# EXTRACTION AND CLASSIFICATION OF LONGLINE FISHING TRIPS FROM VESSEL MONITORING SYSTEMS DATA WITH SEQUENTIAL RECORDING GAPS

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**ABSTRACT:**

The evaluation of fish stocks exploitation is a complex task that comprehends the analysis of several types of data including information on the spatial and temporal dynamics of commercial fishing fleets. Satellite-based Vessel Monitoring Systems (VMS) is one of the best independent data sources available that can provide information on fishing fleet operations. This type of system allows the transmission of data from a satellite-tracking device installed on board to a land-based Fisheries Monitoring Centre. The data transmitted typically contains information on date/time, longitude and latitude coordinates and vessel's speed and course.

Aiming to characterize the fishing operations of the Portuguese deep-water longline fleet targeting black scabbardfish (*Aphanopus carbo* Lowe, 1839), to identify its main fishing areas and also to calculate fishing trip durations, IPIMAR has been analysing VMS data provided by the Portuguese General Fisheries Inspections Service (IGP). In general, data points from the Portuguese VMS are recorded in a constant time lag of 10 min. However, owing to several technical and non-technical problems related with the transmission device installed on board, vessel's datasets can exhibit large time differences ( > 4 hours) between consecutive data points. These temporal discontinuities pose serious difficulties to the analyst when trying to track down vessel's operations at sea.

The present paper presents a software toolkit composed by a set of procedures developed using Oracle PL/SQL and Oracle SPATIAL tools to extract and classify fishing trips held by the longline vessels from VMS discontinued data. The set of procedures was implemented taking into account ancillary information about the fishing operations characteristics and the number of fishing hauls held by fishing trip. The toolkit enabled to identify fishing operations held at sea by fishing trip, namely setting and hauling of the gear and their duration. The validation of the number of trips processed by the toolkit for each vessel was conducted by comparative analysis with daily landings records data, assuming that each landing record corresponds to a unique fishing haul. From a total of eight vessels analysed in the period 2000-2004, the toolkit was able to process 76% of the total fishing trips held with landings on black scabbardfish.

## 1. INTRODUCTION

A deep-water longline fishing fleet has been targeting black scabbardfish (*Aphanopus carbo* Lowe, 1839) in the Portuguese continental slope since the early 80's at grounds around Sesimbra landing port (south of Lisbon – Latitude 38º 20' N). In the first years of the fishery, the fleet was composed by small longliners with an average Length-Over-All (LOA) of 12 m and a sea crew of more or less six fishermen. The annual landings reported were below 1.000 tons. Later on in the 90's, in response to a higher market demand landings figures increased (up to 4.000 annual tons in some years), reflecting both vessel's technological improvements and larger fleet size. At the same time in the west of the British Isles, a French deep-water trawl fishery was producing large landings of this species (about 2.500 tons per year in the period 1991-1994).

The increasing exploitation of black scabbardfish, among other deep-water species, in the Northeast Atlantic did not remain unnoticed by the International Council for the Exploration of the Sea (ICES). This fisheries regional organization recognized that uncontrolled fishing activity targeting deep-water species cause levels of fish mortality that put in peril the sustainability of the fisheries and the recovery of the stocks. Such cause for concern relied on the evidence that human impacts, especially over-fishing, plays a significant role in fish stock declines and on the knowledge of deep-water species particular life-cycle characteristics that make them more vulnerable to fishing pressure: usually top-level predators exhibiting late maturity and high longevity. Taking these facts into consideration, ICES decided on the establishment of the Study Group on the Biology and Assessment of Deep-Sea Fisheries Resources (SGDEEP) to provide management advice relating to deep-water fisheries in order that development could be controlled before long-term damage was done.

When evaluating the impact of commercial exploitation on fish stocks, one of the most important topics to be addressed by researchers is the behaviour of the fleet in space and time. Fisheries tend to exhibit a spatial component and seldom cover all the extent of the target species distribution, operating only in grounds where higher yields can be obtained (Bordalo-Machado, 2006). Until recently, most of the information analysed on vessel's fishing activity came from skipper logbooks and interviews, which inevitable have biases associated with the skipper declarations. Fortunately, the development of automatic satellite positioning central systems with the ability to compile information from GPS data loggers installed on fishing vessels has enabled fisheries researchers to get access to much less biased and fine-resolution fisheries independent data. These records commonly referred to, as Vessel Monitoring System (VMS) data are a good independent source of information available to describe the distribution of fishing activity. The VMS data transmitted to an earth based

central system typically contains information on date/time, longitude/latitude coordinates and vessel's speed and course.

In the literature, there are already some papers that make use of VMS data to analyse the activity of fishing fleets. However, most of them deal with trawl fishing data (Afonso-Dias *et al.*, 2004; Deng *et al.*, 2005). Bordalo-Machado *et al.* (in press) presented one of the first approaches to the analysis of VMS data from longline fisheries. Using a limited VMS dataset with information on two longliners from the black scabbardfish fishery of mainland Portugal, these authors have developed data mining procedures running on an Oracle 9i relational database to classify fishing operations and navigation periods. The results were very promising considering that almost 90% of the fishing trips held by the two vessels was identified by the database software procedures. However, using a new and enlarged VMS dataset for the period (2000-2004), the set of procedures did not proved so well in the identification of fishing trips and classification of fishing operations. This occurred because the new dataset showed large temporal discontinuities. Instead of a regular recording interval of 10 minutes, some consecutive records exhibited a time difference of more than 45 minutes. This was critical to the failure of the developed database procedures, since these large time gaps difficult the correct delimitation of vessels' operations at sea.

The present paper presents a new set of procedures developed on an Oracle 9i relational database that aims to extract from longline fisheries discontinued VMS data all possible knowledge on: fishing operations (hauling and setting of the gear), fishing effective time (time difference between setting and hauling operations) and additionally create Oracle SPATIAL objects containing the fishing areas of fleet vessels. The procedures developed comprise an assemblage of algorithms that use an attribute-oriented approach to knowledge discovery. The validation of the fishing hauls identified was based on the number of records by fishing operation and on a comparative analysis with daily landings records.

### 1.1. Fishing operations description

The longline fishery targeting black scabbardfish in Portuguese continental waters still follows an artisanal regime after 20 years of existence, where the majority of the tasks involved are the result of hand labour operations. The activity of the fishing fleet typically follows a well-defined pattern: vessels leave the port (usually Sesimbra or Peniche) early in the night and navigate offshore for a period that varies between 1.5 hours to almost six hours towards the fishing ground. Upon reaching the fishing ground two operations generally occur: 1) a set longline gear is deployed at depths greater than 900 m; and 2) another longline gear previously set in the last 24–48 hours is recovered. The recovery of the gear is generally slow and highly dependent on prevailing sea conditions. The whole process lasts till noon the next day. Landings occur three times a week, immediately after vessels arrive in port, and generally last from late morning till late afternoon or dusk. In general, a whole fishing period between setting and hauling of the gear can range from 35 to more than 72 hours depending if there is no fishing during weekends or public holidays.

## 2. DATA

Data was retrieved from the surveillance and monitoring system that records the activity of fishing vessels (MONICAP) which is maintained by the Fisheries Inspection Department (FID) of the Portuguese General Directorate of Fisheries and Aquaculture. MONICAP uses GPS for geographical positioning and Inmarsat-C for satellite communications between the vessels and a control centre. It is composed of individual continuous monitoring equipment - 'Blue Box' installed on board each vessel. The Blue Box transmits the vessel's position, heading and speed through a landing earth station directly to the Fishery Control and Surveillance Centre of the FID.

The dataset analysed in this study comprised eight vessels (hereby referred to as V01,…,V08) from the black scabbardfish fishing fleet covering the period 2000-2004. Each data record contained information on vessel's identification code, date, time (HH:MI:SS), geographic position (Longitude and Latitude, geographic coordinate system: WGS84) and speed in knots. Data points should ideally have a time lag of 10 minutes.

Information on daily fish landings used to compare with fishing trips dates identified by the data mining procedure was provided by the Portuguese General Directorate of Fisheries and Aquaculture.

## 3. METHODS

The data mining procedures that extract and classify fishing trips from VMS discontinued data were developed in PL/SQL language and compiled as two Oracle 9i software code packages entitled RECOTAB and RECOVMS. The first package contains two procedures that employ 'dynamic cursors' to create and drop temporary tables that are needed to run the procedures from the second package. Package RECOVMS includes several procedures that perform queries and calculations on tabular information stored in the relational database. The execution of the above packages is preceded by a preliminary data processing described below.

The dataset was initially imported as an ASCII text file to an Oracle 9i relational database using 'SQL*Loader'; a tool that loads data from external files into tables in an Oracle database (Fig. 1). After loading the data into a unique table, a software code package is run. This initial processing package entitled INIT, described in detail in Bordalo-Machado *et al.* (in press), assumes that each fishing trip comprises all records between each vessel's departure from the harbour and its return. Packages RECOTAB and RECOVMS require the following processing steps to run from the initial package:

i. <u>Assignment of a *status* attribute to each record</u>. The *status* attribute classifies vessel activity at the instant of data record generation by the Blue Box equipment. According to vessel's geographic position and speed it is possible to define five types of *status*: 10 – Not moving inside the fishing harbour area; 20 – Moving inside the fishing harbour area; 40 – Moving outside the fishing harbour area; 41 – Moving outside fishing harbour area and hauling (vessel speed: 0 – 1 knot); 42 – Moving outside fishing harbour area and setting the gear (vessel speed: 2 - 5 knot).
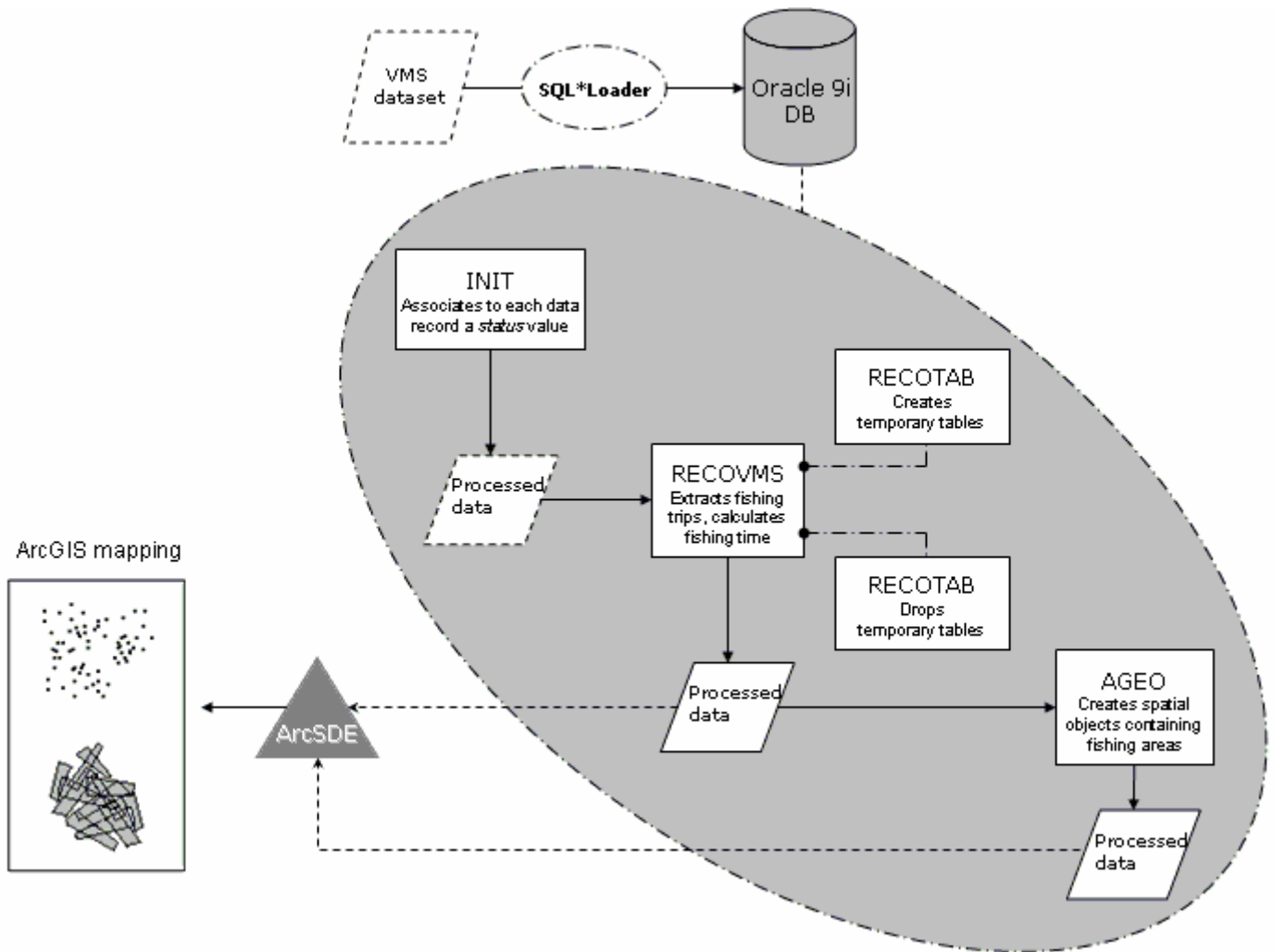
Figure 1. General workflow of VMS data processing in an Oracle 9i database from data loading to geographic visualization.

ii. <u>Determination of the time difference (tdiff) and distance to the port (dist) parameters</u>. These parameters are useful for the identification of records with *status* 40, 41 and 42. tdiff is calculated as the difference (minutes) between two consecutive records, dist corresponds to the distance in kilometres between the beginning of the trip and the present record. Distance is calculated using a spherical approximation as follows:

$$\text{dist} = Rm \times Acos[(90° - Long1) \times \\ Cos(90° - Long2) + Sin(90° - Long1) \times \\ Sin(90° - Long2) \times Cos(Lat1 - Lat2)] \quad (1)$$

where   Rm = mean radius of curvature = 6373.3014 km
Long1, Lat1 = coordinates of 1st data point
Long2, Lat2 = coordinates of 2nd data point

iii. <u>Execution of a short algorithm to correct for wrong *status* classification</u>. Wrong classifications may occur when there are isolated records that are not part of a record sequence between two *status* 10 records (the

limits of a fishing trip). The algorithm works on records that are sequentially ordered in time.

The important outcome of package INIT, is the association of *status* information to each data record, a condition necessary to execute the procedures existent in packages RECOTAB and RECOVMS. The processing then follows by running the Create procedure from RECOTAB, which generates 18 temporary tables. Having these tables created, the user can execute the package RECOVMS for each fishing vessel by calling a procedure entitled *main_tab* on the SQL*Plus command prompt. For example, 'EXEC recovms.main_tab('V01');' for vessel V01.

Next are described the key procedural steps of this package:

1. <u>Main information table</u>. Insert into a temporary table the following information: Record ID, Vessel ID, Date (YY-MM-DD HH24:MI:SS), Longitude, Latitude, Speed, *status*, tdiff, dist.

2. <u>Hauling operations lower boundaries</u>. Insert into a temporary table the Record ID's that correspond to the lower boundaries of the hauling operations

(records with *status*=41), i.e., the temporal start of the operation. During this procedure two situations are taken into account: a) hauling occurs in only one day (e.g., start 9:00, end 15:00) and b) hauling occurs throughout two days (e.g., start 22:00, end 03:45). To assure that the lower boundaries selected are part of a fishing operation and do not constitute isolated records, records located two positions below and three positions above are checked for the *status* value.

3. Setting operations lower boundaries. Insert into a temporary table the Record ID's that correspond to the lower boundaries of the setting operations (records with *status*=42). During this procedure the same two situations of step 2. are taken into account as well as the check procedure.

4. Pairs of consecutive hauling boundaries. Insert into a temporary table pairs of time consecutive hauling boundaries (haul1 and haul2) associated with an unique record sequential code. Each record represents a fishing haul characterized by the start of a hauling operation at date of haul2 and the unknown start of its correspondent setting operation conducted between the date of haul1 and haul2.

5. Fishing trips and fishing operations lower boundaries. Insert into a temporary table the lower boundaries of setting (set) and hauling operations by fishing haul code. The date of the setting operation for each fishing trip was determined as the lowest date existent in temporary table of step 3. that lies between the start of two consecutive hauling operations (bound1 and bound2). Together with the record ID values of the fishing operations lower boundaries, the following time differences (minutes) were calculated: haul2-haul1, set-haul1 and haul2-set.

6. Deletion of possible duplicate trips. Due to the occurrence of temporal discontinuities in the data it is possible to obtain more than one pair of dates (setting/hauling) for each haul. Based on the differences obtained in step 5., duplicate fishing hauls were accepted if corresponded to the lowest values of the difference between hauling and setting dates and rejected otherwise.

7. Hauling operations records. Insert into a temporary table all the records that correspond to the hauling operation of each fishing haul by using the lower boundaries of the temporary table from step 5. This procedure uses a cursor type variable and a loop to select all the consecutive records with *status*=41, beginning with the lower hauling boundary and finishing just before the first record with *status*=40 is found.

8. Setting operations records. Insert into a temporary table all the records that constitute the setting operation of each fishing haul by using the lower boundaries determined in step 5. This procedure uses a cursor type variable and a loop to select all the consecutive records with *status*=42, beginning with the lower hauling boundary and finishing just before the first record with *status*=40 is found.

9. Removal of spurious fishing operation records. Delete from the temporary tables of steps 7. and 8. records with *status*=10 or 20. Also in this procedure, the *status* and time difference of records located one, two and three positions below and above each record are checked. This aims to find out the existence of: a) incorrect operations boundaries and b) large time discontinuities between records.

10. Landings dates. Insert into a temporary table the landings dates of the vessel.

11. Fishing operations and landing date by fishing haul. Insert into a temporary table fishing operations records together with the corresponding landing date by fishing haul code. In this procedure, data from temporary tables of steps 7., 8. and 10. are used. Landings dates must comply with one of the following conditions: landing date=hauling date; landing date-1=hauling date. The hauling date is given by the date of the last record of each hauling operation. The validation code 'V' (valid trip) is provisionally associated to each record.

12. Update of the fishing hauls validation code. The validation code of records from the table of step 11. are updated to code 'P' (partial valid haul) if at least one of the following conditions are met for each fishing haul: a) setting operations with less than four records, b) hauling operations with less than 9 records and c) fishing operation records with time differences equal or higher than 60 minutes.

13. Hauling operations without corresponding setting operations. Insert into a temporary table all the records that constitute hauling operations of fishing haul codes without any correspondent setting operation records identified. The procedure is the same of the one described in step 7.

14. Removal of spurious hauling operation records. Follows the same procedure described in step 9. for the records of the temporary table of step 13.

15. Hauling operations and landing date by fishing haul. Follows the same procedure described in step 11. The validation code 'I' (invalid haul) is associated to each record from the temporary table of step 13.

16. Final table with information on fishing hauls. Insert into a permanent table one record for each fishing haul with the following data attributes: Vessel ID; Fishing haul code; Landing date (YY.MM.DD); Setting date (YY.MM.DD); Hauling date (YY.MM.DD); Setting minimum and maximum record ID's; Hauling minimum and maximum record ID's; End time of setting (HH24:MI); Start time of hauling (HH24:MI); Longitude, Latitude at the start and end of setting; Longitude, Latitude at the start and end of hauling; Fishing time and Validation code. Fishing time was calculated as the time difference between the last setting record and the first hauling record.

The final processing step is the execution of the Drop procedure from RECOTAB, which cleans the database from the 18

temporary tables previously created. The resulting geographic locations from setting and hauling operations points can later be visualized in a geographic context throughout an ArcSDE connection in the application ArcGIS.

In order to have an idea of the spatial extents of fishing areas and produce rough depictions of them, another software package was developed using Oracle SPATIAL tools. This package entitled AGEO uses data from the final information table of package RECOVMS by only considering the boundary records of each fishing operation to define fishing areas. Thus, fishing areas are represented by four-point polygons. The main procedural steps of AGEO are described below:

17. <u>Fishing operation data points as Spatial objects</u>. Insert into a permanent table the records from the final information table of package RECOVMS. In this procedure, each latitude, longitude pair relative to the boundaries of hauling and setting operations is included in an unique SDO_GEOMETRY datatype attribute with the option SDO_POINT_TYPE. These table columns have spatial indexes associated that use the WGS84 as the ellipsoid of reference.

18. <u>Distances between fishing operations boundaries</u>. For each fishing haul, the distance between the four fishing operations' boundary points (ps1, ps2 for setting, and ph1 and ph2 for hauling) is calculated in km using the function SDO_DISTANCE with a tolerance of 0.005. This result in six pairs of distance: ps1-ps2, ps1-ph1, ps1-ph2, ps2-ph1, ps2-ph2 and ph1-ph2. The distance values are then ordered from maximum to minimum.

19. <u>Definition of a preliminary order for boundary points</u>. For Oracle SPATIAL tools to draw a polygon representing a fishing area limited by the four fishing operations' boundary points it is necessary to have the points in a certain order to guarantee that no intersection occurs between polygon boundary segments. In this sense, this procedure creates two main segments: one connecting the two points exhibiting the largest distance, denoted 'line_13', and the other connecting the remaining two points denoted 'line_24'. line_13 has the points with order 1 and 3, whereas line_24 has the points with order 2 and 4. In the hypothetical case of Figure 2, the fishing area polygon boundary will be drawn starting in point 1 passing in points 2 and 3 and finishing in point 4. However, there are cases where the two segments do not intersect each other (Fig. 3). In cases like these, the points order will originate polygons with intersecting boundaries. To avoid this problem, the function SDO_INTERSECTION is used to detect line segments intersections. When an intersection is not detected, the order of points is modified.

20. <u>Final table with the fishing areas' polygons</u>. Using the information gathered from steps 17. to 19., the four fishing operations' boundary points from each fishing haul are inserted in an ascending order into a SDO_GEOMETRY datatype table column to produce a 2D polygon representing a fishing area. In the same table is inserted: the Vessel ID; the Fishing haul code; the Landing date (YY.MM.DD); the Setting date (YY.MM.DD); the Hauling date (YY.MM.DD); the

End time of setting (HH24:MI) and the Start time of hauling (HH24:MI).
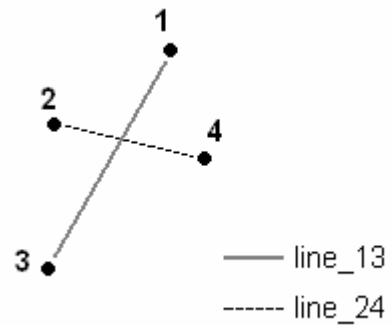


Figure 2. Representation of two line segments generated with the four fishing operations' boundary points: line_13 corresponds to the largest distance between two points and line_24 corresponds to the distance between the remainder two points.

Finally, the table produced in step 20., can be visualized as a geographic layer in ArcGIS, after its registration in ArcSDE using the command 'SDELAYER' with the options '-O' and REGISTER.
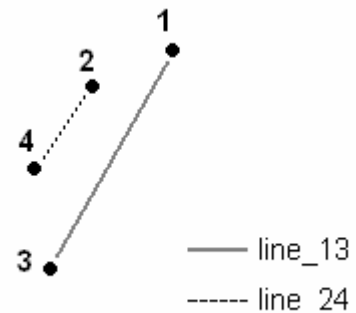


Figure 3. Representation of the two line segments generated with fishing operations' boundary points in the case when the two segments do not intersect.

## 4. RESULTS AND DISCUSSION

The combination of the different software packages produced a swift data processing and assignment of fishing haul identifier codes in the Oracle 9i database environment. For instance, the 24,030 VMS records of vessel V08 were processed in nearly 4 minutes time from the start of package INIT until the end of package AGEO in a Pentium 4 (2.8 GHz CPU speed; 1.0 GB RAM) with Windows XP as the Operating System. The achievement of this performance largely depends on the use of temporary tables within the software code (Danchenkov and Burleson, 2006). PL/SQL and Oracle SPATIAL tools extended the capacity of SQL to implement rules on which the query-driven data mining was based. No rule type queries (Imielinski and Mannila, 1996) were developed. The fishing hauls classification alongside with the tabular and graphic outputs

produced, constitute adequate information outputs for analysts and researchers to assess the quality of the VMS data and select the appropriate set of records to calculate fishing effort and fishing grounds' boundaries of a longline fishing fleet. Nevertheless, the software packages are sufficiently flexible to accommodate other data mining techniques based on mathematical and statistical approaches.

Package RECOVMS has identified 2,642 fishing hauls from a total of 3,456 daily landings of the black scabbardfish fleet carried out in the period 2000-2004 (Tab. 1). Package INIT has discovered, for almost every vessel, more pairs of fishing hauls than the number of daily landings produced. This is due to the temporal discontinuities of the VMS dataset that causes the software to consider small groups of records, sometimes isolated records, as individual fishing trips. These temporal discontinuities can be originated by malfunctions, interference with other vessel equipment or improper use of the Blue Box equipment. Regardless of the different approaches used in the classification of a fishing trip, package RECOVMS has the advantage of promptly associate the two fishing operations that define one fishing catch into a unique code. Moreover, the processing of fishing trips is largely dependent on the daily records information available for each vessel, which determines that the total number of fishing hauls detected by this package will always be lower or equal to the total registered landings.

The number of records by fishing operation has varied with vessel (Tab. 2). Vessel V08 showed the highest median number of records of setting operations, while, vessel V04 presented the highest median number for hauling operations. The different number of records observed per fishing operation is probably

| Vessel | | Number of records | | | | |
| | | Average | Median | Std.Dev. | Max | Min |
|---|---|---|---|---|---|---|
| V01 | Setting operations | 9,2 | 10,0 | 3,359 | 17 | 1 |
| V02 | | 6,3 | 7,0 | 2,942 | 16 | 1 |
| V03 | | 9,8 | 11,0 | 4,805 | 25 | 1 |
| V04 | | 7,5 | 5,0 | 5,389 | 18 | 1 |
| V05 | | 7,4 | 8,0 | 1,831 | 16 | 2 |
| V06 | | 7,3 | 8,0 | 4,674 | 32 | 1 |
| V07 | | 10,6 | 11,0 | 2,985 | 23 | 1 |
| V08 | | 10,8 | 12,0 | 4,795 | 27 | 2 |
| All | | 8,5 | 8,0 | 3,569 | 32 | 1 |
| V01 | Hauling operations | 39,5 | 46,0 | 16,324 | 17 | 1 |
| V02 | | 38,0 | 46,0 | 15,991 | 16 | 2 |
| V03 | | 42,3 | 49,0 | 18,970 | 25 | 2 |
| V04 | | 54,9 | 68,0 | 25,479 | 18 | 3 |
| V05 | | 34,9 | 37,0 | 10,072 | 16 | 2 |
| V06 | | 35,0 | 32,0 | 20,271 | 32 | 1 |
| V07 | | 44,7 | 53,0 | 19,127 | 23 | 2 |
| V08 | | 34,7 | 23,5 | 23,968 | 111 | 2 |
| All | | 38,3 | 40,0 | 18,653 | 111 | 1 |

Table 2. Summary statistics on the number of records per individual fishing operation for each vessel.

| Vessel | Fishing hauls | | Fishing areas | Landings | % hauls RECOVMS | % areas |
| | RECOVMS | INIT | | | | |
|---|---|---|---|---|---|---|
| V01 | 271 | 289* | 260 | 462 | 59 | 56 |
| V02 | 519 | 1818 | 491 | 605 | 86 | 81 |
| V03 | 312 | 518 | 302 | 477 | 65 | 63 |
| V04 | 145 | 957 | 144 | 288 | 50 | 50 |
| V05 | 507 | 933 | 498 | 575 | 88 | 87 |
| V06 | 609 | 1267 | 504 | 625 | 97 | 81 |
| V07 | 203 | 1166 | 203 | 230 | 88 | 88 |
| V08 | 76 | 185* | 75 | 194 | 39 | 39 |
| All | 2642 | 7133 | 2477 | 3456 | 76 | 72 |

* More than 70 % of the fishing hauls with only one record.

Table 1 – General results from the data mining processing: total number of fishing hauls identified by vessel after packages RECOVMS (valid, partial valid and invalid) and INIT (pairs of hauling and setting operation trips); number of fishing areas generated by vessel; number of daily landings (corresponding to the number of fishing hauls) conducted by each vessel in the period of the dataset and percentage of hauls (only package RECOVMS) and areas obtained in relation to the number of landings by vessel.

related with the characteristics of the fishing gear used (e.g., no. of hooks) and the speed of the vessel during fishing operations.

The visualization of the fishing areas produced by the package AGEO (Fig. 4) enabled the detection of potential fishing grounds of the vessels and made possible the uncovering of wrong classifications of fishing operations by the package RECOVMS. In these situations, polygons exhibit unusual geometric shapes and area values (e.g., 0.5 sq.km or 78 sq.km).
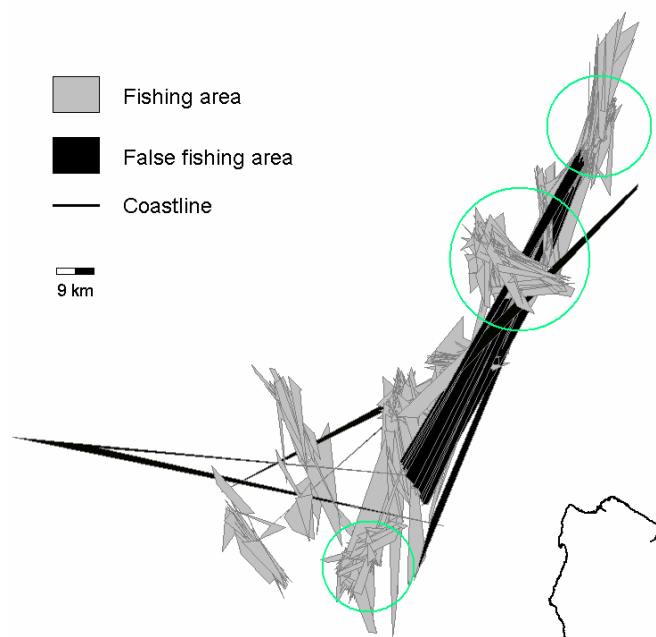


Figure 4. Example of fishing areas generated by package AGEO. Areas encircled represent possible fishing grounds of the fleet vessels. Spatial references are not included due to data confidentiality.

The analysis of VMS datasets offers great potential in the management of fisheries as a means to control fishing effort. However, this investigation should be accomplished by researchers with sufficient knowledge on the fishery under study to guarantee that: a) the data algorithms developed have the necessary specifications to successfully spot fishing operations and b) records temporal discontinuities are properly evaluated to get a good perception of the VMS data quality.

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