Deriving Fishing Monthly Effort and Caught Species from Vessel Trajectories

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Abstract—**Vessel Monitoring Systems (VMSs) are mainly meant to monitor and control fishing activity in ocean areas. VMSs have been realized and used in many ways, their principal aim being the monitoring, controlling and surveillance of fishing activity. The term VMS may refer to electronic or software systems aiming at those scopes. VMSs often rely on information transmitted by vessels during navigation, which are used both by security systems in ports and by scientists who want to extract information about oceans fishing exploitation. In this paper we present a semi-automatic method, to be used in a VMS, to calculate fishing monthly effort in ocean areas during a certain period. The method is based on a collection of vessels trajectories referring to that specific period. The monthly effort is calculated at 0.5 degrees resolution and is displayed on an interactive GIS map. Furthermore, the method produces a list of species that are likely to live in the most exploited areas. Thus, our method can be integrated by a VMS to understand the degree of exploitation of ocean areas and to estimate the species that are involved in a catch, which can help in limiting destructive fishing practices.**

I. INTRODUCTION

The term *Vessel Monitoring System* (VMS) refers to an electronic or software system aiming at monitoring and controlling fishing activity in the oceans. VMSs often rely on information transmitted by vessels during navigation, and are used both by security systems in ports and by scientists who want to extract information about oceans fishing exploitation. VMSs have been largely studied and promoted during last years. Mechanisms for electronic management of vessels have been proposed [1] or patented [2] aiming at enhancing maritime security. Attention has been given also to signal transmission technologies, by evaluating tracking systems effectiveness [1]. In more recent works, attention has moved to computer science applications that process vessel transmitted information (VTI). Their most common purpose is still the monitoring of fishing activity, in particular the identification and control of the unreported, unregulated and illegal (UUI) one as well as of the *purse seine* types. In [3], a proposal is given for a monitoring and surveillance model based on a digitized data network: measures are proposed to facilitate the identification of UUI activity by adopting catch documentation schemes. Vessel activity classification is crucial in VMSs and has involved complex statistical models as well as rule-based approaches. It has been used to check the precision and reliability of fishing reports [4] [5] [6] or to perform species behaviour analysis [7]. In most cases, vessels activity classification is based on VTI datasets which involve speed, direction and coordinates. Few examples can be found of procedures that combine VTI data with environmental data [8]. Several methods use complex models. In [9], Bayesian models are used for activity classification on a VTI database of purse seiners in the Indian ocean. Artificial Neural Networks are used in [10] for the same purpose, while trawling spatial extent is estimated in [11] by modelling the mean deviation angle and the length of the mean vector of movement. On species behaviour analysis, Votier et al. [7] use VTI to assess the influence of commercial fisheries activity on the behaviour of the *Morus bassanus*. Among the computer science approaches that combine VTI data with environmental information, Campanis [8] combines speed and direction with bathymetry information in a rule based classifier, while Tello et al. [12] use Spaceborne Synthetic Aperture Radar (SAR) images. Some approaches use gear-specific information [5] [6] or logbooks information [13] to enhance classification. Other works indicate the need for introducing distributed infrastructures (both physical and digital) to share data among ports and to enhance the surveillance level on vessel activities [14] [3].

In such context, we present a semi-automatic method, to be used in a VMS, to calculate the fishing monthly effort in ocean areas during a certain period. The method is based on a collection of vessels trajectories referring to that specific period. It relies on two algorithms for punctual activity classification, one of which uses also ocean bathymetry information. The monthly effort is then calculated at 0.5 degrees resolution and is displayed as an interactive GIS map. Furthermore, the method produces a list of species that probably live in the most exploited areas. Our method can be used to understand the degree of exploitation of ocean areas in a certain period and to estimate the species that are involved in the catch, which is of particular importance in limiting destructive fishing practices. The paper is organized as follows: Section II explains our method. Section III reports the results we obtained by applying the method to a set of vessels operating near the Canadian coasts from 2008 to 2010. Finally, Section IV draws the conclusions.

II. METHOD

Our method consists of an interaction between a user and an automatic system. The system is made up of a set of processing facilities and one visualization GIS tool written in Java programming language. It relies on two vessel activity classifiers that estimate the areas where the vessels operated and the kind of fishing activity they performed. The input to the method is a set of records reporting information transmitted by some vessels (VTI) via GPS during a certain period. Each record must contain at least the recording time, the vessel

identity, its speed, coordinates and direction. The set of messages associated to a certain vessel should allow to reconstruct its trajectory. The sending rate of the messages is expected to be variable because of voluntary or accidental factors. A VTI records set can be supplied to our procedure in a raw format, such as a plain csv file. The first step of the procedure, associates environmental information to each vessel record. This operation allows the next steps to use such information to better classify vessels activity. Furthermore, this can be important to users to qualitatively evaluate the geographical characteristics of the catch areas. Currently, information about bathymetry, temperature, salinity and ice concentration is attached to each record. This is automatically retrieved from the GeBCO [15] and MyOcean [16] repositories.

Two algorithms were implemented for vessels activity classification on the basis of the considerations in [8]. According to those indications, a rule based system could distinguish among few classes. We implemented two rule based algorithms that associate an activity type to each point in a vessel trajectory. The former (*speed-based*) only takes into account speed and classifies the activity by the following rules:

1) Hauling ($speed <= 2kn$);
2) Fishing ($2kn < speed <= 5kn$);
3) Steaming ($speed > 5kn$).

The latter (*speed-bathymetry-based*) uses bathymetry information and classifies in the following way:

1) Hauling ($speed < 2kn$);
2) Trawling ($2kn < speed <= 4kn$ and $bath. >= -500m$);
3) Midwater Trawling ($2kn < speed <= 4kn$) and $bath. < -500m$);
4) Steaming ($speed > 5kn$).

Differently from [8], we decided the second class to be considered as *generic* trawling, instead of *bottom* trawling. In fact, the bathymetry range in the trawling class is too wide to state the fishing activity is only bottom trawling. Currently, only the *speed-based* algorithm is used by the presented method, while the *speed-bathymetry-based* has only an informative role to the user. Thus, the output of this one is provided to the user to perform qualitative evaluation of the vessels activity. The reason is that, at this first stage, we wanted to rely on a more generic classification of the fishing activity.

As next step, the procedure calculates the amount of fishing activity hours (*fahs*) spent by a vessel at each point. Each *fah* is calculated with respect to the previous point in the trajectory, according to the following rules:

1) the first point of a trajectory has 0 *fahs*;
2) a point differing from the previous one for more than 4 hours has 0 *fahs*. We consider this as unreliable;
3) for all the other points, if the *speed-based* classification is of *Fishing* type, then the number of *fahs* is the time difference (in hours) with respect to the previous point.

As output of this step, each vessel record is associated to a number of fahs. At this point the dataset is ready to be processed to produce the *fishing monthly effort* (FME)

Figure 1. Fishing Monthly Effort distribution displayed on a GIS map. The legend reports the fishing hours per month referring to the activity of 21 vessels near the Canadian coasts from 2008 to 2010.

distribution. The FME calculation can be applied to a set of records belonging to several vessels, enriched with fishing hours indication. The procedure aggregates all the fishing activity hours in 0.5 degrees squares. Each square is then associated to the sum of the average fishing hours per month in that square for the evaluated time period. The full range of average monthly hours is then divided into six adjacent ranges and a colour is associated to each, ranging from bright yellow (the lowest) to red. The fishing monthly hours distribution gives a measure of the fishing monthly effort in the analysed area. The result is saved as table on a database and a GIS map is produced by means of a GeoServer [17] instance. GeoServer allows to expose the content of the table by means of OGC standards [18]. A GIS visualization tool (GisViewer [19]) is able to visualize and interact with the produced map. It allows to have a graphical representation of the FME and of the classifiers output. Figure 1 shows the appearance of a GIS layer reporting a fishing monthly effort distribution. GisViewer is a web interface that allows the user to interact with the maps and to filter or post-process the results. GisViewer interacts with the GeoServer instance on which the maps have been indexed by the previous steps of the procedure. By means of such tool the user is able to (i) overlap the fishing monthly effort visualization to the vessels trajectories, (ii) get the details about the FME values and retrieve the vessels records by means of OGC-WFS interrogations [20], (iii) visualize the classifications of the vessels trajectory points, (iv) perform filtering to extract the most exploited areas, (v) launch a niche modelling intersection procedure to retrieve the most probable marine species occurring in the FME locations, as explained later. GisViewer allows the user to write and run CQL [21] queries on the layers. Such functionality can be used to build a filter on the fishing monthly hours that can remove some squares from the map. In particular the user can set a threshold on the amount of hours and get a reduced distribution which displays only the most exploited areas at 0.5 degrees resolution.

After the application of the CQL filter, our procedure invokes an Ecological Niche Modelling algorithm which produces a list of species that probably live in the most exploited squares. In our method we decided to rely on the *AquaMaps Native* niche modelling algorithm [22]. This is a model using species presence information that allows the incorporation of expert knowledge about habitat. The algorithm estimates the actual distribution of a species, that is the area with a

high probability of occurrence. AquaMaps Native is a reference algorithm for marine species distribution modelling, and shows good performance if compared to other purely automatic procedures [23]. It relies on the FishBase [24] database and contains trained models for about 32000 marine species. By invoking the AquaMaps Native algorithm through the GisViewer, an automatic procedure intersects the squares with the niche models pre-calculated for the 32000 species. Eventually, the procedure lists the species living in the those squares with an occurrence probability higher than 80%. The list is then ordered by the probability of occurrence.

We can summarize the above steps in the following workflow, that outlines the interaction between a user and the set of procedures constituting our automatic system:

1) the user collects VTI records about a group of vessels over a certain period and supplies the dataset to the system. Each record contains (i) a unique record identifier, (ii) the recording time, (iii) a unique vessel identifier, (iv) the vessel speed, (v) coordinates and (vi) direction;

2) the system enriches each record with environmental information involving bathymetry, temperature, salinity and ice concentration. For such purpose we used datasets from GeBCO [15] and MyOcean [16];

3) the system applies two vessel activity classifiers to distinguish at least among the fishing, hauling and steaming status for each point in the trajectory. The former (*speed-based*) relies only on speed information, while the latter (*speed-bathymetry-based*) uses also bathymetry information from GeBCO. Only the *speed-based* algorithm is used in the fishing monthly effort calculation, while the *speed-bathymetry-based* is reported to the user for comparative and informative purposes;

4) the system calculates the fishing activity hours (fahs) spent by the vessels at each point. This is a rule-based procedure relying both on the time distance between adjacent points and on the *speed-based* activity classifier;

5) the system calculates the monthly fishing hours at 0.5 degrees resolution on the basis of the fahs. This procedure spatially aggregates all the trajectory points in 0.5 degrees squares and calculates the overall average fahs per month for each square. We consider this to be an estimate of the fishing monthly effort (FME) distribution in the involved area;

6) the system visualizes the FME distribution on an interactive GIS map. The user is also supplied with a GIS representation of the activity classifications and can retrieve the vessels records by interacting with the viewer;

7) the user writes and executes a CQL filter and sets a threshold for the FME, which removes low effort areas;

8) the system applies the filter and then intersects the remaining squares with the fundamental niche distributions [22] of a set of species. It selects those species with probability higher than 80% to live in the filtered areas;

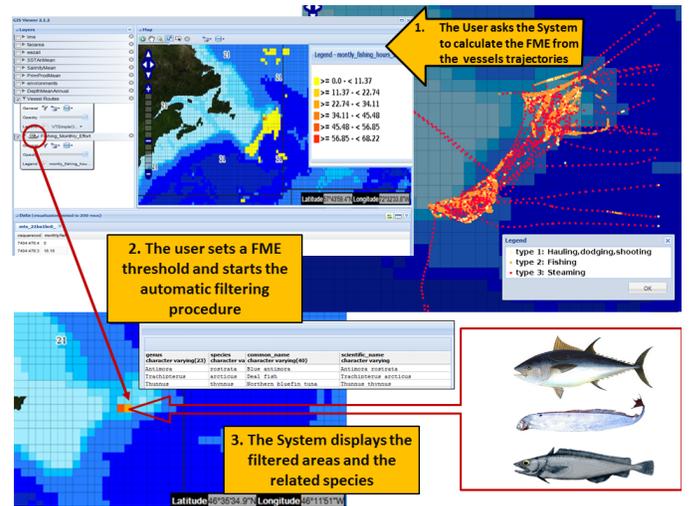9) the system displays the filtered squares and returns the list of species that were likely to be involved

Figure 2. Workflow of our method: the system processes vessels trajectories and reports the most exploited areas and the species which are likely to live there.

in the catch. The list is sorted by the probability of occurrence of the species in those squares, which represent the most exploited areas.

Figure 2 displays the workflow of the method. The next Section reports a practical application to a real dataset.

III. RESULTS

In order to evaluate the effectiveness of our method, we applied it to a real case. We used a VTI dataset provided by NAFO [25], which involved 10000 VTI records belonging to 21 vessels that operated near the Canadian coasts from 2008 to 2010. The vessels identities were hidden for policy reasons and a unique identifier (*vesselID*) was used instead. The *speed-based* classification output is displayed in Figure 3, while the *speed-bathymetry-based* is shown in Figure 4. The maps are visualized by the GisViewer and the user can make qualitative comparisons by overlapping them with some transparency.

Each point in the trajectory was classified and associated to some environmental parameters. Furthermore, the system calculated the fishing monthly hours at each point. By means of a CQL filter (e.g. $vesselID = 1$) the user could visualize the trajectory of a single vessel. By clicking on a certain trajectory point on the map in the GisViewer, the user could retrieve the associated VTI record.

The FME calculation on the NAFO dataset is displayed in Figure 1. FME is reported for each 0.5 degrees square and the user can retrieve the exact value by clicking on a square. We applied a CQL filter on the FME map. We removed the squares containing less than 46 monthly fishing hours, and obtained only two squares. Figure 5 displays the resulting map. GisViewer automatically run the Niche Modelling intersection described in Section II on those squares. Such procedure returned a list of 159 species. This list included the endangered *Thunnus thynnus* (Atlantic blue fin tuna), which was probably the main target of the vessels because of its commercial interest. The system's execution time to produce the FME and the list of species was 5 seconds, using a CentOS 5.7 x86 64
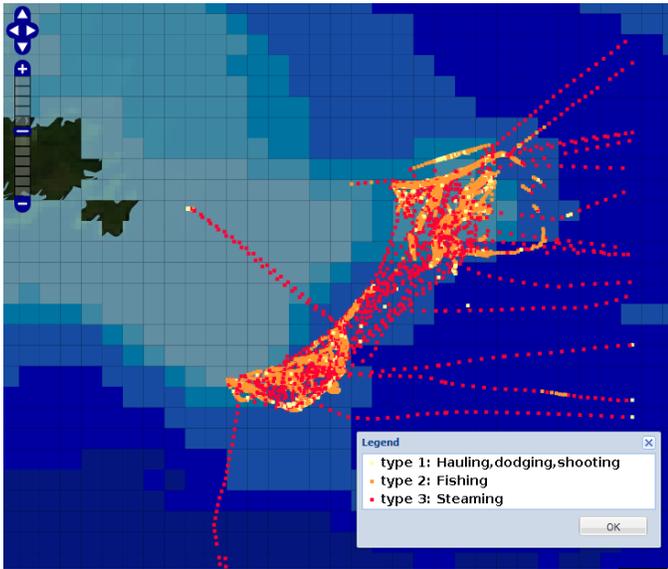
Figure 3. Vessels trajectories with colours associated to *speed-based* classification.
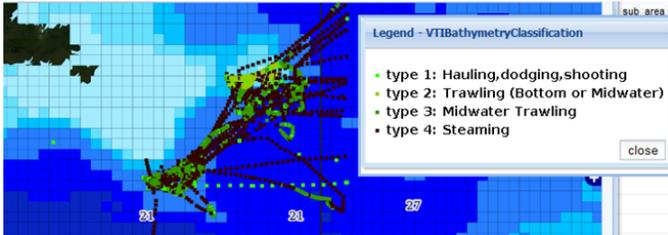

Figure 4. Vessels trajectories with colours associated to *speed-bathymetry-based* classification.
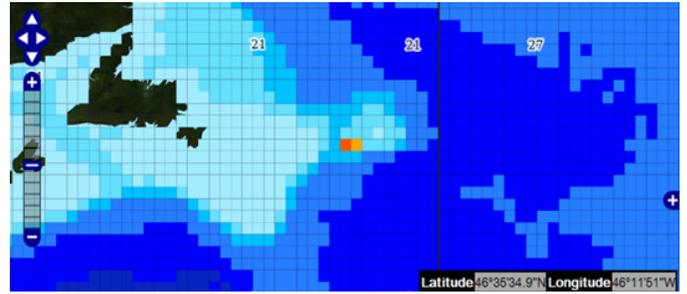

Figure 5. Fishing Monthly Effort distribution after the application of a CQL filter that removed the squares containing less than 46 average monthly fishing hours.

will focus on enhancing the classification procedures by means of more complex algorithms. These will take into account the complete environmental information attached to the vessel records, which is currently used mainly for informative purposes. On the other side, we will refine the retrieval of the species involved in the catch. More information can be used to better sort the list, e.g. commercial interest or level of endangerment. Our method is currently used by the i-Marine project [26] community through the VMS hosted by the gCube e-Infrastructrure [27].

machine with 4 CPUs and 4 GB of RAM. The process was therefore able to identify, starting with 10000 VTI records, two precise areas with considerable fishing rate, involving at least one endangered species and other species possibly involved in the catch, perhaps accidentally.

IV. CONCLUSION

We have described a novel method that can be used in a VMS, which relies on a data processing software and an interactive web interface. It allows a user to estimate the fishing monthly effort distribution on an ocean area in terms of the amount of average monthly fishing hours spent by a set of vessels during a certain period. We have described two procedures to classify the vessels fishing activity. The interface allows users to investigate also the environmental data associated to the trajectories. Furthermore, it provides a graphical and interactive representation of the activity classifications according to two algorithms. A set of facilities allow to select only the locations with high fishing activity and to retrieve a list of species that were probably involved in the catch. We have evaluated the effectiveness of the method on a use case involving a set of vessels moving in the coasts near Canada from 2008 to 2010. In that case the method was able to select very precise locations that had been highly exploited and to detect the presence of an endangered species of commercial interest in the most exploited area. Future work

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