Human use characterization and visualization in marine spatial planning efforts in the Northeast

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Abstract— *Comprehensive ocean planning must account for the diversity of human uses that converge in coastal waters and their potential impacts on marine ecosystems. Ocean plans have been developed at the federal, regional, and state level to address these issues; however, the under-documentation of human activities has hindered the ocean planning process. SeaPlan, an independent non-profit ocean science and policy group, has worked to address these data gaps through projects focusing on collecting and visualizing human use data. One project developed a cumulative impact model and maps by combining spatial data on environmental stressors and ecosystem distribution and expert opinion on ecosystem vulnerability, characterize the intensity of impacts in Massachusetts waters. The analysis revealed that areas near the coast and along major shipping routes were highly impacted from the co-occurrence and intensity of multiple uses and the vulnerability of underlying habitats. One outcome of this assessment was an identified need to improve and develop robust data on recreational ocean uses. This informed the development of a statewide and a regional recreational boater survey informed by extensive stakeholder outreach. Recreational boaters reported on their boating expenditures and mapped their boating activity using an interactive mapping application. The results of these surveys revealed a high concentration of boater routes near the coast, and identified fishing as the most popular activity associated with recreational boating. To increase the utility of these datasets in the ocean planning process, SeaPlan has contributed to the development of the Massachusetts Ocean Resource Information System (MORIS), and the Northeast Ocean Data Portal, which contain downloadable datasets and interactive mapping tools relevant to ocean planning in Massachusetts and the Northeast. Characterizing and mapping human uses allows managers to visualize the potential impacts of human activity in the ocean environment and to identify areas of special concern. These projects represent the first time these particular data types are quantified and visualized on a state or regional scale. Stakeholder and expert engagement, filling data gaps on human uses, and developing interactive mapping technologies have allowed us to provide necessary datasets and tools which improve the marine spatial planning process in the Northeast.*

Keywords—*coastal and marine spatial planning, human use characterization, spatial data, recreation, environmental impacts*

I. Introduction

Coastal and marine environments support an increasingly diverse array of human uses, including recreation, tourism, aquaculture, energy and commerce. As these uses continue to emerge and expand, it becomes increasingly difficult for ocean managers to minimize conflicts between user groups while upholding conservation objectives. These issues are now being addressed at federal, regional and state levels. At the federal level, the National Ocean Policy (NOP) establishes a policy imperative to "respect and preserve our Nation's maritime heritage, including our social, cultural, recreational and historical values" and provides a framework for developing a coastal and marine spatial planning (CMSP) process, which it defines as a "comprehensive, adaptive, integrated, ecosystem-based and transparent spatial planning process, based on sound science, for analyzing current and anticipated uses of ocean, coastal and Great Lakes areas"[1]. The NOP also led to the formation of nine regional planning bodies to address ocean planning and data needs based on geography and existing efforts in a region. On a state level, the Massachusetts Ocean Management Plan puts forth a goal to "balance and protect the natural, social, cultural, historic, and economic interests of the marine ecosystem through integrated management" [2].

Balancing the needs of multiple ocean users while protecting critical ecosystems and enhancing the sustainability of coastal and marine economies is a common goal among these ocean management plans; however, the issue of accounting for multiple human uses and other stressors and their linkages with marine ecosystems has hindered the ocean planning process, especially given the under-documentation of human activities. SeaPlan, an independent non-profit ocean science and policy group, has worked to address these data gaps through a series of projects focusing on collecting and visualizing human use data for the purposes of comprehensive and integrated marine spatial planning.

In one such project, SeaPlan partnered with scientists based at the National Center for Ecological Analysis and Synthesis (NCEAS) to produce a cumulative impact model.[1] Cumulative impact models account for the additive effects of anthropogenic stressors on ecosystem health, rather than examining individual impacts on a sector-by-sector basis. The

The Gordon and Betty Moore Foundation provided funding for these projects. The Maine Coastal Program provided additional major funding for the 2012 Northeast Recreational Boater Survey.

[1] See the technical report for further details. C. V. Kappel *et al.*, "Mapping Cumulative Impacts of Human Activities on Marine Ecosystems," SeaPlan, Boston, MA, Tech. Rep. #03.NCEAS.12, Jan. 2012. Available at: http://www.seaplan.org/wp-content/uploads/mapping_cumulative_indicators-nceas-12.pdf

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project team designed the project using a framework developed NCEAS-based scientists to support the development and implementation of the Massachusetts Ocean Management Plan by filling two major data gaps. First, in order to understand ocean use compatibilities, we gathered comprehensive information on the relative vulnerability of marine ecosystems and habitats to as many human ocean uses as possible. Second, we developed spatial data and visual representations of the cumulative impacts of human activities which had been previously unavailable to ocean managers.

The overall cumulative impact analysis and resultant data products combine ecosystem vulnerability, ecosystem distribution, and intensity of human stressors, using a method which has been vetted at a global [3] and regional scales [4, 5]. Together these data products provide insight into which types of ecosystems and places are most vulnerable and which human uses, alone and in combination, are putting the most stress on marine ecosystems in the waters off Massachusetts. Although the analysis focused on Massachusetts and its surrounding waters, the framework was designed to be flexible, transparent, and easily updateable, and represents a tool that could be applied at larger geographic scales.

One outcome of the cumulative impact assessment and the Massachusetts Ocean Management Plan completed in 2009 was an identified need to develop data on recreational ocean uses. This is a sector where little to no data had previously existed but which represented an important human use to consider in the planning process. Specifically, the plan recognized recreational boating as an activity with "significant actual and prospective conflicts among multiple waterway uses in Massachusetts". It further recognized that the economic value of recreational boating was a key socio-economic indicator which could be used to inform ocean planning [2].

The lack of statistically robust data on recreational boating activity led to the development of a statewide and a regional recreational boater survey. For the 2010 Massachusetts Recreational Boater Survey,[2] SeaPlan (then the Massachusetts Ocean Partnership) worked with a team led by the Urban Harbors Institute (UHI) of the University of Massachusetts (UMass) Boston. This statewide survey aimed to gather temporal, spatial and economic data on recreational boating to supplement existing but limited local knowledge using scientifically-accepted social science survey methodologies and advanced participatory mapping technologies.
The success of the Massachusetts survey and the establishment of a the Northeast Regional Planning Body which coordinates ocean planning efforts throughout New England led to the launch of the 2012 Northeast Recreational Boater Survey,[3] which applied the methodology of the 2012 survey at a regional level. The 2012 survey included registered boaters in Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, and New York and aimed to capture more comprehensive region-wide information on boater routes, economic impacts, types and locations of boating-based recreational activities, demographic information on the boating community, and boaters' opinions on boating-related topics.

To increase the utility of these datasets in the ocean planning process, SeaPlan has played a role in projects which display these and other ocean datasets using an interactive tool interface. SeaPlan worked with MA CZM and the Massachusetts Office of Geographic Information (MassGIS) to develop the Massachusetts Ocean Resource Information System (MORIS)[4], which contains the datasets used to develop the Massachusetts Ocean Management Plan. Similarly, SeaPlan works with the Northeast Regional Ocean Council (NROC), The Nature Conservancy (TNC), Applied Science Associates (ASA), National Oceanic and Atmospheric Administration Coastal Services Center (NOAA CSC), and the Northeast Regional Association of Coastal Ocean and Observing Systems (NERACOOS) to maintain and develop data for the Northeast Ocean Data Portal,[5] which contains datasets related to ocean planning covering the Northeast region.

II. Methods

Cumulative impacts

We modeled cumulative impacts by looking at the relationship between 21 human stressors and 15 marine ecosystem types. The study team defined 58 current and emerging human stressors based on their previous work. A stressor is defined as anything that may perturb an ecosystem beyond its natural limits of variation. However, as spatial data for all 58 stressors were not available, we synthesized, aggregated, and in some cases modeled a wide array of data to produce 21 human stressor data layers that represent many of the most important human uses in the waters off of Massachusetts for use in this analysis.

We modeled stressors using a variety of data sources and techniques. The data sources and approaches are summarized in Tables 1 and 2. The impact that a stressor has on a given ecosystem depends on the ecosystem vulnerability. Vulnerability is dictated by the probability of exposure to a

[2] See the technical report for further details. D. Hellin *et al.,* "2010 Massachusetts Recreational Boater Survey," SeaPlan, Boston, MA, Tech. Rep. #03.UHI.11, Jun. 2011. Available at http://www.seaplan.org/wp-content/uploads/2010_massachusetts_recreational-tr-uhi-11.pdf

[3] See the technical report for further details. Report available in August 2013 at http://www.seaplan.org/project/2012-northeast-recreational-boater-survey/

[4] http://www.mass.gov/eea/agencies/czm/program-areas/mapping-and-data-management/moris/

[5] http://www.northeastoceandata.org/

TABLE 1. SOURCES OF LAND-BASED STRESSOR DATA USED IN THE CUMULATIVE IMPACTS ANALYSIS

	Stressor Type	Stressor	Metric	Source	Data Provider	Key processing steps
Land Based Stressors	Pollution	Upstream Farming	Nitrogen Input	County-level fertilizer application data	USGS	Aggregated by watershed; assigned to coastal pour points; applied least cost path diffusive plume model
		Sewage Input		Wastewater treatment plants	EPA	
				Combined sewer overflow locations	MWRA	
				Sewage outfall diffuser pipe locations	MWRA	
				Modeled septic system discharge	US Census	
		Atmospheric Deposition		Nitrate and ammonium deposition measured at recording stations	National Atmospheric Deposition Program; EPA Clean Air Status and Trends Network	
		Organic point-source pollution	Organic chemical input	Known surface water discharges of organic chemicals	EPA Toxic Releases Inventory	
		Organic non point-source pollution	Pesticide loads	Modeled pesticide application rates	Coastal Change Analysis Program; National Pesticide Use Database	
		Inorganic point-source pollution	Heavy metal releases to surface waters	Point source release	EPA's Toxic Releases Inventory	
		Non-point source pollution	Heavy metal releases to surface waters	Impervious surface data used as proxy	National Land Cover Database	
		Atmospheric pollution	Atmospherically derived pollutant input	Wet and dry atmospheric deposition of sulfate as proxy for other atmospherically derived pollutants	National Atmospheric Deposition Program; EPA Clean Air Status and Trends Network	
		Light pollution	Light seen in coastal ocean pixels	Light pollution from coastal development	NOAA Stable Lights at Night database	
		Marine debris	Average annual weight of trash	CoastSweep beach clean-ups	MA CZM	Data summarized by county and distributed evenly along county shorelines
	Coastal infrastructure	Entrainment plumes	Scale and impact of plume	Power plant locations	EPA Facility Registry System	3 km buffer applied to each location
		Hardened shorelines	Adjacency to impacted shoreline	Locations of human-modified shorelines	NOAA Environmental Sensitivity Index	Ocean pixels next to coastal engineering shoreline types classified as impacted

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	Stressor Type	Stressor	Metric	Source	Data Provider	Key processing steps
Ocean Based Stressors	Seafood Harvests	Aquaculture	Shellfish bed locations	Derived from Google Earth 2009 Images	Stone Environmental, MA DMF, MA Department of Agricultural Resources, coastal town shellfish authorities	
		Fishing	Average annual landings	Catch data from statistical reporting areas (SRAs); Vessel Trip Reports (VTRs); Marine Protected Areas	MA DMF; NOAA NMFS; National Marine Protected Areas Center's Marine Managed Areas Inventory	Analysis applied to five categories of commercial fishing: pelagic low-bycatch, pelagic low-bycatch, pelagic high-bycatch, demersal habitat modifying, demersal non-habitat modifying low-bycatch, and demersal non-habitat-modifying high bycatch
	Climate Change	Sea Surface Temperature (SST) anomalies	Weeks when average SST or UV radiation exceeded long-term standard deviation in average SST or UV radiation for a given location and week of year	Advanced Very High Resolution Radiomater (AVHRR) Pathfinder Version 5.0 SST Time Series 1985-2005	NOAA	Global dataset clipped to Massachusetts study region
		UV radiation anomalies		GSFC TOMS EP/TOMS satellite program	NASA	
		Ocean acidification	CO_2 concentrations	Modeled change in aragonite saturation state from pre-industrial times to modern times at each location used as proxy	Guinotte et al. 2003	
	Pollution	Commercial vessel traffic	Organic and inorganic pollutants	Commercial vessel traffic from AIS (Automatic Identification System) used as proxy	USCG, Applied Science Associates (ASA)	Linear decay rate applied to tracks > 25km from shore; 1km buffer applied to vessel tracks
		Ports	Pollutants	Port locations used as proxy	USACE Principal Port file	Pollutant spread modeled using a diffusive least cost path surface model
	Invasive species	Introduction and spread of invasive species	Invasive spread	Port volume used as proxy for potential of invasive species introductions	USACE Principal Port file	Invasive spread modled using a least cost path surface model
	Commercial Vessel Traffic	Noise and light pollution; direct impacts (e.g. vessel strikes)	Average annual density of ship tracks	AIS and ferry route data	USCG, ASA, MA Executive Office of Transportation, Office of Transportation Planning	Linear decay rate applied to tracks > 25km from shore; 1km buffer applied to vessel tracks
	Tourism	Whale Watching	Average number of transits by whale watching vessels per grid cell	Aggregated GPS data points from 2003 - 2004 Whale Watching Guidelines study and 2008-2009 Whale Watching tracks by USCG Auxiliary	Stellwagen Bank National Marine Sanctuary	Number of transits per port normalized by research effort

stressor, the sensitivity of the ecosystem to the stressor, and the resilience of the ecosystem following the stressor [6].

Regional experts with experience studying each ecosystem or habitat type responded to a structured survey in which they were asked to assess an ecosystem's vulnerability to a list of stressors using five vulnerability criteria: spatial scale in km^2 of a single occurrence of the stressor, frequency in days per year that the stressor occurs at a given location, trophic impact from single species up to entire community, percent change in biomass of the affected ecosystem component, and recovery time in years required for the ecosystem to return to natural conditions [7].

We modeled cumulative impacts at each location in a 250 m raster grid by adding up the combined impacts of human stressors, weighted by the average vulnerability of the ecosystem(s) found in the location of each stressor. The model runs in the open source GIS software GRASS v. 6.3 and the maps were produced using ArcGIS. To create the cumulative impact maps, we combined ecosystem vulnerability and human stressor intensity scores with spatial information on ecosystem distribution to create a cumulative impacts map as well as other stressor-specific maps.

Recreational boating

In both the 2010 and the 2012 surveys, we used boater registration data from each state to recruit survey participants, screening for eligibility by targeting boaters in coastal counties that were using their vessels for recreational purposes, had vessels that were over 10 feet in length, had a principal mooring area or hailing port in the Northeast, and did the majority of their boating in saltwater. Based on the number of eligible boats, we selected a random sample of boaters to invite to the surveys. In 2010, of the 10,000 boats to participate in this study, 22% responded. We had a similar response rate in 2012, where 18.5% of the 68,000 invited boaters participated. In both studies, survey participants completed both monthly surveys from May through October, describing their last trip of the season, as well as an end of season survey which asked for feedback on the survey instrument, estimates of yearly boating expenditures and opinions on relevant boating topics. In each monthly survey, participants used an online mapping application designed by EcoTrust to plot their routes, and identify locations where boating-related activities (i.e. swimming, fishing, etc…) took place.

We imported the spatial data into ArcMap, where we plotted the route data and activity data, clipped to the region of interest and to exclude routes and points drawn in error over land or in freshwater. Using the route data, we also created an interpretive map product highlighting areas of high densities and low densities of boater routes, using the line density tool. The results were three map types, one which displayed boater routes, one which showed the locations of activities (both aggregated and separated by activity type), and one which showed boater route density. The study team used statistical methods to analyze demographic information and the Impact analysis for PLANning (IMPLAN) economic model to develop economic impact assessments.

Stakeholder engagement was also an integral component of these projects. An advisory group which included representatives from boating organizations throughout the states and other stakeholder groups informed the study design and development of surveys, facilitated data access, encouraged boaters to participate, reviewed results, and disseminated results to the boating community.

III. RESULTS

Cumulative Impacts

Expert judgment identified coastal and offshore benthic habitats, specifically hard bottom shelf, nearshore soft bottom, soft bottom shelf, algal zone, nearshore hard bottom, and tidal flats to be most vulnerable to human impacts in this region. Top stressors and threats to New England marine ecosystems include climate change impacts from rising ocean temperatures and ocean acidification, invasive species, increased ultraviolet radiation exposure, and ocean pollution.

Not surprisingly, this analysis revealed that the areas near the coast had the highest potential cumulative impacts [Fig.1] In these areas, there were as many as twenty and no fewer than five different coincident anthropogenic stressors over the course of the year. Areas with the highest cumulative impacts occur in generally results from the co-occurrence of multiple uses, the high intensity of those uses and stressors, and the relatively high vulnerability of underlying habitats. Maps of individual stressors and stressor subsets reveal differences in the spatial footprint of various stressors, especially those that occur on a watershed level, such as land-based pollutants compared to the more widespread impacts of climate change [Figs. 2, 3].

Recreational Boating Use Characterization

In both the 2010 and 2012 surveys, route and route density maps revealed that the highest amount of boating activity took place close to the coast. In the 2012 survey, route maps and the density analysis also revealed areas of high boating activity close to ports and in semi-protected bays and harbors, and along major transit results throughout the northeast (Figs. 4, 5).

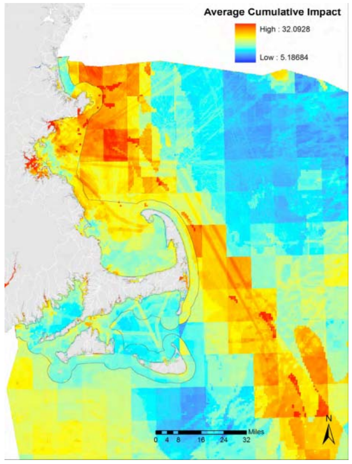

Fig. 1. Average cumulative impacts of human stressors on marine ecosystems

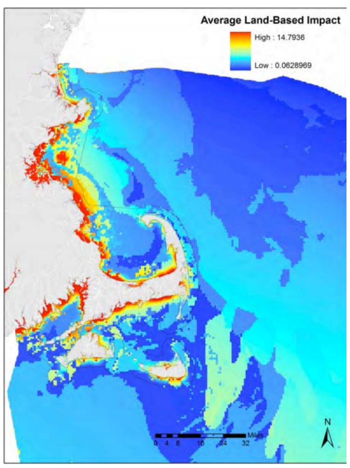

Fig. 2. Average land-based impacts of human stressors on marine ecosystems

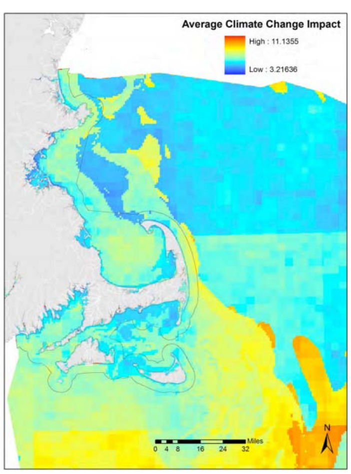

Fig. 3. Average climate change impact on marine ecosystems

In both the 2010 and 2012 survey, survey participants identified fishing as an activity taking place during boat trips more than any other activity. The 2012 survey results highlight important areas for different boating-based activities, as well as specific types of fish targeted and species of wildlife viewed. In some cases, hot spots coincided with well-known fishing grounds and wildlife viewing locations, such as Jeffreys Ledge and Stellwagen Bank (Fig. 6).

Survey results demonstrate that recreational sport fishing was the predominant activity in the region and in each state, except in Maine where other activities such as wildlife viewing and relaxing outnumber fishing. The survey also confirms the iconic status of Striped Bass as a premiere sportfishery in the Northeast. Boaters most commonly targeted Striped Bass (*Morone saxatilis*) while fishing in state waters. Outside of Northeast state waters, boaters primarily targeted Atlantic Cod (*Gadus morhua*) and Haddock (*Melanogrammus aeglefinus*).

Economic results from the 2010 survey show a $529 million contribution to the economy, although this should be considered an underestimate, as it doesn't include expenditures from out of state boaters. The 2012 survey was able to capture spending on a regional level, estimating a $3.5 billion contribution to the Northeast economy.

IV. DISCUSSION

The cumulative impacts project revealed that most coastal areas in Massachusetts are impacted by a number of human uses. While this project was a significant first step in describing the interactions of multiple human activities on coastal and marine environments, it excluded a number of potential stressors due to a lack of data. The 2010 and the 2012 recreational boater surveys attempted to fill one of those gaps on both a state and regional level. Both projects provide a framework for developing improved quantitative understanding of the extent and impact of human uses in coastal and ocean environments. The cumulative impacts project highlights the need for comprehensive data on regional human-uses affecting the ocean, and the recreational boater surveys provide a framework that can be applied to other under-documented uses such as characterizing a known data gap in the spatial extent of recreational fishing activities. Future cumulative impact models or similar studies could incorporate these improved human use datasets to better characterize the impact of recreational uses on coastal and marine ecosystems.

Characterizing and mapping human uses allows managers to visualize the potential impacts of human activity in the ocean environment and to identify areas of special concern. These projects represent the first time these particular data types are quantified and visualized on a state or regional scale. By engaging experts and stakeholders into

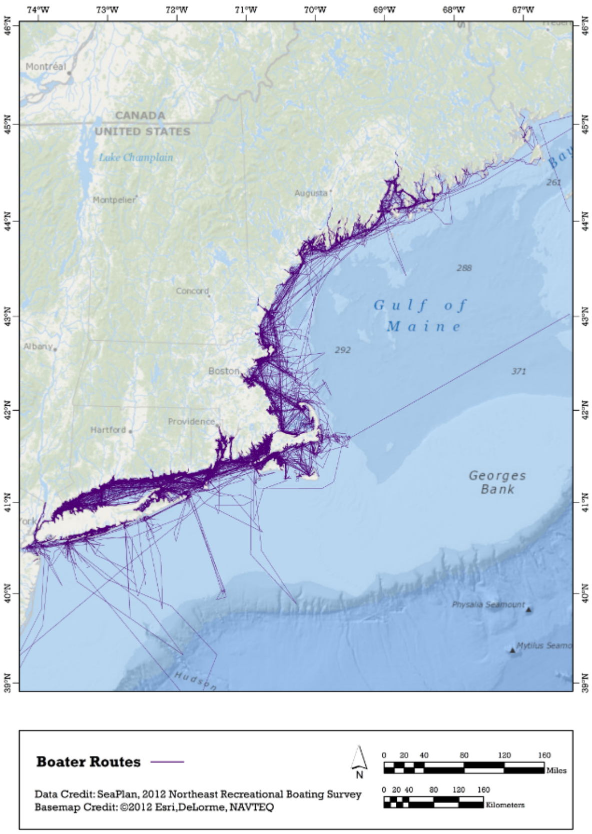

Fig. 4. 2012 mapped recreational boater routes

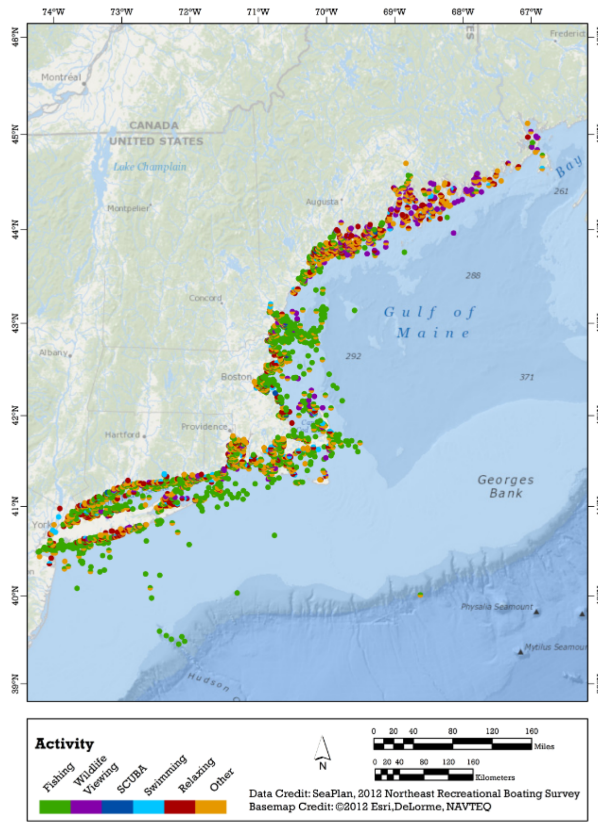

Fig. 6. 2012 recreational boater activities

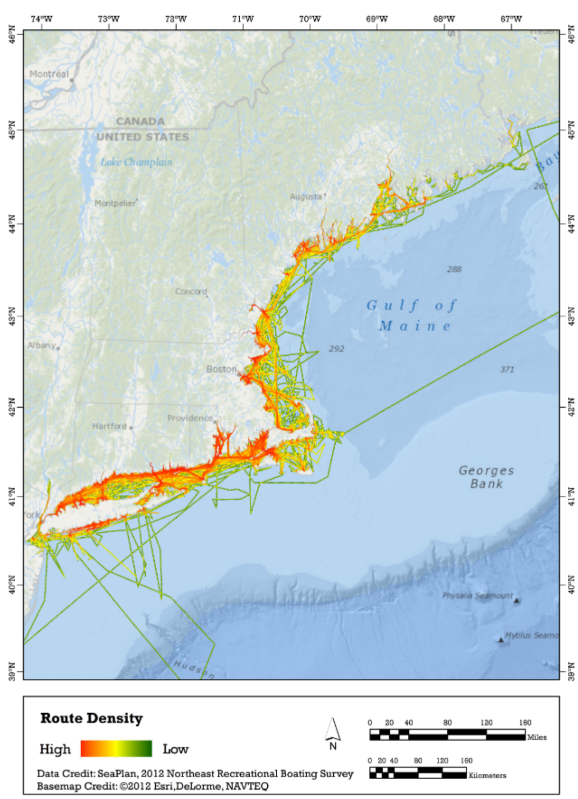

Fig. 5. 2012 recreational boater route density

project design and implementation, filling in the data gaps on human uses, using advanced participatory mapping technologies to visualize these datasets, we provided necessary tools and datasets to improve the marine spatial planning process in the Northeast.

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