied to research questions of a similar nature.

Introduction

Each year countries around the world dedicate significant effort and expense to rebuilding fishery resources in ocean areas where commercial fish populations have been severely depleted. The hope is that with various restrictive measures in place, such as the closure of certain areas to fishing, prohibitions on the use of certain types of gear, and strictly managed quotas, species will rebound. Off the coast of New England there are some positive signs of success from fisheries management measures (Brodziak et al., 2005; Worm et al., 2009), but in the near term it is expected that decreases in stocks will be reflected in the spatial character of communities dependent on commercial fishing (Hall-Arber et al., 2006).

Some impacts may be observed in the characteristics of cities and towns with major fishing ports, including in portside land use and physical infrastructure. If fishery resources do increase, the related land-based infrastructure that is lost when stocks are low will not be available if land use has switched in the meantime to non-marine related use (Bergeron et al., 2005). In some ports throughout New England and on the eastern seaboard, many waterfront businesses have diversified into non marine-related businesses in past decades (Hall-Arber et al., 2006). In others, marine-related activities have increased (Portman et al., 2009). Simultaneous examination of spatial changes within the context of fish stock increases or decreases in ports of different types and location will further our understanding of the multiple socio-spatial effects of fluctuations in marine resources and the related fisheries industry.

Certainly, we can better understand longitudinal changes by modeling the fisheries stock and land use change relationships in two ports and by making comparisons. This paper begins with a brief summary of theoretical background that highlights the importance of integrating environmental change with various aspects of human communities including spatial characteristics. The next section describes the two case study areas. The Methods section describes the modeling approach, both theoretical and applied. Results of the research follow. The penultimate section of the paper points out some limitations of the method and the study and pos-

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sibilities for further research efforts. The final section presents conclusions from research findings and provides a brief discussion in view of our findings.

Integrating the physical and the socio-economic

Until recently ecology and socio-economics addressed physical (non-human) or human systems, respectively, without making strong connections between the two; scientists and resource managers addressed either the biocentric physical aspects of the environment or socio-economic "anthropocentric" concerns (Norgaard, 2008). Consequently, approaches emerged such as integrated coastal management (ICM) and ecosystem-based management (EBM) that consider the various elements of ecosystems, including humans, and the myriad of activities they espouse that impact or are impacted by the physical environment. These two approaches emphasize the need to maintain coastal environments in a healthy, productive and resilient condition to provide the *services* humans want and need (Cicin-Sain and Knecht, 1998; COMPASS, 2005). But they do more than set the stage for integrating the physical with the social–economic. As it became clear how significantly ocean and coastal land uses and users can affect one another, practitioners and policy experts articulated the need for integration across varying landscape units especially across the land-sea divide. ICM refers to the integration of all relevant policy areas, sectors, and levels of administration. It supports integration of the terrestrial and marine components of the target territory that makes up the coastal zone in both time and space while balancing conservation with development.

Although the exact meaning of ICM may be debated, in broad terms it seeks to address the conflicts between economic demands and ecological needs in the coastal area (Olsen, 2003; Lau, 2005). Olsen et al. (2004) points out that ICM should be a "stepping-stone" toward making EBM for the marine environment an operative reality. With respect to integrating human concerns, EBM is akin to bioeconomics and ecological economics. The former studies the dynamics of living resources and relates these to economic models. It is related to the early development of theories in fisheries economics, initiated in the mid 1950s (Gordon, 1954; Scott, 1955). The latter – ecological economics – is a trans-disciplinary field of academic research that aims to address the interdependence of human economies and natural ecosystems. It focuses on how to operate an economy within the ecological constraints of earth's natural resources. Both these fields recognize the need to examine relationships between populations of culled species, associated human activities and their repercussions for coastal land use whether these activities occur on land, at sea or both. This interconnectedness is quite salient when one examines the fishing industry. Fishing and interaction with marine resources can be much more than an economic activity occurring solely in the sea (Kaplan, 1999; Hall-Arber et al., 2006; Olson, 2006; Le Heron et al., 2008).

Marine resource management authorities whether sectoral or integrated, recognize the consequences of fisheries management for ecosystem health and community well-being. On a global level, Agenda 21, revealed at the United Nations Conference on Environment and Development ("Earth Summit") held in Rio in 1992, devotes a chapter to ocean and coastal issues in which fisheries management problems play a predominant role.[1] In the US, fishery management problems were addressed by passage of the Sustainable Fisheries Act (SFA) of 1996. National Standard 8 of the SFA requires explicit consideration and minimization of community impacts resulting in a focus on social science aspects of fisheries management. As a consequence, the US National Marine Fisheries Service (NMFS) has committed itself to understanding the well-being of surrounding human populations that are dependent on fisheries (Pollnac et al., 2006).

Experience and extensive literature show that management actions will affect a wide range of social entities including individuals, firms, families and communities (Martin, 2006; Rosenberg, 2009). The US National Oceanic and Atmospheric Administration funded studies that have developed frameworks for the analysis of community responses to changes in fisheries and for the development of methods that can be used to assess social impacts. Social impact assessments examine socio-cultural impacts of regulation similar to how environmental impact assessments examine impacts of regulatory programs and projects on the physical environment. Social scientists have worked to improve social impact assessment for fisheries regulation since the 1960s; such assessments have become more institutionalized over time (Pollnac et al., 2006). However, they fall short of what some researchers would like to use for identifying fisheries–community interactions (Martin, 2006; Le Heron et al., 2008) and largely ignore physical impacts on communities as these are observable through land use change and related to market or regulatory forces.[2]

As an example, one theoretical framework developed to facilitate the study of effects on communities of changes in the fishing industry is the concept of vulnerability. It has been applied to fisheries management both in regards to fish populations and human communities. While "vulnerability" is used in different ways in various fields, it is generally accepted as referring to a state of pending loss (Füssel, 2007). For example, vulnerability is used in assessing the potential damage from sea-level rise caused by climate change to coastal properties (Bin et al., 2008). In regards to fisheries, Tuler et al. (2008) explores the utility of considering vulnerability in the assessment of potential impacts on communities from proposed fisheries management measures in the Northeastern US Webster (2009) uses a related framework centering on "vulnerability response" and applies it to highly migratory species of fish regulated in the international arena using the North Atlantic fisheries as a case study. For both these fisheries-related applications, vulnerability is related to risk. In the former, vulnerability defines the magnitude of the undesirable outcomes whose probability of occurring is expressed as risk. For the latter, vulnerability is gauged based on capacity for competitiveness and flexibility (availability of alternative revenue sources). Understanding the level of vulnerability is key for predicting community or institutional positions[3] on regulatory design and on access to and conservation of fishery resources.

While these and other approaches cover numerous aspects of communities (e.g., economic development, lost revenues or sources of employment, changes in social organization and political orientation) none of them explore spatial changes. Yet spatial change can be an indicator of well-being and physical infrastructure can be an important socio-economic support element (Hall-Arber et al., 2006). Surprisingly, little work examines the influence of ocean resource extraction on coastal land use, par-

[1] Problems discussed include local overfishing; unauthorized incursions by foreign fleets; ecosystem degradation; overcapitalization and excessive fleet size; undervaluation of catch; insufficiently selective gear; unreliable databases; and increasing competition between artisanal and large-scale commercial fishing and between fishing and other activities (Cicin-Sain and Knecht, 1998).

[2] Changes can also be the related indirectly to combinations of market and regulatory forces. For example, infrastructure investment required for public access or for consistency with harbor management plans may encourage gentrification within fishing ports or may lower profitability of private commercial fish docking facilities.

[3] At the nation state level in Webster's (2009) case study.

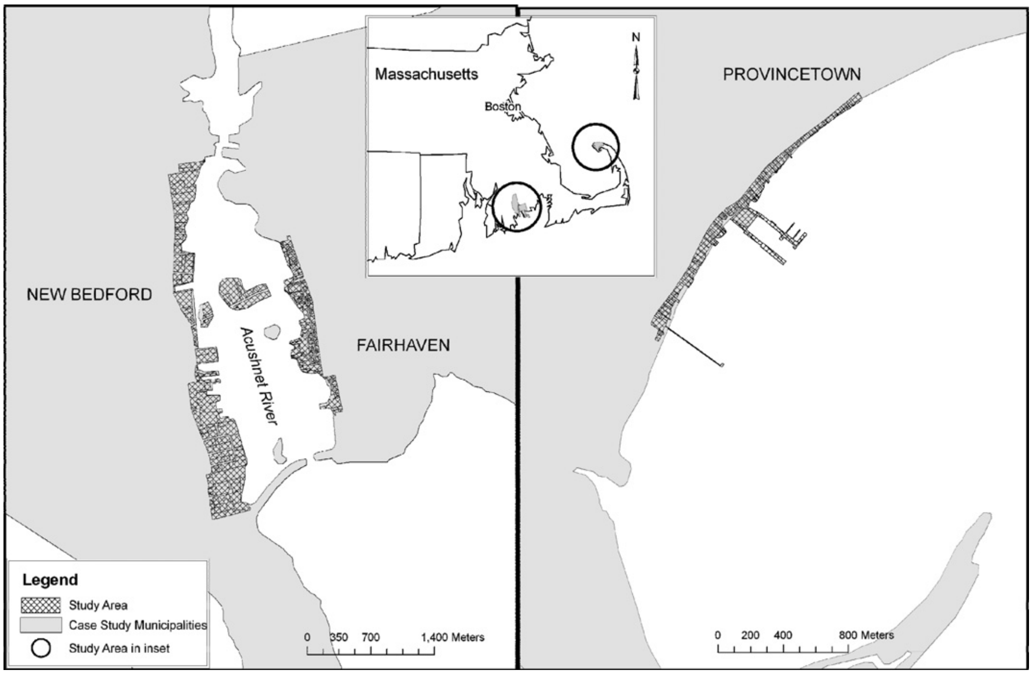

Fig. 1. Study areas.

ticularly working waterfronts and how these are impacted by the demise of fisheries.[4] In regards to fisheries, significant work now exists on how land-use influences the marine environment by eutrophication, pollution, impacts to habitats, development in estuaries, etc. Here we take a contrasting approach that measures spatial change in communities as a function of changes in fisheries resources. By doing so we are able to confirm the connection between commercial fishing in New England, fisheries biomass (stock) and perhaps undesirable community spatial change. More importantly, we can gain insights to which factors, both long term and short term, are most influential. This is important information for the development of appropriate land use policy as fisheries and the fisheries industry changes.

The case study—two New England fishing ports

The New Bedford/Fairhaven ("New Bedford") Harbor was selected as a study area because of its prominence among East Coast and US commercial fishing ports. In New Bedford, commercial fishing revenue totaled $241.3 million in 2008. Although much smaller, Provincetown Harbor was chosen for this case study because its similarities and relative proximity to New Bedford Harbor, namely its history as a major fishing port, a relatively-contained port, and its location – 140 km from New Bedford. Provincetown commercial fishing revenues, reported together with the nearby small port of Chatham, totaled only $18.3 million in 2008.

Despite some similarities, Provincetown is different from New Bedford and therefore provides interesting comparisons (see Fig. 1). The New Bedford harbor straddles the banks of the Acushnet River. The eastern side includes part of the Town of Fairhaven. The harbor flows into Buzzards Bay at the southern end of Cape Cod in the southeastern-most part of Massachusetts. Provincetown is on the opposite end of Cape Cod at the tip of a long northward curving peninsula, and the eastern-most part of the state.

The New Bedford-Fairhaven area is much larger than Provincetown. Together the City of New Bedford and the Town of Fairhaven have a population of 107,973 and a combined area of 84.4 km^2 (Vanasse Hangen Brustlin, 2002). Provincetown's population was estimated to be 3376 in 2008 (U.S. Census Bureau, 2009) and it covers a total area of 45.2 km^2 with an upland land area of 25 km^2 (Executive Office of Housing and Economic Development—State of Massachusetts, 2009). However 20 km^2 (44.4%) of the town area is within the boundaries of the Cape Cod National Seashore (CCNS). There are some developed properties within the CCNS (Portman, 2007) but none that are of interest to this study. The developed, unprotected area of the town is approximately 5 km^2 and the study area for this research encompasses an area of 0.13 km^2.

The waterfront areas examined in the two study sites are comparable in relation to the total areas of their respective municipalities. The Provincetown study area is one half of one percent (0.5%) of the total town area or 2.6% of the developed area of the town that is not within the Cape Cod National Seashore. The study area in New Bedford is much larger (1.04 km^2) than the Fairhaven study area (0.26 km^2), but put together the waterfront areas we used in the New Bedford-Fairhaven study area constitute approximately 2.8% of the total areas of the two municipalities combined.

New Bedford Harbor has a rich fishing history; it is where the whaling industry began during the mid 1800s. Once New Bedford was well established as a fishing port, ship owners and captains bought property and built homes in Fairhaven. Today, most of the commercial fishing activity takes place on the New Bedford side of the harbor whereas the Fairhaven side contains most of the marine service establishments. In any case, it is recognized that the two sides function as a unit (Vanasse Hangen Brustlin, 2002).

Provincetown has changed significantly over the years. Although its population grew slowly in the 18th century, in the early 1800s its population boomed. By mid-century Provincetown,

[4] With the notable exception of Hershman, M.J. (Ed.), 1988. Urban Ports and Harbor Management: Responding to Change along U.S. Waterfront. Taylor & Francis, New York, NY.

with the largest and safest natural harbor on the New England coast, had become one of the busiest seaports in the country. It had a fishing fleet of more than 700 vessels and more than 5000 residents. The Civil War, that destroyed so much New England business, provided more markets for Provincetown's fish. Portuguese sailors, picked up by American ships in the Azores and Cape Verde Islands to fill out their crew, came to Provincetown to live. Many more Portuguese immigrants had moved to town by the late 19th century to work on the whaling boats and other fishing vessels. The town had lively ancillary maritime and fish processing businesses that included ship chandlers, sail makers, caulkers, riggers, blacksmiths and buildings for smoking and canning herring, and fish-flaking racks for curing codfish (Hall-Arber et al., 2006; Executive Office of Housing and Economic Development—State of Massachusetts, 2009).

In recent decades the Provincetown fish harvesting sector has suffered from a lack of diversity in its development by concentrating efforts on dragging for groundfish or whiting, and failing to diversify into other fisheries or gear. Provincetown has the second deepest natural harbor in the world, but at the northernmost tip of Cape Cod, it is distant from major fish markets. The one major access road is regularly clogged with tourists in the summer and past winter storms have closed it down hindering the transport of harvested fish (Hall-Arber et al., 2006). As a result of these factors and others the Provincetown fishing industry has faltered. Today Provincetown is better known for its artists' colonies and tourist establishments, many of which began developing during its past fishing heyday.

Methods

We used a probability model to characterize land use choice decisions that provide a basis for evaluating the relationship between the fishing industry conditions and marine-related land use changes. In this section, we first describe the theoretical foundations relied upon and then describe how we collected the data, analyzed it and developed the models.

Theoretical foundations

Generally, land use decisions are driven by profitability. The probability of a parcel being used for a specific marine industry operation is a function of factors such as current and expected future profits from fish harvesting and parcel characteristics; the phenomenon modeled is discrete rather than continuous. The individual parcel owner's utility function can be written

$$U(y_i, s) = u(y_i, s) + \varepsilon_i \tag{1}$$

where u is the measurable component of utility, i is the land use option, y is profit from the use, s signifies the parcel's characteristics, and ε is the random component. Following the usual random utility specification (Hanemann, 1984; Opaluch et al., 1993), the owner would choose a marine use option i over a non-marine use option j if

$$u(y_i, s) + \varepsilon_i > u(y_j, s) + \varepsilon_j \tag{2}$$

The probability to choose option i is

$$p_i = \text{Prob}(\eta < \Delta u) = F(\Delta u) \tag{3}$$

where $F(\cdot)$ is the cumulative distribution function (c.d.f.) of $\eta = \varepsilon_j - \varepsilon_i$ and $\Delta u = u_i - u_j$. A simple way of representing the dependence of probability p_i on Δu is to choose the logistic c.d.f. Λ[5] for $F(\cdot)$:

$$p_i = \Lambda(\Delta u) = \frac{e^{\Delta u}}{1 + e^{\Delta u}} \tag{4}$$

Generally, the utility difference may be modeled as

$$\Delta u = \beta' x \tag{5}$$

where x is a set of explanatory variables and β is a set of corresponding parameters reflecting the impact of a change in x on the probability p_i.

From (1), an individual land owner's utility u_i is a function of income y from the use option i, and the parcel's characteristics s. For fishery-related industries, y is affected by profits from commercial fishing. In a standard bioeconomic analysis (Clark, 1976), profit from fishing at time t is $Ph - cE$; where P is the price of fish, h is harvest, c is the unit cost of fishing effort (E). Fish harvest $h = qEX$, where q is the catchability coefficient and X is the fish stock. Thus, profitability is influenced by several variables including quantity and value of fish landed as well as fish stock (X). While short-term profitability is mostly affected by revenues from harvesting, stock is the key driver that affects the long-term profitability of the industry. This is especially true when fishery stocks are at relatively low levels. Thus, in addition to affecting short-term profitability, fish stock can also significantly influence land use decisions in the long-term.

For the analyses of marine land use probability, the explanatory set of variables x included quantity and value of fish landed, fishery stock size, parcel size, and township. We expected the relationships between fish landings, revenue, and stock size and the probability associated with a marine use p_i to be positive, meaning an increase in harvest and larger stock sizes to be associated with higher income when a parcel is used for marine-related activities, *ceteris paribus*. The expected signs of other variables, such as parcel size, were unclear from the outset.

Data collection

The spatial data consist of land uses and parcel characteristics, namely size and location, and are primary data. The unit of analysis is a parcel. We included parcels that are upland, filled or pile-supported piers and wharves. Information for the other explanatory variables, the volume of fish landings and stock data, are secondary data we collected from government agencies such as NMFS.

We limited the study both temporally and spatially. The years studied were limited to 1986–006 due to the availability of information on both land use (explained in the Limitations section) and the fisheries. The twenty-one years were grouped into three 5-year periods and one 6-year period. We obtained land use information pertaining to165 parcels in New Bedford,[6] 193 parcels in Fairhaven, and 153 parcels in Provincetown. This gave a total 1426 observations and 612 observations for the New Bedford-Fairhaven and Provincetown studies, respectively.

The sources of information we used to track land use activities and changes over the study period were varied and included assessor's data forms, historical building surveys and key informants. On the state level, an initial source of information was the Massachusetts Waterways Regulation Program (MWRP). This is a state-level regulatory program promulgated in 1866 that strives to

[5] For a discussion of the logit regression model see Cox (1970) and Greene (1997).

[6] For most of the study period there were only 164 parcels in New Bedford. The additional two parcels in the last time period (2001–2006) resulted from fill and parcel reconfiguration.

preserve water-dependent uses and of public use rights for "fishing, fowling and navigating" through the issuance of licenses for the operation of properties within or at a certain distance from filled or flowed tidelands (Portman, 2006). Since 1984, the MWRP regulations require use statements in licenses. Any change in use requires a new or modified license and thus our review of licenses proved a way to track land use in all three towns. Otherwise the sources of documented information for spatial data depended to a large extent on the clerical culture of the municipality. We also collected information about land use activities from city officials and from members of the community familiar with the waterfront by displaying and discussing sets of maps indicating land uses for different periods based on the other sources. In New Bedford the most important source of spatial data was the assessor's records. In Fairhaven, the most important source was key informants. In Provincetown, the best source of spatial information turned out to be a Massachusetts Historical Commission Survey of buildings in the waterfront areas. A number of these surveys were conducted at intervals throughout the 21-year time period of the study. The use of several sources of cross-referenced information allowed validation of the classifications.

We determined the land uses of interest to be: fishing, processing, repair, transport, and boating. The categorization of these land uses as marine-related is based on our observations and is similar to the categories used by Pontecorvo et al. (1980).[7] 'Fishing' referred to parcels that provided docking and tie-up facilities for non-recreational, commercial fishing vessels. 'Processing' included anything described by sources as a fish plant, or fish or seafood processing establishment. 'Repair' consisted of retail establishments selling vessel parts, vessel service, and/or machine and service shops which due to their proximity to the harbor most likely service seafaring vessels. An example is a welding shop. 'Transport' included uses related to transit of goods or passengers plus adjacent packaging facilities, storage of goods for transport, and cold storage. Lastly, 'boating' included land areas adjacent to marinas, recreational boat storage lots, parks with boat ramps, and tie-up areas if these accounted for a significant portion of a parcel. As with commercial fisheries docking, 'boating' included only upland, filled, pile-support structures, and only those used for business purposes (as opposed to floats, docks, and ramps associated with residential properties).

We tracked changes in land use in a spatial database using GIS (ArcMap 9.2). The GIS software facilitated calculation of the area dedicated to each use. Because it was possible to determine only the approximate year of land use change using the sources described, we organized the data into shape (data) files of five-year periods. Up to three land uses were defined according to activities taking place on a parcel during or up to the last year of a multi-year period. This provided four periods (1986–1990, 1991–1995, 1996–2000, and 2001–2006) spanning 21 years. For the statistical analysis we tried both "snapshot" values from the last year of each of the periods and averages calculated over each of the four time periods.

Marine resource conditions are represented by species abundance indices compiled by the Northeast Fisheries Science Center of the NMFS. The agency has collected data for 62 finfish and invertebrate species stocks represented by estimates of species biomass based on extensive bottom trawls conducted bi-annually off the northeastern U.S. coast for more than 40 years. For principal groundfish, pelagics and elasmobranchs, an aggregate biomass index is computed as the sum of the individual species' stratified mean catch per tow values, smoothed (with LOESS smoother using 20% of the data) to account for inter-annual variability (NOAA, 2009a,b). There are separate dedicated surveys conducted for sea scallops, and for surfclams/ocean quahogs using different gear and in areas specific to these species. For this study, we used abundance indices of seven aggregated groups of species, which overall combine some 28 types of marketable fish and shellfish.

Other data we used in the regression analysis were annual quantity landed and annual value of product landed in millions of kilograms and 2006 dollars, respectively. The data were from NMFS for the same seven aggregated groups of species used for the abundance indices. We also used both "snapshot" values and averages for each of the periods as we did for the abundance indices.

Following Eq. (5) and based on the land use utility choice model (Eq. (2)), we used parcel level land use data, parcel characteristics, volume and value of fish landings, fish stock data, and the logistic regression procedure available within the SAS statistical software package to model the relationship between the explanatory variables and the probability of land use change. Although the sign of an estimated logit coefficient will suggest either an increase or decrease in likelihood of a marine use, the coefficient itself does not measure the marginal probability effect for non-zero observations of the dependent variable. Therefore, we derive estimates of correct marginal probability effects using the estimated coefficients and the following equation (see Eq. (4); Greene, 1997):

$$\frac{\partial \Lambda(\beta' x)}{\partial x} = \Lambda(\beta' x)[1 - \Lambda(\beta' x)]\beta \qquad (6)$$

This gives a percent probability increase (or decrease) associated with an additional unit of each variable.

Results

We found only modest land use change in both harbor areas during the period studied, yet a statistically significant relationship exists between the marine-related land uses and important specific fish biomass and industry data. We first used statistical evaluation to identify general trends in land use activities over the study period. Then we performed logistic regression using a maximum likelihood estimation approach to arrive at the models. The next section describes general changes observed followed by a description of findings.

Descriptive statistics and evaluation

Over the past two decades, there has been a slow but steady increase in parcels dedicated to marine related uses in the New Bedford Harbor study area (Fig. 2) and decrease in these types of uses in Provincetown (Fig. 3). During the study period, the most actively changing use categories for both harbors were seafood processing and marine supply and repair (Tables 1 and 2). For the New Bedford area seafood processing went from 40 to 54 parcels and marine supply and repair increased from 29 to 36. In Provincetown, fish processing activities altogether disappeared from the area after 1990 whereas marine supply and repair decreased from 7 to 2 parcels. In New Bedford, perhaps the most significant change was the addition of new fish processing plants on vacant land. In Provincetown, the loss of fish processing is likely related to losses in commercial fishing activities which we also observed, although at a lesser rate of decrease (see Table 2).

[7] Pontecorvo et al. (1980) used supply-side and demand-side criteria to categorize ocean and non-ocean businesses. These include extractive and spatial criteria in which the primary activity of the establishment involves extraction of living or inanimate objects from the ocean, utilizes ocean water as a significant element in the production process, or involves some manner of transportation of passengers, cargo, natural resources, or electrical impulses upon or below the ocean surface. Demand-side criteria are either complementary or geographic—either a significant portion of the establishment's output is attributable to the ocean or the establishment is located within a region proximate to the ocean.

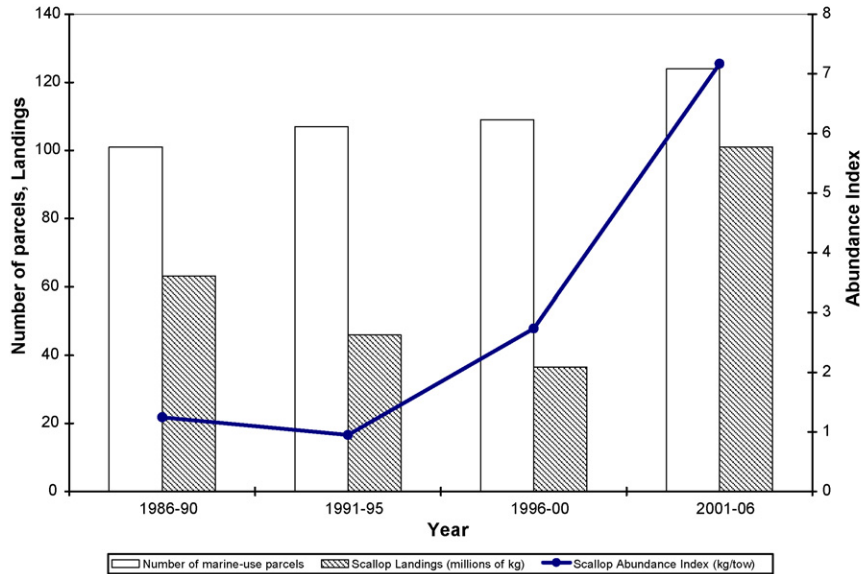

Fig. 2. Fishery conditions and marine land use (parcel count), New Bedford/Fairhaven.

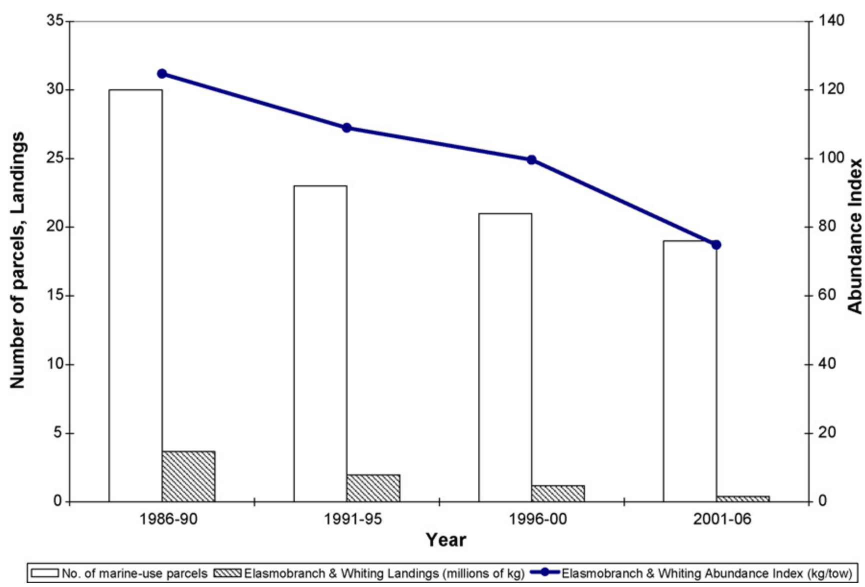

Fig. 3. Fishery conditions and marine land use (parcel count), Provincetown.

Table 1
New Bedford-Fairhaven waterfront land uses by categories.

Year	Fishing	Processing	Repair	Transport	Boating	Marine total	Total parcels
1986–1990	20	40	29	16	14	101	356
1991–1995	21	44	31	14	16	107	356
1996–2000	23	46	31	12	19	109	356
2001–2006	24	54	36	16	19	124	358

Unit: number of parcels. Fishing: commercial fishing vessel docking, storage, and parking facilities; Processing: fish processing facilities; Repair: marine supply and repair facilities; Transport: transport, packaging, cold storage facilities; Boating: marinas, recreational boating, boat storage, recreation and docking facilities. The numbers of parcels for individual marine uses do not sum to those of the totals due to multiple uses (e.g., fishing and processing, and boating and repair).

Table 2
Provincetown waterfront land uses by categories.

Year	Fishing	Processing	Repair	Transport	Boating	Marine total	Total parcels
1986–1990	15	6	7	7	16	30	153
1991–1995	14	0	5	5	18	23	153
1996–2000	11	0	3	4	18	21	153
2001–2006	12	0	2	4	16	19	153

Unit: Number of parcels. See notes below Table 1.

Table 3
Provincetown volume and value of fish landed.

Year	Principal groundfish	Scallops	Monkfish	Clams	Whiting	Elasmobranchs	Pelagics	Invertebrates	Others	Total
Annual average live weight in thousands of kilograms										
1986–1990	1163	13	274	1311	1236	2427	66	14	586	7090
1991–1995	742	47	242	141	630	1339	6	29	96	3273
1996–2000	442	51	77	89	539	658	6	29	86	1977
2001–2006	371	802	45	72	251	153	3	128	84	1908
Annual average ex-vessel value in thousands of 2006 dollars										
1986–1990	3678	34	443	555	736	635	74	37	1490	7683
1991–1995	2435	93	408	63	564	400	6	134	586	4689
1996–2000	1477	112	146	42	747	289	6	306	616	3741
2001–2006	1126	1277	77	38	310	75	2	1477	468	4849

Fig. 2 illustrates the changes in the number of marine use parcels by period, as well as the average sea scallop survey abundance indices and average annual sea scallop landings during each of these periods. Note that the Atlantic sea scallop fishery has been the most important fishery in the New Bedford Harbor area. Other researchers have pointed out the importance of this species in the region (e.g., Edwards, 2002; Baskaran and Anderson, 2005) and particularly for the New Bedford fishing sector (Olson, 2006). For Provincetown in addition to testing each species independently and grouped we tried modeling various combinations of species as well. Between 1986 and 2000, the quantity of landings of elasmobranchs and whiting made up from 52% to 62% of the total fish landed, attesting to their aggregate importance to this fishing community (see Table 3 and Fig. 3). Therefore these two species groups are used in Fig. 3.

On the New Bedford side of the harbor, 59% of the study area fell in parcels dedicated to at least one marine related activity by 2006 (i.e., commercial fishing, fish processing, marine supply and repair, transport and packaging or recreational boating). For the combined New Bedford-Fairhaven study area this figure was 31% and for Provincetown it was 35%. Along the New Bedford Harbor the five marine uses account for 35% of the total parcels in the study area and in Provincetown they accounted for 12% of the total parcels. These rates give a sense of the importance of marine uses to each community. It is clear (see Tables 1 and 2) that marine-related uses are much less important during the study period in Provincetown Harbor than they are in New Bedford Harbor.

The specific measurements and descriptive statistics of variables we utilize in the land use change probability model estimations are listed in Tables 4 and 5. The average sea scallop survey biomass index during the study period was 3.03 kg (meats)/tow. The average of the sum of whiting and elasmobranchs survey biomass indices during the study period was 102.05 kg (meats)/tow. The size of waterfront parcels varied over a great range and therefore we used a log-scaled area variable to achieve improved model results. For Provincetown the size of waterfront parcels range from 77 to 10,500 square meters with an average of 861 square meters. The average annual quantity and value of all species of fish landed in Provincetown combined was 3.56 million kilograms and $5.24 million, respectively.

Logistic regression models compared

To analyze the New Bedford Harbor case, we developed separate model runs for each marine use category and for combined marine uses. Generally, marine resource condition alone is not a determinant strong enough to influence land use choice for four of the five individual marine use categories, except seafood pro-

Table 4
New Bedford-Fairhaven land use model: variables, measurements, and descriptive statistics.

Variable	Measurement	Mean	Std Dev	Min	Max
Dependent variables					
Marine 5[a]	1 for marine uses, 0 otherwise	0.31	0.46	0	1
Independent variables					
Scallop stock	Kilograms/tow	3.03	2.49	0.95	7.17
Groundfish stock	Kilograms/tow	24.23	11.65	12.84	42.98
Area	Square meters/parcel	3621.79	5980.31	30.24	41,085.22
ln Area	Natural logarithm of Area	7.29	1.35	3.41	10.62
Fairhaven	1 for parcel in Fairhaven, 0 otherwise	0.54	0.50	0	1

[a] Marine 5 includes commercial fishing, fish processing, marine supply/repair, transport/packaging, and recreational boating.

Table 5
Provincetown land use model: variables, measurements, and descriptive statistics.

Variable	Measurement	Mean	Std Dev	Min	Max
Dependent variables					
Marine 4[a]	1 for marine uses, 0 otherwise	0.12	0.33	0	1
Independent variables					
Stock[b]	Kilograms/tow	102.05	18.11	74.85	124.76
Average annual quantity landed[c]	Millions of kilograms	3.56	2.11	1.91	7.09
Average annual value landed[c]	Millions of 2006 dollars	5.24	1.47	3.74	7.68
Area	Square meters/parcel	861.22	1426.92	76.90	10,503.00
ln Area	Natural logarithm of Area	6.23	0.91	4.34	9.26

[a] Marine 4 includes commercial fishing, fish processing, marine supply/repair, and transport/packaging.
[b] Stock is the sum of abundance indices for whiting and elasmobranchs.
[c] All species combined.

Table 6
New Bedford-Fairhaven marine land use probability: logit estimates.

Variable	Model A Scallop (Marine 5)	Model B Groundfish (Marine 5)	Marginal probability§
Coefficient (p-value)			
Stock	0.0505* (0.0480)	0.0105* (0.0480)	0.99%
ln Area	0.4604** (<0.0001)	0.4603** (<0.0001)	8.99%
Fairhaven	−1.2239** (<0.0001)	−1.2237** (<0.0001)	−23.91%
Intercept	−3.8626** (<0.0001)	−3.9640** (<0.0001)	−75.45%
# of observations	1426	1426	
# of marine	441	441	
# of nonmarine	985	985	
Likelihood ratio test	306.05	308.84	

* against the reported coefficients denote significance at 5% significance level.
** against the reported coefficients denote significance at 1% significance level.
§ Marginal change in land use switch probability with respect to change in each independent variable based on Model A results and calculated using Eq. (6).

Table 7
New Bedford-Fairhaven volume and value of fish landed.

Year	Principal groundfish	Scallops	Monkfish	Clams	Whiting	Elasmobranchs	Pelagics	Invertebrates	Others	Total
Annual average live weight in thousands of kilograms										
1986–1990	23,513	63,224	4166	5354	5	1316	177	570	7535	105,860
1991–1995	15,102	45,989	7737	2724	141	7207	130	476	15,395	94,899
1996–2000	10,756	36,550	8302	1230	137	5751	634	1311	65,484	130,156
2001–2006	15,270	100,983	5055	4710	1800	5897	16,193	1793	52,717	204,418
Annual average ex-vessel value in thousands of 2006 dollars										
1986–1990	79,642	121,862	6583	2222	5	469	434	4423	20,129	235,769
1991–1995	52,487	91,287	12,339	1665	182	3896	30	3871	13,634	179,393
1996–2000	35,106	71,259	15,949	534	127	3230	255	6966	16,893	150,318
2001–2006	41,473	161,251	9669	1487	1627	2627	3106	10,711	12,651	244,602

cessing (Portman et al., 2009). The scallop stock variable was a significant factor in determining cumulative marine land use when we combined the different use categories. Data on commercial fish landings (volume and value) were not statistically significant and thus excluded from the final regression models.

Table 6 presents logistic regression estimates of marine land use probability in New Bedford for two representative model applications. The results indicate that the models fit the data well. For example, for Model A (using scallops and "Marine 5" indicating all five uses) the likelihood ratio statistic is 306.05, well above the 11.34 critical value for significance at the 0.01 level for 3 degrees of freedom. As expected, the sign for the scallop stock coefficient is positive. The sign of the (parcel) area coefficient is also positive. The area variable is highly significant with p-values less than 0.01 in all cases. For this model, the scallop stock serves appropriately as an indicator species. Scallops make up on average between 28% (1996–2000) and 60% (1986–1990) of the live weight landed and between 47% (1996–2000) and 66% (2001–2006) of the value of all species landed over the four time periods (see Table 7).

The results of Model A suggest that an increase in scallop stock is associated with an increase in marine use probability. The probability decreases when a waterfront parcel is located on the Fairhaven side of the harbor. Model A was re-estimated separately using the groundfish abundance index for Model B. The groundfish stock variable was also statistically significant at the 5% level (see Table 6).

We also re-estimated Model A recreational boating ("boating") excluded from the marine land use definition (Marine 4). While the relationships among fishing, processing, repair, and transport are largely complementary, the relationship between recreational boating and the fishing industry is more complex and could be competitive in some cases. For example, commercial fishing boats may compete with recreational boats for dock space when the fishery is in decline and vessels are tied up for long periods (Goodwin, 1988). The results were consistent with those of Model A, suggesting that our main results are robust with respect to changes in marine-related land use classifications.

We ran models for each marine use category and combined marine uses for Provincetown (Table 8). As suggested by the results of Model C, fishery-related land use (Marine 4)[8] in Provincetown was significantly affected by the stocks of whiting and elasmobranchs. As noted the two species have been important to the community. The declines in the stocks of these indicator species have led to the contraction of marine land uses in the community. The species of tertiary importance to Provincetown in terms of volume landed for most of the study period is groundfish (see Table 3). Although its stock increased (from a mean of 16.5 kg/tow in the first period to 42.98 kg/tow in the last) it was unable to reverse the downward trend in fishery-related land uses.

Unlike in the case of New Bedford, marine land use decisions in Provincetown were significantly affected by both quantity and value of fish landings (see Models D and E) indicating the importance of short-term fluctuations in revenue from commercial fishing based on year-to-year landings. The effects of the parcel size variable are consistent with those in New Bedford.

We estimated the marginal effects associated with unit increases in stocks using Models A and C results (see Tables 6 and 8). An increase in the scallop stock by one kg/tow is associated with an increase in marine use probability of 1% in the New Bedford Harbor area. For New Bedford, the marginal effect of the natural logarithm of area suggests that marine use probability rises on average by 9% when the log-scaled area measure is increased by one unit. As for the categorical (or dummy) variable, a parcel in the town of Fairhaven has a reduced probability of 24% to be used for marine-related operations, compared with parcels in the city of New Bedford.

[8] In this paper we report results of two models of Marine 5 in New Bedford-Fairhaven and three models of Marine 4 in Provincetown. Recreational boating, the fifth use, accounts for over 50% the total marine use parcels in Provincetown and its number did not change much over the study time period. Therefore, we dropped boating in the Provincetown models to show only the significant decline in parcels closely related to commercial fishing.

Table 8
Provincetown marine land use probability: logit estimates.

Variable	Model C Elasmobranchs and whiting (Marine 4)	Model D All species (Marine 4)	Model E All species (Marine 4)	Marginal probability[§]
Coefficient (p-value)				
Stock	0.0155* (0.0320)	–	–	0.15%
Quantity of landings	–	0.1312* (0.0177)	–	1.30%[a]
Value of landings	–	–	0.1739* (0.0295)	1.73%[b]
ln Area	0.6277** (<0.0001)	0.6286** (<0.0001)	0.6273** (<0.0001)	6.22%
Intercept	−7.5676** (<0.0001)	−6.4569** (<0.0001)	−6.8884** (<0.0001)	−74.99%
# of observations	612	612	612	
# of marine	78	78	78	
# of nonmarine	534	534	534	
Likelihood ratio test	29.23	29.87	29.03	

Variables are defined in Table 5. The stock variable is for elasmobranchs and whiting species groups. Quantity and value of landings variables used are for all species groups combined.

a Calculated using Model D.
b Calculated using Model E.
* against the reported coefficients denote significance at 5% significance level.
** against the reported coefficients denote significance at 1% significance level.
§ Marginal change in land use switch probability with respect to change in each independent variable based on Model C (unless otherwise noted) and calculated using Eq. (6).

For Provincetown, an increase in the sum of whiting and elasmobranchs stock by one kg/tow is associated with an increase in marine use probability by 0.15% (Model C). By contrast, an increase in the quantity of total landings by one million kilograms is associated with an increase in marine use probability by 1.3% (Model D) or by 1.7% probability when the value of total landings is increased by one million dollars (Model E). The marginal effect of the natural logarithm of area suggests that marine use probability rises on average by 6.3% when the log-scaled area measure is increased by one unit (Model C).

Based on all models for these two harbor areas, land use choice probability is primarily influenced by marine resource conditions, parcel size, and location (township). A waterfront parcel is more likely to be used for marine purposes when fishery resource conditions are good, if its area is large, and if it is in the city of New Bedford. In the New Bedford/Fairhaven Harbor, scallop stocks are major land use decision drivers. In Provincetown, biomass measures (stock abundance) of major species groups are important land use decision drivers but so are value and volume landed for all species groups combined. There is an approximate one percent (0.99%) increase in probability that a random parcel will be marine-related in New Bedford associated with a one unit increased in scallop stock. Scallop stocks did increase during the time period 1986–2006 in New Bedford. By contrast, the sensitivity to land use change in Provincetown is evidenced by model results that tells us that a one unit decrease in value landed of all species aggregated is associated with a 1.73% decrease in likelihood that the parcel will be marine related. In Provincetown annual average value of fish did in fact decrease during the study period (see Table 3).

New Bedford is a regional center for commercial fishing in New England. As a major fishing port, its fishing industry is more resilient. Furthermore, marine land uses in New Bedford are not subject to an easy conversion due to the Designated Port Area (DPA) status[9] existing for many of the parcels in the harbor. There is no DPA in the Provincetown Harbor study area (see Donovan, 2003; Portman et al., 2009). For New Bedford it appears that land use decisions are driven by long-term conditions, as reflected by fish biomass. By contrast, Provincetown is a minor fishing port which is vulnerable to market conditions. Its land uses seem to be affected by more short-term changes in fish harvesting.

The implications of these findings for land use policy are that additional controls will probably be necessary if policy makers intend to maintain marine-related land uses in Provincetown. Although planners' vision for the town includes the support for such uses (Executive Office of Housing and Economic Development, 2009), existing land use controls, such as those provided by the Massachusetts Waterways Regulation Program, are insufficient to counteract conversion pressures for such a vulnerable fishing port. The Designated Port Area status found to be significant in the New Bedford models (see Portman et al., 2009) would not be appropriate for Provincetown because it lacks marine-industry. Based on the findings of this study, if left to fluctuating market forces, marine related uses will continue to be lost in Provincetown. In both communities, carefully devised land use policy should accompany the significant efforts being made to rehabilitate fish stocks. It should ensure that current marine infrastructure will still be in place to support the fishing industry if and when species rebound.

Limitations

Above and beyond the models' results, this research implements a unique approach to gauging the extent of influence that marine resource conditions, particularly fisheries, have for land policy as it relates to maintaining fisheries industry infrastructure. However, the model has limitations worth noting for future research.

The period studied was limited to years of good extant data that could be compared between communities. While sufficient longitudinal spatial data is available for Provincetown from the Massachusetts Historical Commission Survey to expand the study time period,[10] equivalent spatial data for New Bedford Harbor and for the fisheries is lacking.

Using parcels as the unit of analysis has its limitations. The current methodology fails to account for intensity of parcel use. Large parcels may support uses only on a small portion of their area. A parcel may have different daytime and nighttime uses which the study does not account for. The study area in each of the three municipalities is determined differently. For Fairhaven the study is

9 In 1978 the Massachusetts Office of Coastal Zone Management created designated port areas (DPAs) in order to encourage use of coastal resources in a manner that is consistent with the federal Coastal Zone Management Act of 1972. There are 11 DPAs throughout Massachusetts which are implemented as overlay districts (bounded zones). 5 DPA regulations promote water-dependent marine industrial uses along working waterfronts.

10 If the study went back additional 16 years, to 1975, at least 10,642 m^2 of additional waterfront area would have been identified as converting from commercial fishing related uses. Additional identified changes occurred in the 1950s and 1960s.

limited by waterfront infrastructure—two large marinas, while in New Bedford major transportation infrastructure frames the study area. In Provincetown, parcels that converted in recent decades from marine use to residential use are captured on either end of the study area. These differences are partially a result of community character (e.g., in Provincetown there is no major transportation infrastructure). Although we believe that these boundaries allow us to capture parcels within the most active part of the working waterfront, parcels included or excluded from the study area might skew the results.

Another issue not addressed is that of spatial lag. Such a spatial lag or "error" would suggest a diffusion process whereas uses in one parcel would predict an increased likelihood of similar events in neighboring lots. There may be a tipping point, whereas once the minimum infrastructure needed for supporting any size of home fishing fleet is not present or existing infrastructure declines (for example the last ice facility leaves the harbor) a sudden shift in land use away from marine uses would be detectable. Similar thresholds have been suggested in relation to other land use transitions such as natural to traditional rural landscapes (e.g., Lambin and Meyfroidt, 2010), rural to urban (e.g., Marull et al., 2010) and processes of gentrification (e.g., Amit-Cohen, 2005). Further testing for such a threshold or spatial lag is needed.

Other limitations to the methodology have to do with spatial data collection methods, particularly in relation to identifying land use data from key interviewees. There are of course, memory lapses and interviewees had difficulty disassociating what they saw in background 2005 orthophotos on the maps presented to them and the past uses they were asked about. Some of these problems could be avoided by using detailed street information instead of orthophoto background from a specific year.

From the use of this methodology we discovered the need for flexibility in collecting the data in different localities and from a number of different sources for cross-reference. It would be helpful to examine how public infrastructure investment has helped or hindered the maintenance of marine-related land use in the study areas. Although this is a fine-tuned analysis at the parcel-level, we make assumptions about where fishermen and landed fish are going. Do the fishermen that leave Provincetown fish exclusively in areas where stock abundance is monitored by NMFS? Are all or most of the fish landed in New Bedford processed in New Bedford? To answer these questions, further research is needed.

Discussion and conclusions

Our findings confirm that efforts to conserve and maintain wild fish stocks should be accompanied by efforts to protect the spatial make-up of fishing communities. Furthermore, from the models developed we can gauge how changing marine resource conditions will influence *different* types of fishing communities and where changes in land use policy will be most influential. New Bedford Harbor is a regional center for commercial fishing in New England. As a major fishing port and with land use protections in place including two regulatory programs that protect water-dependent and marine-industrial land uses (see Portman, 2006; Portman et al., 2009) it is less vulnerable to changes; marine land uses are not subject to easy conversion. Based on the models we have developed land use decisions are driven by long-term profitability, influenced by fish stocks. By contrast Provincetown is a smaller fishing port affected by short-term changes in fish harvest as reflected in volume and value landed. These disparate observations coincide with recommendations that analyses of the fishing sector should differentiate between fisheries' activities (i.e., landings) and fisheries' resources (i.e., abundance) (e.g., Massachusetts Ocean Plan Fisheries Workgroup, 2009).

Provincetown, with some pre-existing disadvantages such as limited accessibility and little diversification in the harvesting sector, is more likely to experiences conversions away from marine-related uses. This suggests that with a decline in fish stocks, regional contraction in the fisheries industry will most likely start from smaller ports, as they are more susceptible to change. Such decreasing marine-related infrastructure is frequently described as loss (Goodwin, 1988; Donovan, 2003; Bergeron et al., 2005; Hall-Arber et al., 2006), presumably because of its irreversibility and as such, a sign of vulnerability.

Noting the broad use of the central concept of vulnerability in a variety of contexts including land use and sustainability science, Füssel (2007) identifies dimensions that are fundamental to the definition of vulnerability for research. These include attributes of concern. For studies of the human–environment interdependence in the fisheries context, vulnerability refers to attributes of concern in the realm of economics (e.g., capital and infrastructure) and in community identity and traditions (Hall-Arber et al., 2006). Spatial make-up of a community is related to all of these.

Although it is clear that the discourse of fisheries science and management must integrate human communities' identity and culture, scientists and policy experts are frequently at a loss as to how to accomplish this. In an article addressing this topic, Martin (2006) bemoans the relegation of the term "fishing community" to a third world concept of the isolated rural village. He advocates that communities must be found and analyzed relative to fisheries using some standard methods in the industrial Northeast of the US. These would help break down the divisions existing that separately place management of off-shore fisheries resources in the domain of bioeconomics and on-shore fishing communities in the domain of anthropology. According to Martin (2006), "communities are everywhere".

Also, empirical analyses of spatial changes in fishing ports of different types and locations with different levels of vulnerability are important for developing land use policy as species' biomass and landings fluctuate. Tuler et al. (2008) points out how driving forces of vulnerability are different between locations and attention to these differences offers policy makers opportunities to proactively consider the effects of management alternatives. In their work on New England fisheries Hall-Arber et al. (2006) propose:

> "... understand[ing] human-environmental interactions as shaped and transformed by various forms of capital in their interface with large-scale marine ecosystems .... Communities are not viewed in isolation, but are defined internally through social, ethnic, and historical ties and externally through networks of regional and extra-regional total capital flow. Capital—tangible or intangible resources that contribute to the long-term adaptation of a person, group, or population—is used here in the broadest sense to include human, social, cultural, biophysical, and economic transformations. . .." (Hall-Arber, 2006, p. 6)

Up to now, many analytical methods treating the human-environment interdependence within the fisheries context in the Northeastern US have been qualitative and internally defined (e.g., Kaplan, 1999; Olson, 2006). Those identifying the socio-economic influences of vulnerability such as specific economic stressors are highly dependent on qualitative analysis of stakeholders reporting their perspectives (e.g., Marshall and Marshall, 2007; Tuler et al., 2009). Improved fisheries and land use management can be advanced by quantitative studies that empirically examine environmental and socio-economic data together. Further relating these to institutional arrangements including regulatory programs aimed at stock rebuilding or land use controls is also helpful. A next step for this research would be to look at several ports in a regional context purposely including those that do and do not have land use conversion controls and to add additional elements as variables in the models. For example, added elements could reflect regulation of fisheries off the New England coast such as the closure of scallop beds as these occur throughout the study time period or restrictions on the culling of groundfish.

In this study we identified elements of community–fisheries system changes as reflected in land use along waterfront ports and present a methodology. We surmise that relationships between the described elements of fisheries and land use are measurable, yet they clearly make up part of more complex systems that remain to be better understood. In any case, this type of quantitative empirical analysis can inform integrated coastal land use policy and ecosystem-based resource management approaches. Moreover, this type of land use tracking and statistical analysis can be adapted to examine other cases; for example, if and how conservation measures targeted at rebuilding endangered species' populations are reflected in unintended ecotourism-related land use change.

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