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Use of ship traffic density from Automatic Identification System (AIS) and Vessel Monitoring Systems (VMS) in marine spatial planning: a case study in New England coast, USA

Yong Hoon Kim*, Eoin Howlett*, Jin Hwan Hwang**, and Young Gyu Park***

ABSTRACT

Analyzing current and anticipated uses of ocean and coastal areas based on scientific understanding and information is quite critical to achieve a successful Marine Spatial Planning (MSP). One of key elements in ocean and coastal use is navigation and thus vessel traffic density should be included as part of MSP. One of emerging techniques to quantify ship traffic density is to analyze Automatic Identification System (AIS) and Vessel Monitoring System (VMS) data for a designated area. This study presents a case study conducted in New England area, USA, where the ship traffic density was estimated by analyzing AIS/VMS data. The results of ship traffic density were used in MSP (e.g., Northeast Ocean Data Portal), which were later used by one of stake holders, U.S. Department of Interior, Bureau of Ocean Energy Management when they issued wind lease blocks in outer continental shelf off Massachusetts.

Key words: ship traffic density, ocean planning, environmental assessment, decision making

* Oceanography Division, RPS ASA, South Kingstown, RI, USA
** Department of Civil and Environmental Engineering, Seoul National University, Seoul, Korea
*** Ocean Circulation and Climate Research Division, Korea Institute of Ocean Science and Technology, Ansan, Korea. Corresponding Author, ypark@kiost.ac

1. Introduction

Marine resources are common property resources with open or free access to users. Human uses of the ocean and coasts are expanding at a greater rate, so that our capability in managing and planning them under the conventional sector-by-sector approach has been challenged. Recently, the concept of Marine Spatial Planning (MSP) was introduced to make decisions on how to use marine resources in more efficient, sustainable and ecosystem-based way (Crowder et al., 2006; Douvere, 2008; Dalton et al., 2010; Foley et al., 2010). MSP is a comprehensive, adaptive, integrated, ecosystem-based, and transparent spatial planning process, based on sound science, for analyzing current and anticipated uses of ocean and coastal areas (The White House Council on Environmental Quality, 2010). In MSP, scientific understanding and information are critical to achieve an integrated planning process (Foley et al., 2010).

In MSP, multiple anthropogenic uses including transportation, fishing, and aquaculture should be managed in a manner that reduces conflict and enhances compatibility among uses with sustained ecosystem functions. Ship traffics affect the environments in various ways including risk of collisions, spill of oils, and noise (Hatchet et al., 2008; Perez et al., 2009). For instance, the United Nations International Maritime Organization (IMO) shifted shipping lanes near the Boston Harbor in the USA based on scientific investigation of whale feeding behavior and habitat mapping, which reduces the risk of collisions with critically endangered right whales by an estimated 58% and all other baleen whales by 81% (NOAA National Marine Sanctuaries, 2009). Thus, in addition to studying marine ecosystem, understanding marine transportation system would be one of key elements in setting up MSP.

Among the numerous ways in quantifying ship traffics, the analysis of the Automatic Identification System (AIS) and Vessel Monitoring System (VMS) data is one of emerging techniques (Santos et al., 2012). AIS is an autonomous and continuous broadcast system that transmits electronic data including vessel identification, position, speed and course etc. VMS uses Global Positioning Systems (GPS) in conjunction with shipboard sensors to automatically exchange navigation information electronically. In this study, AIS and VMS data are analyzed to estimate ship traffic density, which later would be used to set up a MSP. Our goal is to present a case study showing how to quantify ship traffic density from AIS and VMS data in the New England area, USA and how this ship traffic density can be used in MSP. Sensitivity of grid resolution when analyzing AIS and VMS data is also discussed in the paper. Chapter 2 describes the data used in the present study. The data analysis method and main results can be found in the following chapter. Chapter 4 shows some sensitivity results depending on temporal and spatial data analysis grid. Finally, how these ship traffic analysis results were utilized in setting up MSP is included in Chapter 5.

2. Data sets

As part of international security regulations, most commercial marine vessels are required to install the Automatic Identification Systems (AIS). The International Maritime Organization (IMO) requires AIS to be fitted aboard passenger ships carrying more than 165 passengers and commercial vessels with gross tonnage of 300 or more and (IMO, 1974). The AIS is used by marine vessels in coordination with Vessel Traffic Services (VTS) to monitor vessel location and movement primarily for traffic management, collision avoidance and other safety applications.

AIS transmitters send data at least every 2 seconds while underway and every 3 minutes while vessels are at anchor. AIS binary message includes time stamp (to nearest second), longitude and latitude (to 1/10,000 minute), position accuracy, speed over ground (0.1 knot resolution), course over ground (to 0.1 degree), true heading, and others (Table 1). In addition, the following data are broadcast every 6 minutes: IMO's ship identification number, vessel name, ship information including type, dimensions, and draught, destination and estimated time of arrival (ETA).

Table 1. Typical data elements received from AIS

Attribute	No. of bits	Description
Message ID	6	Identifier for this message 1, 2, or 3
Repeat indicator	2	Used by the repeater to indicate how many time a message has been repeated
User ID	30	MMSI number
Navigational status	4	Under way using engine, at anchor, not under command, restricted maneuverability, constrained by her draught, moored, aground, engaged in fishing, under way sailing, etc.
Rate of turn	8	±127°
SOG	10	Speed over ground in 1/10 knot steps
Position accuracy	1	High (<10 m) vs. low (<10 m)
Longitude	28	Longitude in 1/10,000 min (±180°)
Latitude	27	Latitude in 1/10,000 min (±90°)
COG	12	Course over ground in 1/10 °
True heading	9	0-359°
Time stamp	6	UTC second when the report was generated
Reserved for regional applications	4	Reserved for definition by a competent regional authority
Spare	1	Not used
RAIM-flag	1	Receiver autonomous integrity monitoring flag of electronic position fixing device
Communication state	19	Communication state

The AIS data used in this study were provided by NOAA Gerry E. Studds Stellwagen Bank National Marine Sanctuary. Five receiving stations were operated by the US Coast Guard, located at Boston, Gloucester, Scituate, and Provincetown, Massachusetts, USA as well as on Fishers Island, New York, USA. The majority of the data used in this study is from the period between September 1, 2007 and August 31, 2008, but data from other period were also analyzed for the comparison purpose.

In addition to AIS data, data from Vessel Monitoring Systems (VMS) are used in the analysis. VMS is utilized by commercial fishing vessels, and thus supplementary to AIS data. It only provides time, position, speed and course via long-range radio technologies. VMS can be a good supplementary data set of AIS, since it is required to be installed even in vessels less than 300 gross tonnes.

3. Analysis of AIS and VMS data

Archived AIS data were extracted and decoded by AISparser® (http://www.aisparser.com). Binary AIS data were reformatted into comma separated files, and passed onto Matlab® for further analysis. VMS data were saved already in Oracle database, so just exported into comma separated format and then loaded onto Matlab. In Matlab, the chronologically-ordered continuous data from both AIS and VMS sources were rearranged as for vessel order based on ship identification number. For each vessel, the location data were saved along with time stamp and sorted into chronological order, resulting in a vessel’s transit.

The location data was then divided into each track line based on time. In our analysis protocol, it is regarded as a separate track line when the time between two consecutive points is longer than 6 hours. AIS data was temporally dense enough to be used for analysis, while the VMS data were sparse so that temporal interpolation was necessary. When the points between two consecutive locations in VMS data were longer than 10 minutes, the data points were interpolated for every 5 minutes. For example, Figure 1 shows a track line of SHIP ID #3353 on the date of March 5, 2008. Black crosses represent the raw data, and red dots are for 5-min interpolated locations. When it had slow speed, the dots could make a line in the main plot but could be seen better in the inset plot. As seen in the zoomed-in box of Fig. 1, this vessel came down from North and stayed along 41.5°N line for hours, and then went out to east direction.

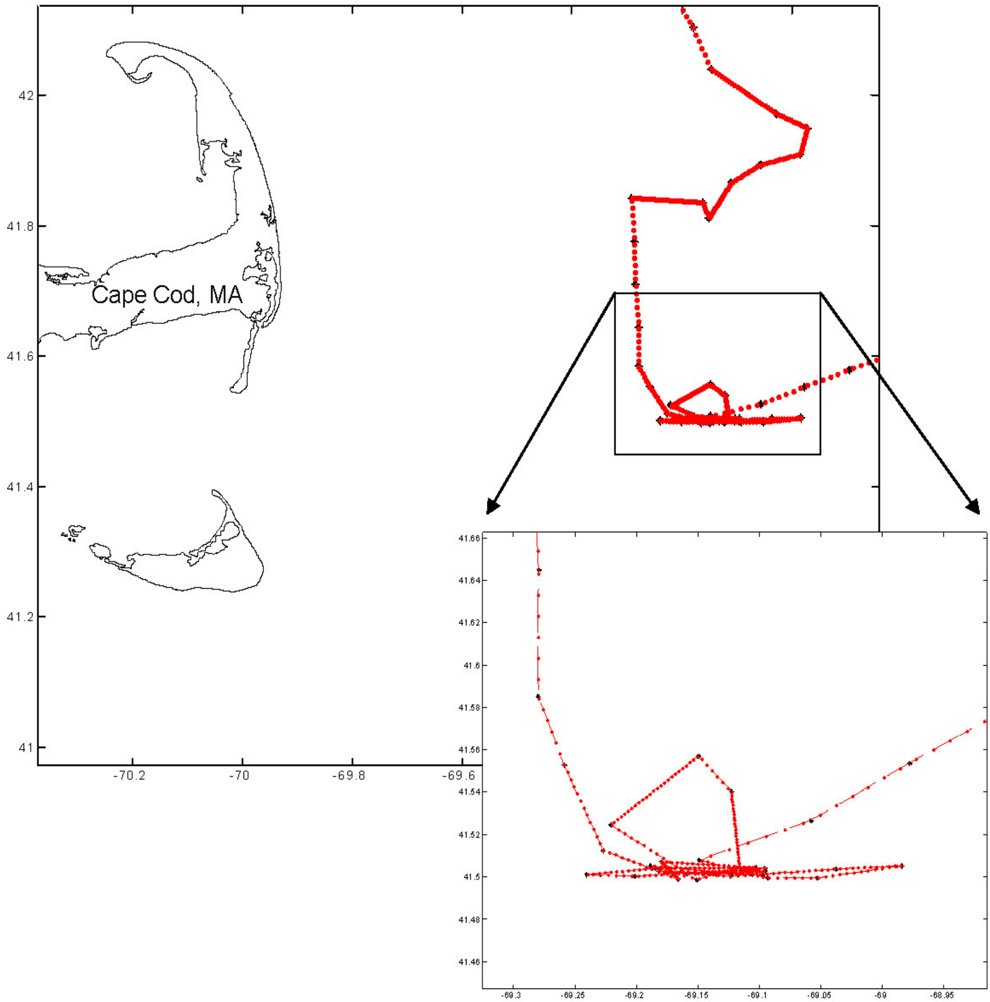

Figure 1. A track line of SHIP #3353 for March 5, 2009 trip. Black crosses represent raw data points and red dots are 5-min interpolated points.

Figure 2a shows all the raw positioning data recorded in VMS for SHIP #3353 between Jan. 2004 - Sep. 2008, which is a total of 17,522 points. The vessel transmitted the location info to the VMS roughly every 30 minutes in this particular vessel. For the analysis, only a year of data set (Sep. 1, 2007 - Sep. 1, 2008) was utilized (see red dots in Fig. 2b). One may note that this vessel spend most of time in the area east of Cape Cod, and did not steam through Northern Right Whale critical habitat area (i.e., a triangle zone around 41°N, 69°W) and north of Stellwagen Bank National Marine Sanctuary (i.e., line of ~42.8°N).

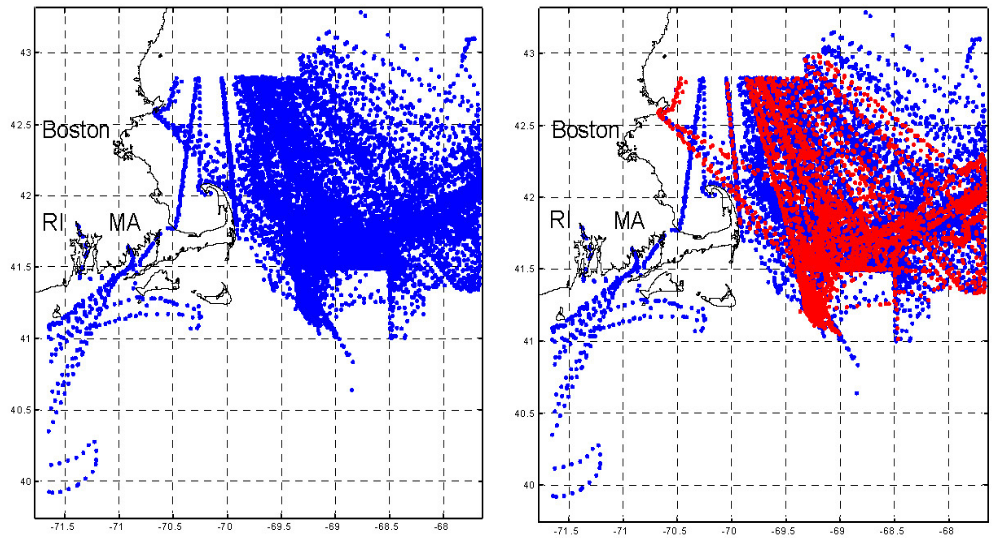

Figure 2. (a) Raw VMS data for SHIP #3353 during Jan. 2004 - Sep. 2008. (b) Same as (a) but data for Sep. 1, 2007 - Sep. 1, 2008 are in red dots.

In order to convert ship track data into traffic density, the study area was divided into a grid with 1 x 1 km cells. When a vessel enters into a cell, it is counted once. While it stays in the same cell within an hour, it is not counted again. If it stays more than an hour, it is counted once every hour after its first entrance. This allows a ship which repeatedly follows the same course over time to be counted properly, while only counting a vessel once even though it may be recorded several times as it passes through a particular cell.

Occupation by a ship in a grid cell was counted for each track line of each vessel for a year, and this is totaled for the ship traffic density for that year. Figure 3 shows the vessel density for SHIP #3353 during 1-year period (September 1, 2007 - August 31, 2008). This can be comparable to the data shown in Fig. 2b, but the traffic density in each cell is represented by color here. It is hard to understand the traffic density in Figure 2 although one could get a sense of where the ship went. In Figure 3, warmer color (e.g., red) depicts higher ship traffic density than cooler color. It should be noted that this vessel occupied the outside of the empty “triangular” area many time (up to 88 times for a year), but did not go into the triangular area often. It indicates that this particular vessel did most of fishing activities around the triangular zone, so those areas should be considered as high navigation uses in MSP procedure. The triangular area matches with the western bound of the Northern Right Whale Critical Habitat Area (Department of Commerce, 1994).

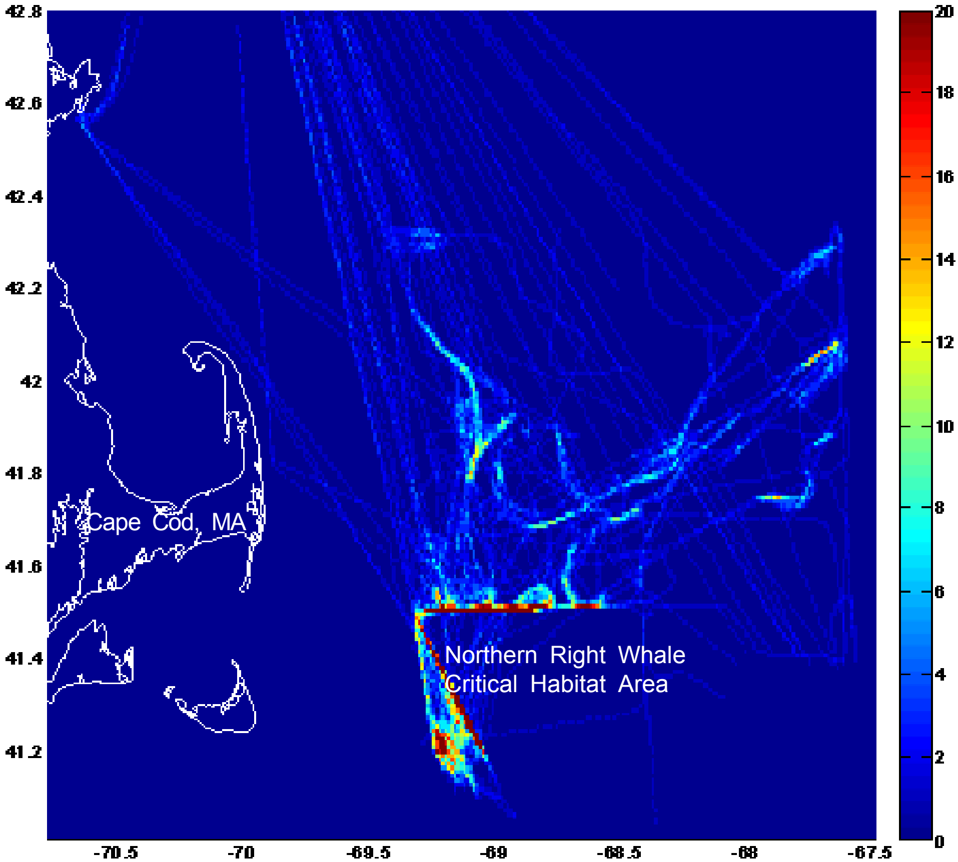

Figure 3. Density of vessels for SHIP #3353 during Sep. 1, 2007 - Sep. 1, 2008.

Ship traffic density for each vessel was accumulated for all the vessels that navigate the study area during the period of interest (e.g., September 1, 2007 − August 31, 2008). A total of ship tracks for ~1,035 vessels from AIS data were counted and summed for the estimate. Figure 4 shows the yearly ship traffic density represented by color for each grid cell. Although the color scheme is maxed out at 100 for the best presentation, the maximum occupancy was up to 8,608 times which might be from the anchor area. In Figure 4, the traffic separation scheme (i.e., traffic lanes) is clearly shown as higher traffic density. Inbound and outbound to/from Boston and New York harbors are denoted by red lines. Use of intracoastal waterways between Massachusetts Bay and Rhode Island coast can also be counted from the density plot.

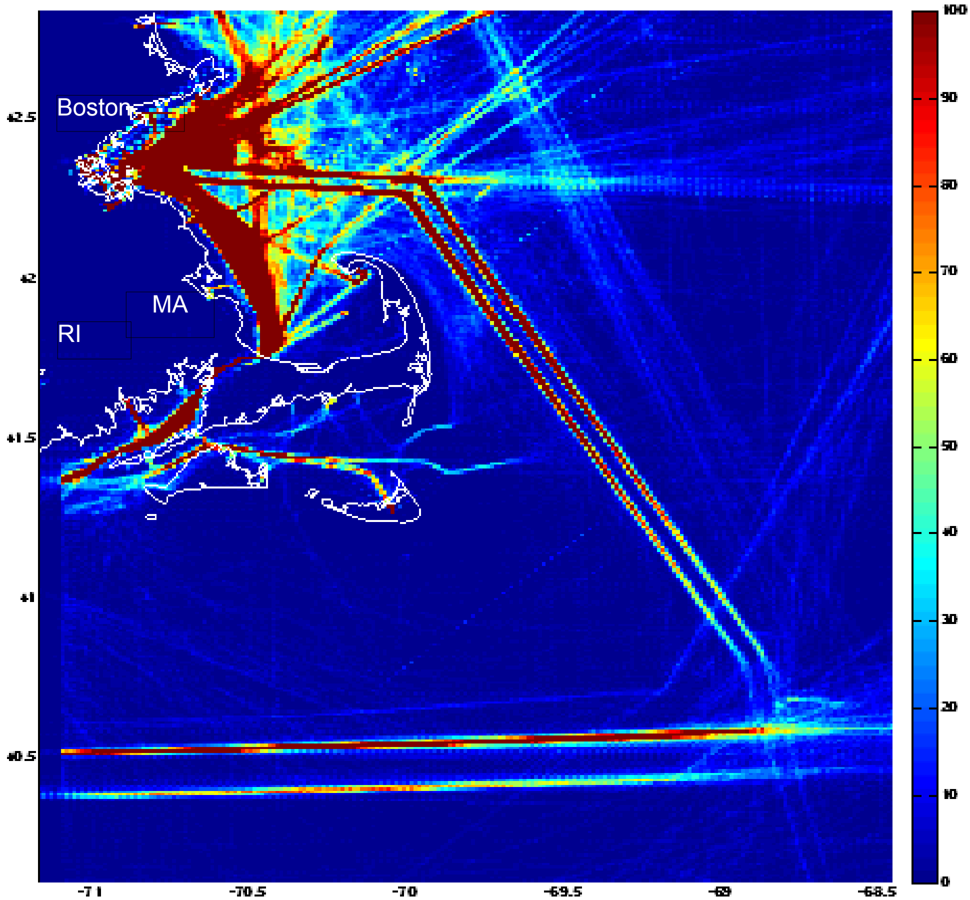

Figure 4. Density of ship traffic based on AIS data during September 1, 2007 - August 31, 2008.

After accumulating all the data from 1,266 vessels from VMS data, the vessel density for the entire study period is shown in Figure 5. This shows the zone of high navigation traffic as well as the location of major port for fishing in Massachusetts and Rhode Islands. When comparing to similar plots derived from the analysis of AIS data (Figure 5), one may note a traffic-empty triangular section located east of the Cape Cod, so called Northern Right Whale Critical Habitat Area. There is also a rectangular box of less traffic in the east of Boston Harbor, which shows the western Gulf of Maine area closure. Relatively heavier activity of fishing occurred near these empty zones, which should be considered in MSP.

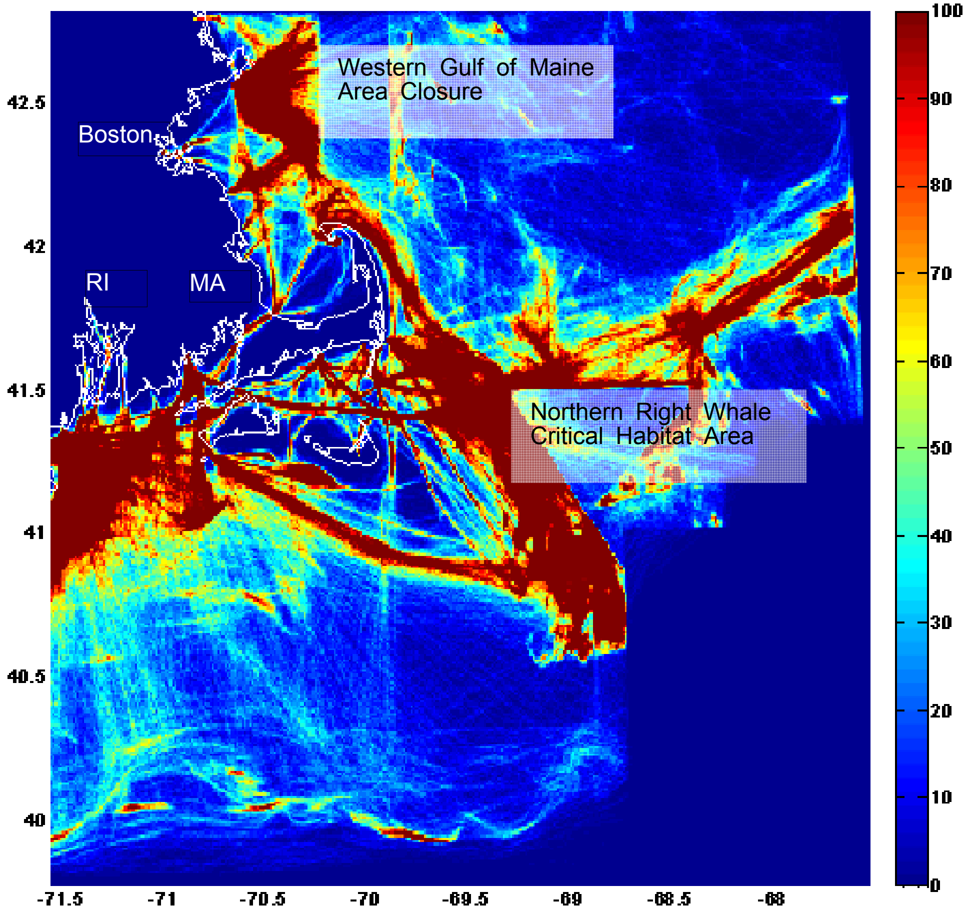

Figure 5. Density of fishing vessel traffic based on VMS during September 1, 2007 - August 31, 2008.

4. Sensitivity of grid resolution on ship traffic density estimates

In this section, the effect of grid resolution (i.e., grid cell size) on the estimation of ship traffic density is evaluated by comparing two different grid cell size, 1 km vs. 250 m. Before going further detail, it is necessary to check out another assumption for temporal resolution. As discussed in the previous section, the traffic density was estimated in an hour basis in this study. At this juncture, it should be mentioned that 1-hour is an arbitrary number we picked after several trials, but it can be altered any number if necessary. In this 1-hour basis scheme, we counted a vessel when it enters a specific grid cell, and does not count it again while it stays in the same grid cell within 1 hour. Thus, in case that a vessel stays in a specific grid cell less than an hour, it is counted only one time. This rule was simply applied to any grid cell size.

The application of this simple rule for two different grid sizes, then, caused quite different results of traffic density for each case. For easy understanding, a simple example is shown in Figure 6. For instance, a vessel shows up in grid #5, passes through 6-14 and heads out from #13 cell in smaller grid scheme. While it steams through each small grid cell (i.e., 250 m), it was counted once for each grid. In the view point of larger cell (i.e., 1 km), however, the count number can be different depending on how long this ship stays in the larger cell. If the entire trip happens within an hour, then it would be counted as one for the larger cell. However, it could be counted 10 times if the entire trip takes for 10 hours. Since the count for the larger grid cell is mainly dependent on the duration of the trip, the relationship between the traffic density in smaller and larger cell may not be simply linear. However, it should be noted that the sensitivity test results show that maximum density in 1-km grid was 4,547 which is roughly 4 times larger than the maximum found in 250-m grid (1,040 counts). This indicates that the ship traffic density might be proportional to the size of grid cells as long as same duration criterion (1 hour in this study) is applied.

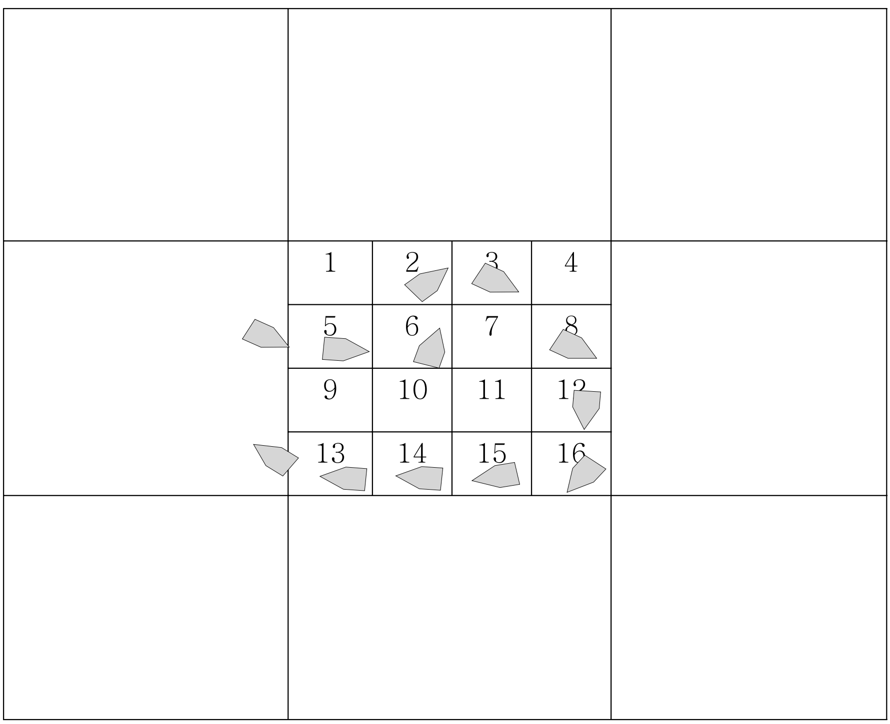

Figure 6. Diagram showing how to count traffic density in two different grid cell size

5. Application of ship traffic density in MSP

Northeast Regional Ocean Council (NROC) operates three standing committees, one of which is Ocean Planning Committee (OPC). The OPC is responsible for helping to scope and provide oversight for regional ocean planning projects. Recently, NROC published Northeast Ocean Data Portal (NODP), an interactive atlas of human and environmental aspects of the ocean in New England region (http://northeastoceandata.org/). This website is a decision support tool for ocean planning, which provides interactive maps including data, tools and information to resource managers, planners, scientists, and stakeholders (Figure 7). The web mapping service (WMS) protocol was used to present the ship traffic density data into a single Geographical Information System (GIS) layer in the system. The ship traffic density results in this paper are also presented in NODP.

The ship traffic density results are presented as part of ocean use along with infrastructures like LNG terminals and submarine cables, energy facilities, ocean disposal sites, and fishing and aquaculture areas in this MSP exercise. Policy makers and stakeholders were able to use those ocean use data when they made decisions on issuance of commercial wind lease blocks or conducting site assessment. For example, when Bureau of Ocean Energy Management (BOEM) developed the wind energy area, they acquired environmental and socioeconomic information from this MSP data (e.g., BOEM, 2012a, 2012b). They also considered the effect of navigation and vessel traffic in the environmental assessment package by referring the ship traffic density layer presented in NODP site (e.g., Fig. 4-12 of BOEM, 2012 a).

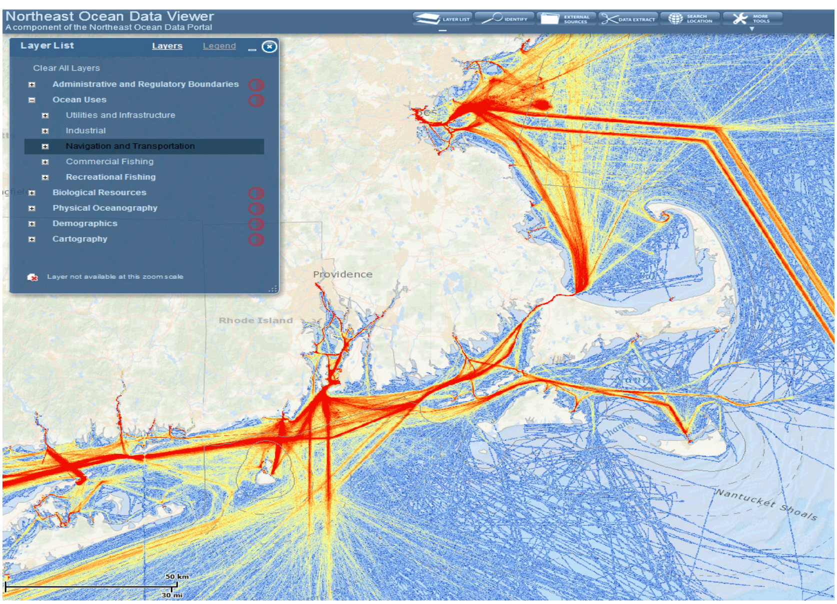

Figure 7. Screen shot of Northeast Ocean Data Viewer showing ship traffic density data as part of ocean use

6. Summary

In this article we present a case study, where Automatic Identification System (AIS) and Vessel Monitoring System (VMS) data were analyzed to estimate ship traffic density in the New England coast, USA. The continuous, chronologically ordered AIS/VMS data were decoded and rearranged for each vessel. The track data of each vessel is counted for prescribed grid cells, once it enters into the cell and one for every hour of staying in the same cell. The counts of entire vessels were totaled for 1-year period, which can be presented in an interactive map. The results clearly show that the location of high navigation use as well as high fishing activities. The sensitivity test results show that the ship traffic density is proportional to the grid cell size.

The ship traffic density data discussed in this paper were published as part of Marine Spatial Planning (MSP) operated by Northeast Ocean Data Portal (NODP). The web mapping service protocol was used to illustrate ship traffic data as an interactive map. These data/layers were later used by one of stake holders, U.S. Department of Interior, Bureau of Ocean Energy Management when they issued wind lease blocks in outer continental shelf off Massachusetts. This case shows an example where established scientific information listed as part of MSP is used in making decisions by a government agency.

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