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Manuscript

Using mobile device's sensors to identify fishing activity

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Abstract

Fisheries management is generally based on the regulation of the fishing effort, by limiting fishing capacity and activity. The fishing capacity can be quantified objectively, however, the calculation of the fishing activity requires knowing the effective fishing time, for which it is essential to monitor the vessels activity. The European Vessel Monitoring System (VMS) only describes the geographical position, course and speed of the vessel at 2-hour intervals, it is an expensive system used only in vessels over 12 meters in length and there are no common criteria to infer the fishing activity from the VMS data. In order to evaluate more precisely the fishing activity, we propose to incorporate new sensors in the vessels that provide additional information. The sensors of mobile devices offer an economic solution that would allow their implementation throughout the fishing fleet. The objective of this work is to evaluate whether the most common sensors integrated in current mobile devices: GPS, Accelerometer, Gyroscope and Magnetic Field, offer relevant information to identify the different phases of bottom trawling fishing activity. The results obtained indicate that these sensors detect, with very high precision, foreseeable changes in the movement of the vessel during the towing manoeuvre.

Keywords: Vessel monitoring system; mobile device; sensor; trawl fishing; ship's behaviour

Software availability

Name of software: FAMIS

Developers: Galotto-Tebar, M.M.

Hardware requirements: Mobile device with Android 5.1 or higher

Programming languages: Java

Availability: The program will be available up on request to Ms. Maria del Mar Galotto-Tebar.

1. Introduction

The sustainable exploitation of fishery resources is based on the use of common indicators to measure fishing activity [1]. The European Union, under the Common Fisheries Policy, continuously analyses how to improve the fishing capacity and effort indicators of its fishing fleet [2]. The fishing capacity can be objectively quantified from the vessel technical characteristics and the fishing gears, however, the calculation of the fishing activity requires knowing the effective fishing time [3]. Therefore, an accurate estimate of the fishing effort requires knowing the time when the fishing gear is working, for which it is essential to monitor the vessels activity.

With the aim of improving the effectiveness and efficiency of monitoring, control and surveillance of fishing activity, the European Union regulated in 2009 the use of Vessel Monitoring System (VMS) [4]. Thus, from January 1, 2012, every vessel with a total length of more than 12 meters has a VMS transmitter installed, which provides each State Fishing Monitoring Centre with real-time information on the geographical position, course and speed of the vessel.

VMS data have become an indispensable tool to research on the control and planning of fishing activity [5-6]. For example, they have been used to complete and verify the information provided by the Electronic Recording and Reporting System (ERS) and to establish spatial and temporal maps of fishing activity, to study patterns of fishermen's behaviour [7] as well as to accurately assess the vessels trajectories [8-14]. Several authors such as Lee [15] and Szostek [16] have developed and validated fishing effort estimation methods based on the recorded VMS data in United Kingdom vessels. On the other hand, Marzuki [17] used the VMS data for the monitoring and identification of unauthorized fishing activities. In this sense, Gerritsen [5] analysed the effects on CPUE (catch per unit of effort) of the seasonal closure of cod (*Gadus morhua*) from the VMS data. Currently the information provided by the VMSs is available on platforms such as those developed in the Global Fishing Watch projects whose purpose is to provide a tool that allows governments, fishery management organizations, scientists, private industry, and non-governmental organizations to implement rules and regulations that will ensure a sustainable and abundant ocean (www.globalfishingwatch.org).

Despite the undoubted advantages of the availability and use of VMS data, there are certain aspects that hinder to interpret the information they provide. In the first place, as indicated in [4], the installation of transponders is only mandatory for vessels with a length exceeding 12 meters, so that the information coming from a large part of the artisanal fleet is not available. On the other hand, the information transmitted is relatively scarce since the devices send data with a very low frequency (intervals of at least 2 hours) limiting the reliability and precision of the obtained results. Likewise, the use of the VMS data for the determination of trajectories, spatial and temporal fishing maps, and estimation of the fishing effort requires a validation with the auxiliary information provided by the logbooks and / or the on board observers reports [11]. Another VMS deficiency is that it does not provide information on the state of the sea to assess its influence on the trawl gear performance [18] and improve the fishing effort estimation. In addition, the VMS only provides the vessel's speed over the ground, and does not report the vessel's true speed over the surface, obtaining erroneous results in areas with high sea currents. Therefore, we think that in order to evaluate fishing effort more accurately, it is necessary to develop new devices that provide better quality information and whose cost favours their implementation throughout the fishing fleet.

Considering that the presence of an active trawl gear affects the dynamic behaviour of the vessel, as it is affirmed and mathematically modelled by Sun [19], a device equipped with sensors and sufficient processing capacity could record the movement of the vessel and identify the different phases of fishing activity. This task could be carried out by a mobile device (tablet or Smartphone) thanks to the sensors it usually incorporates, its high processing capacity and facility for the development of specific applications (APP). At present there are many fishing APPs, most of them for sport fishing, which take advantage of the sensors potential to georeference the fishing activity. For example, Fishing Status (https://play.google.com/store/apps/details?id=com.FishingStatus) is an application that provides resources and information (local fishing reports and hotspots with GPS coordinates) around 100 miles of the current device location. For its part, Fishing Log (https://play.google.com/store/apps/details?id=com.WebAndPrint.FishDiary) is a logbook application that uses the GPS to georeference the information. Therefore, from the technical point of view we consider it interesting to explore the use of mobile devices on the control and planning of fishing activity.

The objective of this work is to evaluate if the most common sensors integrated in current mobile devices: GPS, Accelerometer, Gyroscope and Magnetic Field, are capable of offering relevant information that allows the identification of the different phases of fishing activity.

2. Material and Methods

2.1. Mobile device, sensors, variables and data

Nowadays, most mobile phones and tablets incorporate GPS, Accelerometer, Gyroscope and Magnetic Field sensors. In this work we used a Samsung SM-P600 tablet with a 6-axis inertial sensor (Bosch Sensortec BMI055) consisting of a digital tri-axial 12 bit acceleration sensor and a digital tri-axial 16 bit gyroscope, a 3-axis electronic 16 bit compass sensor (Asahi Kasei Microdevices AK8963C) and a GPS receiver. From these sensors, a total of 11 variables can be obtained with a sampling period ranging from 50ms to 1s (Table 1).

The accelerometer measures the acceleration applied to the device ($\overrightarrow{Ace}$). Conceptually, it does so by measuring forces (F) applied to the mass of the sensor. In particular, the force of gravity ($\vec{G}$) is always influencing the measured acceleration (Equation 1). By immobilizing the device on the vessel, it moves in solidarity with the vessel, so the mass of the equation corresponds to the sum of the mass of the device plus that of the vessel, and this term can be disregarded and consider that the accelerometer will record the components of the gravity vector ($\vec{G}$) at each instant.

$$\overrightarrow{Ace} = -\vec{G} - \overrightarrow{\sum F} / Mass \approx -\vec{G} \quad (1)$$

The gyroscope measures, in radians per second (rad/s), the rotation speed around the axes OX, OY and OZ, being positive when the rotation around the axis is made in the anti-clockwise direction seen by an observer located in a positive location of the axis.
For its part, the magnetic field sensor measures, in micro-Teslas (μT), the magnetic field in the device environment. The sensor provides the vector components resulting from the vector sum of the earth's magnetic field and the magnetic field generated by the objects in the environment (motors, wiring, etc.) (Equation 2).

$$\overrightarrow{Mag} = \overrightarrow{Mag_{Earth}} + \overrightarrow{Mag_{Environ}} \quad (2)$$

Finally, the GPS (Global Positioning System) sensor is capable of recording information about its three-dimensional geographic location in the form of latitude, longitude and height, based on a satellite network. It also registers a temporary mark of the measurement and generates additional processed information such as course and instantaneous speed, average speed and precision. In this work it has only been considered necessary to store the bearing (*GpsR*) and the instantaneous speed (*GpsV*) every second during the vessel activity.

2.2. The mobile application

A mobile application (APP) has been developed in order to record the vessel movement during its fishing activity. The Integrated Development Environment (IDE) Android Studio has been used to implement the APP on the Android platform. The user interface allows to start the recording and to select the haul phase. Once the recording has begun, the interface shows the data recorded by the sensors numerically and graphically. In addition, it incorporates a configuration menu with data about the ship, the mobile device and the fishing gear. During the recording, the data provided by the sensors, linked to the haul phase, ship's information, fishing gear and mobile device, are temporarily stored in a local database (SQLite).

The communication with the mobile device is done through a REST API (“Application Programming Interface for the Representational State Transfer”) service. When the mobile device has a connection to the server, it sends the information temporarily stored in its database and the server stores it in a MySql database (Figure 1). The server allows access to information through the REST API service or through the WEB service using the RStudio application (Figure 2).

2.3. Case study

The initial execution of the prototype was carried out on the fishing and oceanographic research vessel Miguel Oliver [20] of the General Fisheries Secretariat of Spain, with one length of 70,00 meters, beam of 14,40 meters, draft of 6,50 meters, gross register tonnage of 2.495 GT, maximum speed of 14 knots and equipped with a small draft trawl GOC-73 with Morguere doors. The data survey was performed in 2016 during the MEDITS-ES [21] survey conducted annually by the Spanish Institute of Oceanography (IEO) to evaluate demersal resources along the continental shelf and slope of the Spanish Mediterranean coast from May 27 to June 5, 2016 in the coasts of Castellón, Tarragona, Barcelona and Gerona (Figure 3). During the campaign, the ship movement was recorded along 22 trawl hauls, at 3 knots speed, distributed in twenty sets of 30 minutes in depths from 50 to 200 meters, two sets of 60 minutes in depth greater than 200 meters and an average capture of 60 Kg. In each set, it was recorded at least 15 minutes before the haul (shipping), the complete periods of setting, towing and hauling, and 15 minutes shipping after the haul.

In order to record as accurately as possible, the roll and pitch of the ship, the device was placed on the bridge about 18 meters above the ship centre of gravity, crossing point of the pitch and roll axes [22]. Special interest was placed on the orientation of the device as the sensors offer vector information referenced to the coordinate axes linked to the screen, placing the axis OY parallel to the longitudinal axis (stern-bow), the axis OX parallel to the transverse axis (port- starboard) and the OZ axis parallel to the vertical axis (Figure 4).

2.4. Data analysis

From the information recorded by the sensors and stored in the database, the data table was made by estimating the mean (X_m) and the standard deviation (X_s) in one minute periods, thus obtaining 22 independent quantitative continuous variables. Likewise, a nominal qualitative independent variable named *Activity* composed of 4 categories (shipping, shooting the gear, towing and hauling the gear) was created. The data table was formed by 22 variables with 2453 data divided into 1140 shipping, 262 during the gear shooting, 786 towing and 265 during the gear hauling.

The data analysis focused on identifying the changes in the static and dynamic vessel behaviour during the haul, in identifying the sensors capable of measuring those changes, in locating the quantitative variables to be used to recognize said changes, and in analysing the variables behaviour in the different haul phases. Each quantitative variable was analysed using the kurtosis and Fisher's asymmetry coefficients, the Shapiro-Wilk test to contrast the normality, the box and density plots by haul phase to observe differences, their median and interquartile range by haul phase to detect differences in its central value and dispersion, its coefficient of variation of the absolute deviation of the median (MAD) to discard unrepresentative variables and the nonparametric test of Kruskall-Wallis to confirm the differences between the median values by haul phase. Likewise, quantitative variables were standardized to compare them with each other. The statistical package R-Studio was used to perform all the analyses.

3. Results

This section shows the obtained results from the data table variables related to the trim of the ship and the 4 degrees of freedom of movement affected by the start of the haul and susceptible to be registered by the available sensors: pitch, roll, yaw and surge.

3.1. Trim

The presence of an active fishing gear causes changes in the ship's trim, modifying the angle formed by its longitudinal axis with the horizontal plane. The accelerometer is the sensor capable of recording information about the ship orientation. The variables $AceX_m$, $AceY_m$ and $AceZ_m$ represent the mean gravity vector components and provide information on the ship's orientation with respect to the horizontal plane. The projection of the gravity vector on the centreline plane, represented by the variables $AceY_m$ and $AceZ_m$, makes it possible to evaluate the longitudinal angle of the ship trim.

The variable $AceY_m$ showed a value of kurtosis ($\beta = 4.27$) and a p-value of the Shapiro-Wilk test ($p < 0.001$) that suggested that the data did not adjust to a normal distribution. The Kruskall-Wallis test ($p < 0.001$) showed the existence of significant differences in its central value and dispersion between activities. During the set, their median increased by 42% and their interquartile range was reduced by 58% (Table 2, Figure 5). On the other hand, $AceZ_m$ presented a clearly non-normal behaviour ($\gamma = 2.74$, $\beta = 21.58$, Shapiro-Wilk test $p < 0.001$) and its density by activity showed the absence of significant differences in its central value and dispersion (Kruskall-Wallis test $p = 0.749$) (Table 2; Figure 6)

3.2. Roll and Pitch

Pitch and roll movements are originated by external forces such as waves, wind, etc. In both cases, the vessel describes the rotational movements around its transverse and longitudinal axis, causing the alternate rise and fall of the bow and stern or of the port and starboard bands. The presence of an active fishing gear causes the displacement of the vessel mass centre (crossing point of the transverse and longitudinal axes) and modifies the pitch and roll movements. The accelerometer, gyroscope and magnetic field sensors detect these changes.

The accelerometer showed higher values of the coefficient of variation in $AceX_s$, $AceY_s$ and $AceZ_s$. Like $AceZ_m$, the deviations associated with the three axes of the accelerator present behaviours with non-normal distributions. In $AceX_s$ and $AceZ_s$ (Kruskall-Wallis $AceX_s$ Test $p < 0.001$; Kruskall-Wallis $AceY_s$ Test $p = 0.168$; Kruskall-Wallis $AceZ_s$ Test $p < 0.001$) (Table 2; Figures 7 and 8)

The gyroscope measures the speed of rotation around the X, Y and Z axes. The sensors orientation on the ship indicates that the variable *GirX* records the pitch movement and the variable *GirY* the roll movement. In particular, the $GirX_s$ and $GirY_s$ variables of the data table must change in the variability or dispersion of the pitch and roll rotation speed. The $GirX_s$ and $GirY_s$ components showed a non-normal behaviour and at least one of them ($GirY_s$) pointed out the possibility of differentiating the navigation from the towing, shooting and hauling activities (Kruskall-Wallis $GirY_s$ test $p < 0.001$) (Table 2; Figure 9), however, $GirX_s$ did not present any difference between the four activities (Kruskall-Wallis test $GirX_s$ $p = 0.198$).

For its part, the magnetic field sensor measures in micro Teslas (µT) the magnetic field in the environment of the device. Therefore, all the components of the vector that register the sensor (*MagX*, *MagY* and *MagZ*) and particularly the variables $MagX_s$, $MagY_s$ and $MagZ_s$ are likely to show the pitch and roll changes in the different haul phases. The Shapiro-Wilk tests indicate that none of the three variables presented a normal distribution. However, a comparison of medians showed differences between the central value and the dispersion between shipping and towing activities in the variables $MagX_s$, $MagY_s$ (Kruskall-Wallis $MagX_s$ test $p < 0.001$) (Table 2, Figures 10 and 11) and to a lesser extent in the variable $MagZ_s$.

3.3. Yaw

The yaw movement is a rotation oscillatory movement around the ship OZ axis that causes small changes in the course of the vessel. The sensors capable of recording the yaw are the gyroscope, the magnetic field sensor and the GPS.

The Z component of the gyroscope measures the speed of rotation around the OZ axis and the variable $GirZ_s$ records the magnitude of the course changes during the fishing activity. The $GirZ_s$ data had a clearly asymmetric distribution ($\gamma = 3.59$) that caused the Shapiro-Wilk test to be highly significant ($p < 0.001$). Likewise, it showed a high variability around its median, which was reflected in the level of significance of the Kruskall-Wallis test ($p < 0.001$) (Table 2, Figure 12).

In turn, the magnetic field sensor X and Y components are the most sensitive ones to the ship yaw along with the variables described in the previous section $MagX_s$ and $MagY_s$ that reflect its magnitude.

The GPS sensor provided also information on vessel the course and speed. $GpsR_s$ is the more sensitive to yaw variable. This variable showed a high variability of 92% around its median (Table 2). The density diagram (Figure 13) showed significant differences in its central value and dispersion among activities (Kruskall-Wallis test $p < 0.001$). Its median decreased by 16% in the shooting phase, increased by 53% in the towing phase and by 160% in the hauling phase.

3.4. Surge

The study of the surge speed during the different fishing activity phases focuses on analysing the average speed and speed stability against external forces. In this way, the sensor that measures the surge speed is the GPS and $GpsV_m$ is the variable to show the average speed evolution. This variable clearly discriminates between the navigation and the rest of the activity phases and this was reflected in significant differences of its central value and dispersion (Table 2; Figure 14).

On the other hand, the surge stability is characterized by the variable $GpsV_s$ (speed variability). The analysis of this variable indicated that both, the asymmetry and kurtosis coefficients, were out of range ($\gamma = 4.56$, $\beta = 28.21$). A Shapiro-Wilk test ($p < 0.001$) confirmed that the data did not show a normal distribution. The variable showed a high variability of 69% around its median (Table 2). The activity density (Figure 15) and the Kruskall-Wallis test ($p < 0.001$) showed significant differences in their central value and dispersion among the activities. Its median decreased by 24% in the towing phase and increased by 125% in the shooting phase and by 62% in the hauling phase. Its interquartile range decreased by 33% in the towing phase and increased by 267% in the shooting phase and by 93% in the hauling phase.

4. Discussion

Significant progress in data collection involves the acquisition of this information for all vessels, including those that are not required to have a VMS system installed, for which it is essential to develop effective, low-cost and easy-to-install systems. Faced with the high cost of current VMS devices, the solution we propose for each fishing vessel is a mobile device running a specific APP and a modem that allows its connection to a satellite network. In the coastal fleet the cost can be reduced if the communication is done through the mobile phone network or using the Wifi network when arriving at the port. The estimation of the cost has been calculated using a medium range mobile phone and an Iridium modem with worldwide coverage, obtaining an estimated cost of 700 € for local equipment and 400 €/year of maintenance and data transmission. These numbers contrast with the current costs of the VMS for deep-sea fishing of 3500€ for local equipment and 800€/year of maintenance, or the costs for coastal fishing such as the SLSEPA system of 1400€ for local equipment and 1200€/year of maintenance [23].

To evaluate if the sensors of mobile devices have the necessary sensitivity to record changes in the movement of the vessel when the trawl is active, we found the most unfavourable test environment where these changes were minimal. The effect of the trawl fishing gear on the vessel depends on the size of the vessel, the size of the fishing gear and the volume of catch dragged [19]. On the one hand, the larger the vessel, the smaller the movement due to wind and waves. On the other hand, the smaller the fishing gear and the volume of catch with respect to the size of the vessel, the smaller its effect on the vessel and the differences in the dynamic behaviour of the vessel between each phase of the fishing set will be smaller. The oceanographic vessel Miguel Oliver during the Medits campaign meets these requirements, it is a large vessel equipped with a small sampling trawl, executing during the campaign sets of short duration and with a small volume of catch. A commercial trawler usually offers more favourable conditions for sensors to record differences in their dynamic behaviour during the set. Therefore, we can state that the results presented in this paper can be applied to most of the trawl fishing fleet. These results are analysed below.

4.1. Trim

During the set, the fishing gear is towed by two cables located on both sides of the stern of the vessel, each one exerting a pulling force on the vessel that causes changes in its the static and dynamic behaviour [19]. This force appears when the gear is released, increases during the trawling phase and is maximal when the trawling speed increases during the hauling phase. The vertical component of these forces causes a progressive ship centre of mass displacement aft and consequently an increase in the ship seat.

4.2. Pitch and roll

When a ship is in equilibrium position, the centre of buoyancy (point through which the force of buoyancy supporting the vessel acts vertically upwards) and the centre of gravity (point through which all of the weight of the vessel acts vertically downwards) are in the same vertical axis. When an external force inclines the ship, the submerged part of the hull is modified; the centre of the hull moves and a righting pair that opposes this inclination is generated [22,24].

The presence of a fishing gear increases the righting torque and reduces the vessel pitch and roll [19]. In both movements there are variations in speed and drag that cause an additional centre of masses displacement increasing its distance from the centre of the hull.

Our results show that the accelerometer, gyroscope and magnetic field sensors were able to detect a decrease in the pitch and roll level during the haul. In the case of the accelerometer, the variables $AceX_s$ and $AceZ_s$ reflected a significant reduction in their median and interquartile range. On the other hand, the $GirY_s$ gyroscope variable reflected a reduction of its median and interquartile range. Finally, the $MagX_s$ and $MagY_s$ magnetic field sensor variables recorded, a reduction in its median and interquartile range during the towing phase.

4.3. Yaw

The yaw movement is a rotation oscillatory movement around the ship's OZ axis that causes small changes in the vessel's course. A starboard turn accelerates the port drag line and slows the starboard line, causing an imbalance in the drag forces that opposes the ship turn. A turn to port provokes the same effect. As a result, during the haul, the yaw movement is reduced and the ship course remains more stable [19].

The gyroscope, the magnetic field sensor and the GPS have been able to detect the reduction of the yaw angle during haul. In the case of the gyroscope, the $GirZ_s$ variable has shown a reduction in the towing phase in its median and interquartile range. As mentioned in the previous section, the $MagX_s$ and $MagY_s$ variables of the magnetic field sensor have also shown greater stability on the course during the haul. Finally, the results obtained with the GPS indicate that the variable shows small reductions of its median and a significant reduction of its interquartile range between the shipping and towing phases. During the setting and hauling phases there is an increase of this movement due to the fact that in these phases there are usually course changes in order to orient the vessel to the haul that will begin or to direct the vessel to the next fishing zone.

4.4. Surge

The study of the ship speed during the different fishing activity phases focuses on analysing the average speed reached voluntarily by acting on the propulsion system and observing the stability of the desired speed against external forces (waves, gusts of wind, etc).

The variable $GpsV_m$ reflected, in each haul phase, velocity values similar to those found in other studies for trawl fishing [15,17,25], with medians of 8.4 knots shipping, 4.5 knots setting, 3 knots towing and 2.1 knots hauling. Furthermore, the expected variability of the speed is reflected in its interquartile ranges of 5.7 knots shipping, 1.2 knots setting, 0.16 knots towing and 1.4 knots hauling.

During the haul, small variations in speed cause changes in the drag force that opposes to the speed change. The trawl net shock absorbing effect allows the vessel to maintain a more stable forward speed [19]. The analysis of the variable $GpsV_s$ data shows that the speed value and speed variation are lower in the towing phase than in the shipping phase. During the set and haul phases, the speed varies voluntarily, which justifies an increase in the $GpsV_s$ median and dispersion.

5. Conclusions

Processing data into information and information into knowledge, in order to optimise the decision-making process, is one of the great challenges facing the managing bodies that plan the exploitation of fishery resources. In this context, the VMS system has become a relevant source of data, boosting research on the fishing activity control and planning as can be seen in Gerritsen [5] and Jennings [6]. In spite of this, the scarce information offered by the VMS system limits its future.

Analysed the results of this article, the proposal to use in the future a mobile like device to overcome the VMS systems seems more viable. As a first step, we have verified that the sensors of a mobile device are capable of detecting significant differences in the movement of the vessel, as stated and mathematically modeled by Sun [19]. The experience was realised under very unfavourable conditions, in a large tonnage oceanographic vessel, with a small fishing gear, a small catch volume, and in weather conditions that did not cause large movements of the vessel. In spite of this, the sensors of the mobile device recorded a progressive increase in the ship's seat, a reduction in the angle of balance, pitch and yaw, and an increase in the stability of surge and speed values according to the haul phase.

In short, the results of this work indicate that the mobile device’s sensors have been able to detect, with a very high accuracy level, the foreseeable changes in the movement of the vessel during the trawling manoeuvre.

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7. References

1. FAO Fishery Resources Division, 1999. Indicators for sustainable development of marine capture fisheries, in: FAO Technical Guidelines for Responsible Fisheries. Rome. Recovered from http://www.fao.org/3/a-x3307e.pdf
2. European Commission, 2007. On improving fishing capacity and effort indicators under the common fisheries policy. Brussels. Recovered from http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52007DC0039&from=LV
3. de Souza, E.N., Boerder, K., Matwin, S., Worm, B., 2016. Improving Fishing Pattern Detection from Satellite AIS Using Data Mining and Machine Learning. PLoS One 11, e0158248. https://doi.org/10.1371/journal.pone.0158248
4. Council of the European Union, 2009. Regulation 1224/2009. Community control system for ensuring compliance with the rules of the Common Fisheries Policy, amending Regulations (EC) No. 847/96, (EC) No 2371/2002, (EC) No. 811/2004, (EC) No. 768/2005, (EC) No. 2115/2005, (EC) No. 2166/2005, (EC) No. 388/2006, (EC) No. 509/2007, (EC) No. 676/2007, (EC) No. 1098/2007, (EC) No. 1300/2008, (EC) No. 1342/2008 and repealing Regulations (EEC) No. 2847/93, (EC) No. 1627/94 and (EC) No. 1966/2006. Official Journal of the European Union, L343: 1–50. Strasbourg. Recovered from http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009R1224&rid=1
5. Gerritsen, H.D., Lordan, C., Minto, C., Kraak, S.B.M., 2012. Spatial patterns in the retained catch composition of Irish demersal otter trawlers: High-resolution fisheries data as a management tool. Fish. Res. 129–130, 127–136. https://doi.org/10.1016/J.FISHRES.2012.06.019
6. Jennings, S., Lee, J., 2012. Defining fishing grounds with vessel monitoring system data. ICES J. Mar. Sci. 69, 51–63. https://doi.org/10.1093/icesjms/fsr173
7. Shepperson, J., Murray, L.G., 2016. Use of a choice-based survey approach to characterise fishing behaviour in a scallop fishery. Env. Mod. & Soft. 86, 116-130. https://doi.org/10.1016/j.envsoft.2016.09.013

8. Palmer, M.C., 2008. Calculation of distance travelled by fishing vessels using GPS positional data: A theoretical evaluation of the sources of error. Fish. Res. 89, 57–64. https://doi.org/10.1016/J.FISHRES.2007.09.001
9. Deng, R., Dichmont, C., Milton, D., Haywood, M., Vance, D., Hall, N., Die, D., 2005. Can vessel monitoring system data also be used to study trawling intensity and population depletion? The example of Australia’s northern prawn fishery. Can. J. Fish. Aquat. Sci. 62, 611–622. https://doi.org/10.1139/f04-219
10. Mills, C.M., Townsend, S.E., Jennings, S., Eastwood, P.D., Houghton, C.A., 2007. Estimating high resolution trawl fishing effort from satellite-based vessel monitoring system data. ICES J. Mar. Sci. 64, 248–255. https://doi.org/10.1093/icesjms/fsl026
11. Bastardie, F., Nielsen, J.R., Ulrich, C., Egekvist, J., Degel, H., 2010. Detailed mapping of fishing effort and landings by coupling fishing logbooks with satellite-recorded vessel geo-location. Fish. Res. 106, 41–53. https://doi.org/10.1016/j.fishres.2010.06.016
12. Gerritsen, H., Lordan, C., 2011. Integrating vessel monitoring systems (VMS) data with daily catch data from logbooks to explore the spatial distribution of catch and effort at high resolution. ICES J. Mar. Sci. 68, 245–252. https://doi.org/10.1093/icesjms/fsq137
13. Hintzen, N.T., Bastardie, F., Beare, D., Piet, G.J., Ulrich, C., Deporte, N., Egekvist, J., Degel, H., 2012. VMStools: Open-source software for the processing, analysis and visualisation of fisheries logbook and VMS data. Fish. Res. 115–116, 31–43. https://doi.org/10.1016/J.FISHRES.2011.11.007
14. Cojan, M., Burgos, C., 2015. Análisis de la información proporcionada por los sistemas de localización vía satélite de la flota que explota la chirla (*Chamelea gallina*) en el Golfo de Cádiz sistemas de localización vía satélite de la flota que explota la chirla (*Chamelea gallina*), in: Teledetección: Humedales y Espacios. XVI Congreso de La Asociación Española de Teledetección. pp. 550–553.
15. Lee, J., South, A.B., Jennings, S., 2010. Developing reliable, repeatable, and accessible methods to provide high-resolution estimates of fishing-effort distributions from vessel monitoring system (VMS) data. ICES J. Mar. Sci. 67, 1260–1271. https://doi.org/10.1093/icesjms/fsq010
16. Szostek, C.L., Murray, L.G., Bell, E., Kaiser, M.J., 2017. Filling the gap: Using fishers’ knowledge to map the extent and intensity of fishing activity. Mar.

Environ. Res. 129, 329–346. https://doi.org/10.1016/J.MARENVRES.2017.06.012

17. Marzuki, M.I., Garello, R., Fablet, R., Kerbaol, V., Gaspar, P., 2015. Fishing gear recognition from VMS data to identify illegal fishing activities in Indonesia, in: MTS/IEEE OCEANS 2015 - Genova. Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/OCEANS-Genova.2015.7271551
18. Politis, P.J., DeAlteris, J.T., Brown, R.W., Morrison, A.T., 2012. Effects of sea-state on the physical performance of a survey bottom trawl. Fish. Res. 123–124, 26–36. https://doi.org/10.1016/J.FISHRES.2011.11.017
19. Sun, X., Yin, Y., Jin, Y., Zhang, X., Zhang, X., 2011. The modelling of single-boat, mid-water trawl systems for fishing simulation. Fish. Res. 109, 7–15. https://doi.org/10.1016/J.FISHRES.2010.12.027
20. "Buque oceanográfico Miguel Oliver," *Ministerio de agricultura, pesca y alimentación*. [Online]. Available: https://www.mapa.gob.es/es/pesca/temas/proteccion-recursos-pesqueros/buques-secretaria-general/investigacion-pesquera-oceanografica/miguel-oliver/default.aspx. [Accessed: 24-Jul-2019].
21. Bertrand, J.A., Gil de Sola, L., Papaconstantinou, C., Relini, G., Souplet, A., 2002. The general specifications of the MEDITS surveys. Sci. Mar. 66, 9–17. https://doi.org/10.3989/scimar.2002.66s29
22. Ibrahim, R.A., Grace, I.M., 2010. Modelling of Ship Roll Dynamics and Its Coupling with Heave and Pitch. Math. Probl. Eng. 2010, 1–32. https://doi.org/10.1155/2010/934714
23. Agricultura y Pesca, C., 2010. Location and Track System for Andalusian Fishing Vessels (SLSEPA). (Technical report). Junta de Andalucía. Recovered from http://www.faocopemed.org/pdf/reg_net_dbases/location and track system for andalusian fishing vessels (slsepa).pdf.
24. Romano, A., Marasco, A., 2014. Fluid Dynamics and Ship Motion. Birkhäuser, New York, NY, pp. 429–461. https://doi.org/10.1007/978-1-4939-1604-7_13
25. Burgos, C., Gil, J., del Olmo, L.A., 2013. The Spanish blackspot seabream (Pagellus bogaraveo) fishery in the Strait of Gibraltar: spatial distribution and fishing effort derived from a small-scale GPRS/GSM based fisheries vessel monitoring system. Aquat. Living Resour. 26, 399–407. https://doi.org/10.1051/alr/2013068

TABLES

Sensor	Measured Parameter	Sampling period	Variable
Acceleration *Range = ±19.6133 m/s²* *Sensitivity = 0,009570 m/s²*	Linear acceleration vector	50 ms	AceX AceY AceZ
Gyroscope *Range = ±8.7266 rad/s* *Sensitivity = 0.0002661 rad/s*	Rotation speed around the 3 axes	50 ms	GirX GirY GirZ
Magnetic field *Range = ±4900 µT* *Sensitivity = 0.6 µT*	Vector of the magnetic field	50 ms	MagX MagY MagZ
Gps	Bearing Speed	1 s	GpsR GpsV

Table 1. Main characteristics of the sensors used, description of the recorded physical parameter, data generation interval of each sensor (sampling period) and variables extracted from each parameter.

	$AceX_m$	$AceY_m$	$AceZ_m$	$GirX_m$	$GirY_m$	$GirZ_m$	$MagX_m$	$MagY_m$	$MagZ_m$	$GpsR_m$	$GpsV_m$
N	2453	2453	2453	2453	2453	2453	2453	2453	2453	2453	2453
Mean	-1,0302	0,0412	9,8941	-0,0001	0,0003	0,0000	-29,2530	60,0077	-15,2240	140,8623	4,9530
Median	-1,0420	0,0440	9,8940	0,0000	0,0000	0,0000	-33,5270	65,4720	-16,0900	114,2770	3,4580
SD	0,0692	0,0162	0,0121	0,0005	0,0005	0,0027	11,6915	15,1598	3,0334	103,6299	2,9446
CV_Pearson	0,0672	0,3932	0,0012	4,7825	1,4049	62,8112	0,3997	0,2526	0,1992	0,7357	0,5945
MAD	0,0667	0,0163	0,0074	0,0000	0,0000	0,0000	12,7593	17,3242	2,8807	116,2092	1,5879
CV_MAD	0,0640	0,3707	0,0007	-	-	-	0,3806	0,2646	0,1790	1,0169	0,4592
Min	-1,4660	-0,0420	9,8300	-0,0040	-0,0010	-0,0270	-50,0170	34,9760	-20,8220	2,6130	0,0580
Max	-0,6170	0,0870	9,9930	0,0020	0,0020	0,0240	-6,8830	81,2610	-7,5720	356,0770	10,3920
Range	0,8490	0,1290	0,1630	0,0060	0,0030	0,0510	43,1340	46,2850	13,2500	353,4640	10,3340
Skewness	0,3780	-0,8532	2,7354	-1,7448	0,7071	0,0192	0,4113	-0,3437	0,6319	0,5513	0,6494
Kurtosis	4,2573	4,2739	21,5804	14,2086	1,6542	36,7724	1,6587	1,5022	2,4319	2,0463	1,9805
Kr.Wallis p-val	0,1177	0,0000	0,7489	0,0158	0,9760	0,0001	0,0000	0,0000	0,0000	0,0000	0,0000

	$AceX_s$	$AceY_s$	$AceZ_s$	$GirX_s$	$GirY_s$	$GirZ_s$	$MagX_s$	$MagY_s$	$MagZ_s$	$GpsR_s$	$GpsV_s$
N	2453	2453	2453	2453	2453	2453	2453	2453	2453	2453	2453
Mean	0,0872	0,0680	0,0645	0,0039	0,0032	0,0019	0,4904	0,5637	0,4417	7,6063	0,2339
Median	0,0680	0,0540	0,0490	0,0030	0,0020	0,0020	0,3290	0,4030	0,3940	1,0430	0,0690
SD	0,0568	0,0395	0,0450	0,0019	0,0020	0,0013	0,7251	0,7283	0,3198	22,0062	0,4935
CV_Pearson	0,6516	0,5815	0,6973	0,4818	0,6135	0,6631	1,4785	1,2921	0,7240	2,8931	2,1097
MAD	0,0356	0,0297	0,0282	0,0015	0,0015	0,0015	0,0593	0,0771	0,1097	0,9563	0,0474
CV_MAD	0,5233	0,5491	0,5749	0,4942	0,7413	0,7413	0,1803	0,1913	0,2785	0,9169	0,6876
Min	0,0180	0,0090	0,0150	0,0020	0,0010	0,0010	0,2330	0,2820	0,2540	0,1040	0,0000
Max	0,4170	0,2610	0,3350	0,0130	0,0150	0,0140	16,2410	16,8470	11,6380	179,0620	4,3130
Range	0,3990	0,2520	0,3200	0,0110	0,0140	0,0130	16,0080	16,5650	11,3840	178,9580	4,3130
Skewness	1,8170	1,2624	1,9776	1,0152	1,9266	3,5891	9,6756	9,3140	20,9884	4,8946	4,5567
Kurtosis	6,9348	4,2777	7,8477	3,5099	7,5787	23,9303	140,6254	139,7816	653,1549	29,7713	28,2055
Kr.Wallis p-val	0,0000	0,1677	0,0000	0,1977	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000

Table 2. Statistical summary of the 22 variables under study. The variable with subscript *m* represents the average of the data generated by the sensor in periods of 1 minute. The variable with subscript *s* represents the standard deviation of the data generated by the sensor in periods of 1 minute. For each variable, the table includes the number of samples (*N*), the mean, the median, the standard deviation (*SD*), the Pearson's Coefficient of Variation (*CV_Pearson*), the median absolute deviation (*MAD*), the coefficient of variation of the median absolute deviation (*CV_MAD*), the minimum value (*Min*), the

maximum value (*Max*), the range of values (*Range*), the skewness, the kurtosis and the p-val of the Kruskal Wallis normality test (*Kr.Wallis p-val*).

double

FIGURES

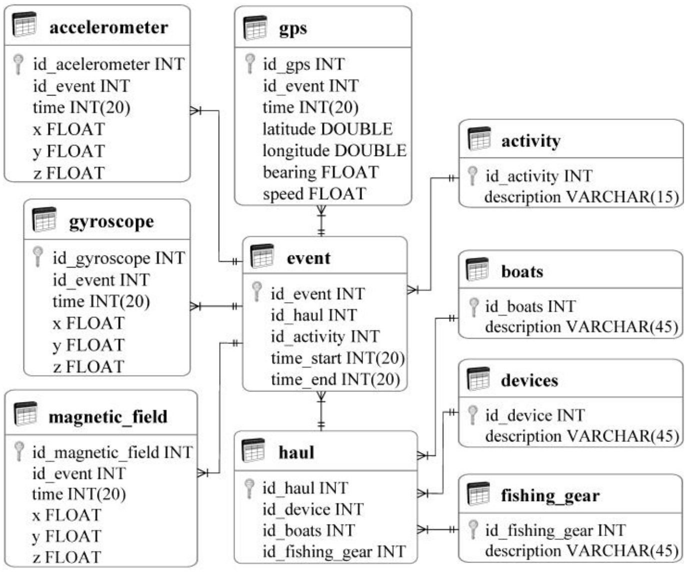

Figure 1. Structure of the relational database that stores the data recorded by the sensors of the mobile device. The *accelerometer* table contains the acceleration applied to the mobile device (vector *{x,y,z}*) and the instant (*time*) in which it has been recorded. The *gyroscope* table contains the rotation speed around the three axes (vector *{x,y,z}*) of the mobile device and the instant (*time*) in which it was recorded. The magnetic_field table contains the magnetic field around the mobile device (vector *{x,y,z}*) and the instant (*time*) in which it has been recorded. The *gps* table contains the position (*latitude* and *longitude*), *bearing* and *speed* of the vessel and the instant (*time*) in which it has been recorded. The *activity* table contains the description of the four different activities of the vessel: *shipping*, *setting*, *towing* and *hauling*. The *boats* table contains the description of the fishing vessels involved in the study. The *devices* table contains the description of the mobile device used. The *fishing_gear* table contains the description of the fishing gear used. Table *haul* contains the registered haul number. The *event* table allows to relate each data stored in the accelerometer, gyroscope, magnetic_field and gps tables to the activity, haul number, fishing vessel, fishing gear and mobile recording device.

***(**Single column)*

Figure 2. Mobile application user interface and information flow.

(*Single column)*

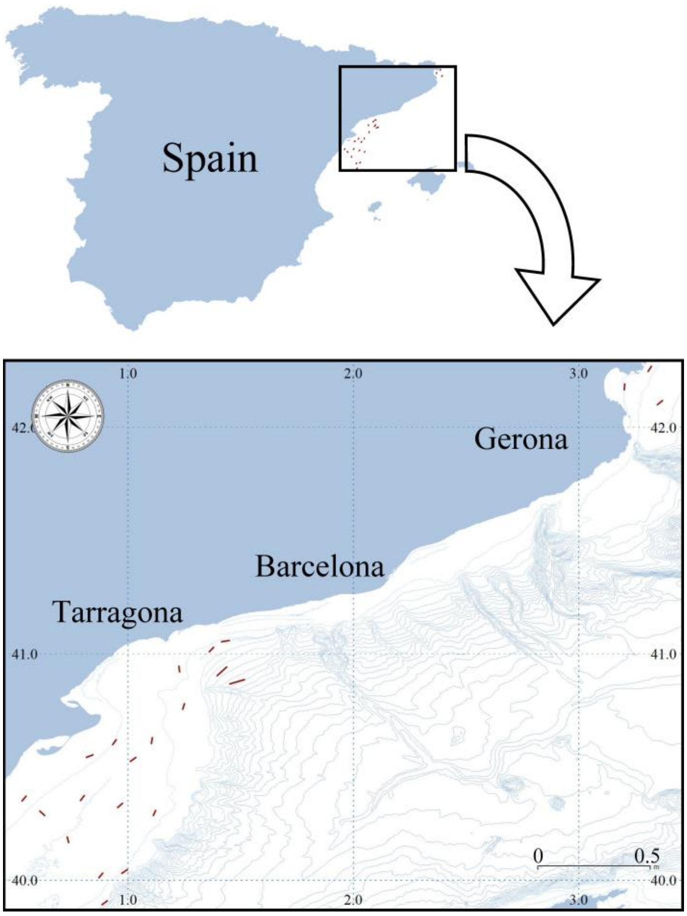

Figure 3. Spatial distribution of the 22 hauls recorded along the coast of Castellón, Tarragona, Barcelona and Gerona (Spain)

(Single column)

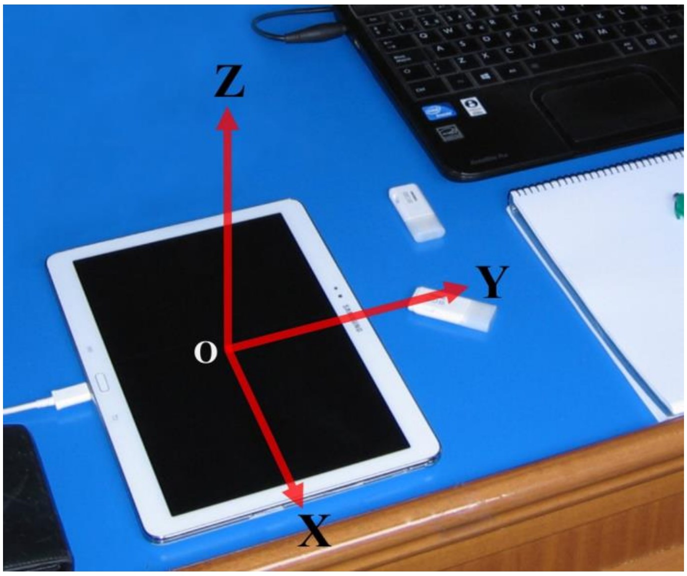

Figure 4. Location of the mobile device on the bridge of the oceanographic vessel.

(Single column)

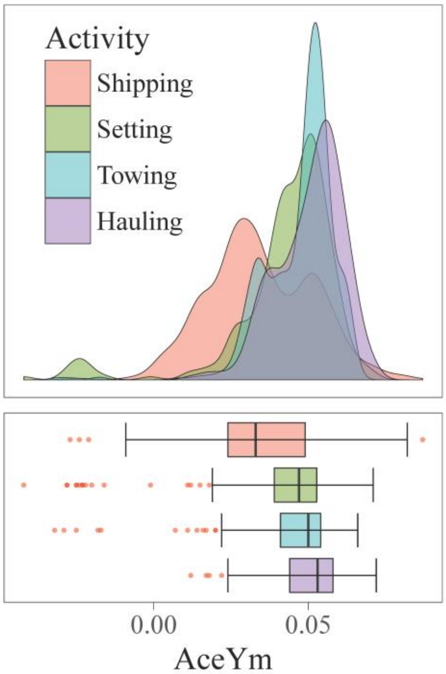

Figure 5. Tukey boxplots and density by activity of the variable $AceY_m$.

(Single column)

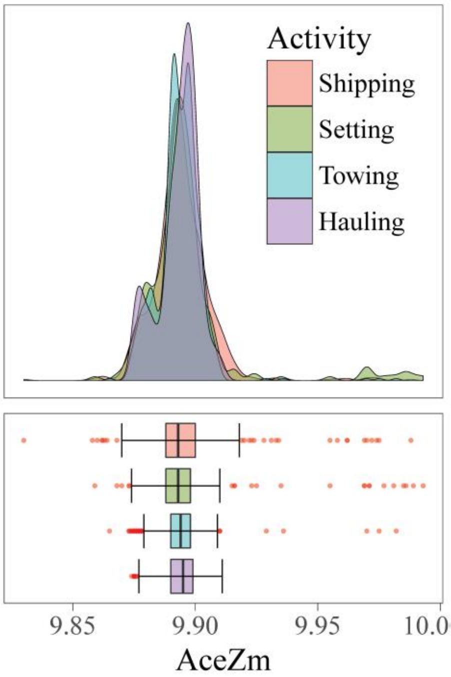

Figure 6. Tukey boxplots and density by activity of the variable *AceZ$_m$*.

(*Single column)*

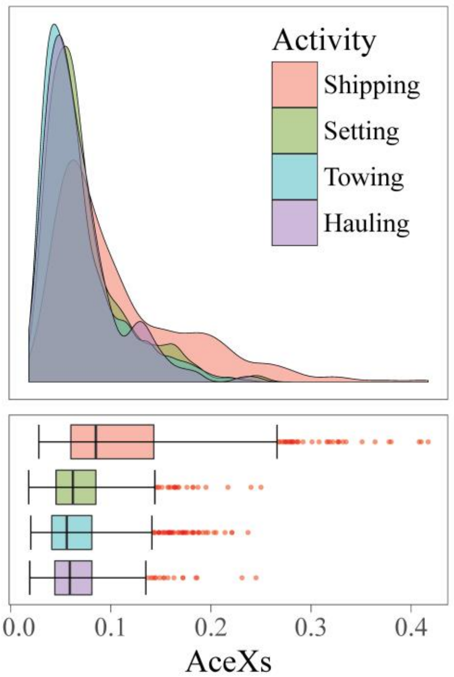

Figure 7. Tukey boxplots and density by activity of the variable *AceX$_s$*.

(*Single column)*

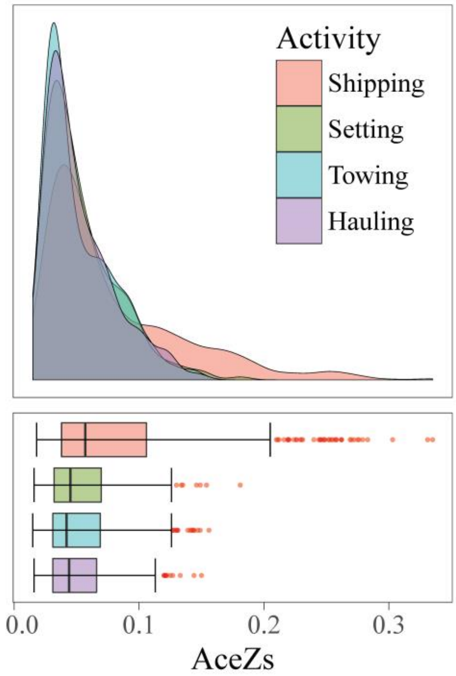

Figure 8. Tukey boxplots and density by activity of the variable $AceZ_s$.

(*Single column)*

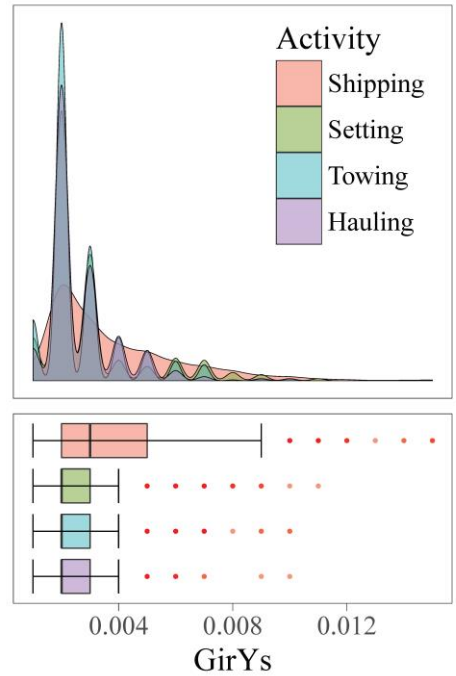

Figure 9. Tukey boxplots and density by activity of the variable $GirY_s$.

(*Single column)*

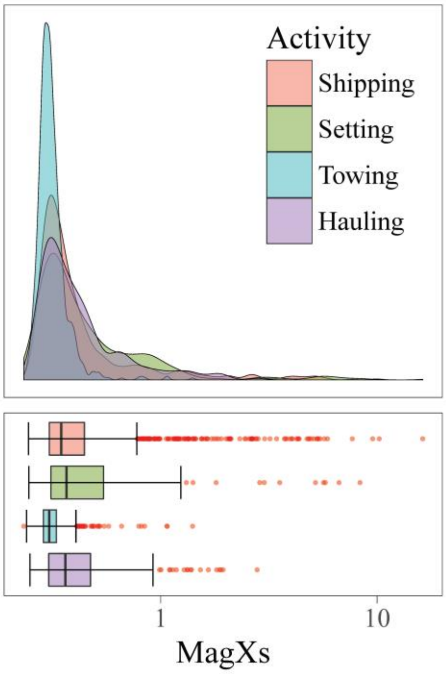

Figure 10. Tukey boxplots and density by activity of the variable $MagX_s$. Logarithmic scale was used on the OX axis.

(Single column)

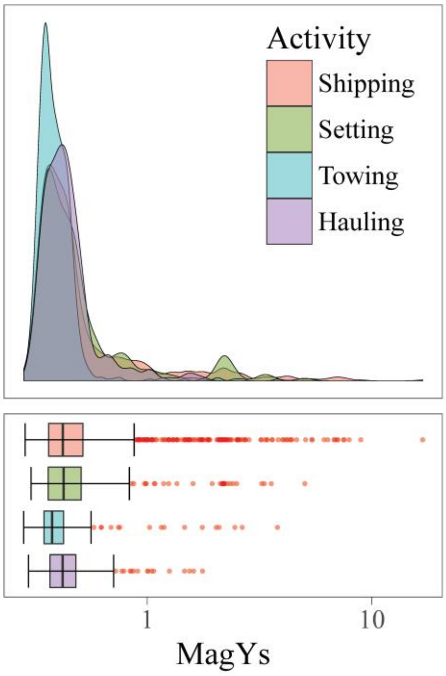

Figure 11. Tukey boxplots and density by activity of the variable $MagY_s$. Logarithmic scale was used on the OX axis.

(Single column)

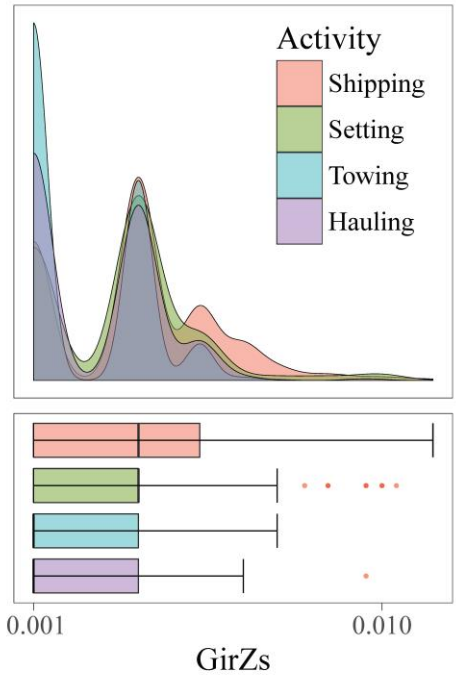

Figure 12. Tukey boxplots and density by activity of the variable *GirZ*$_s$. Logarithmic scale was used on the OX axis.

(Single column)

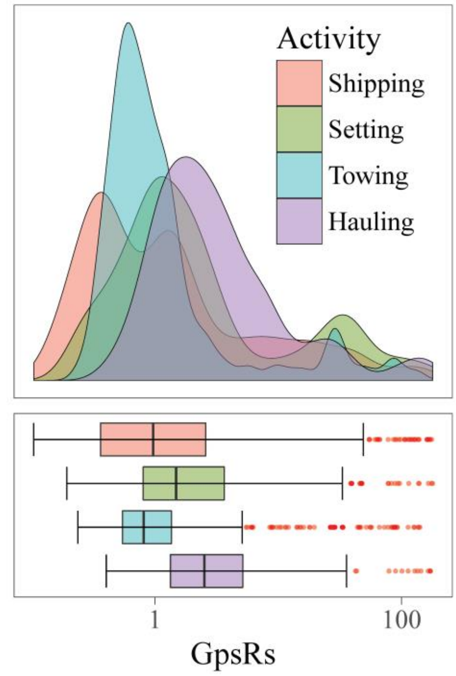

Figure 13. Tukey boxplots and density by activity of the variable *GpsR*$_s$. Logarithmic scale was used on the OX axis.

(Single column)

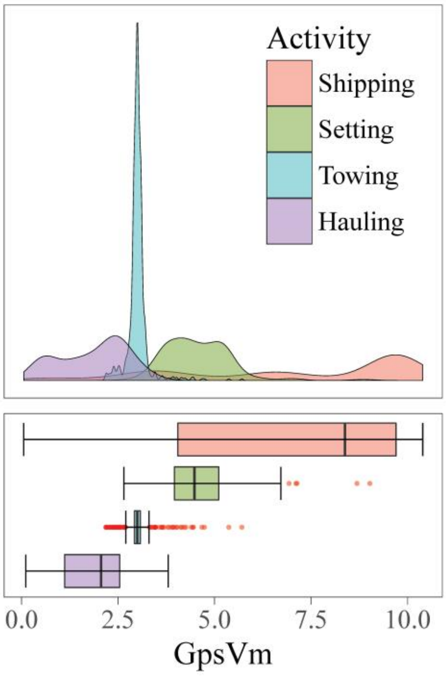

Figure 14. Tukey boxplots and density by activity of the variable $GpsV_m$.

(Single column)

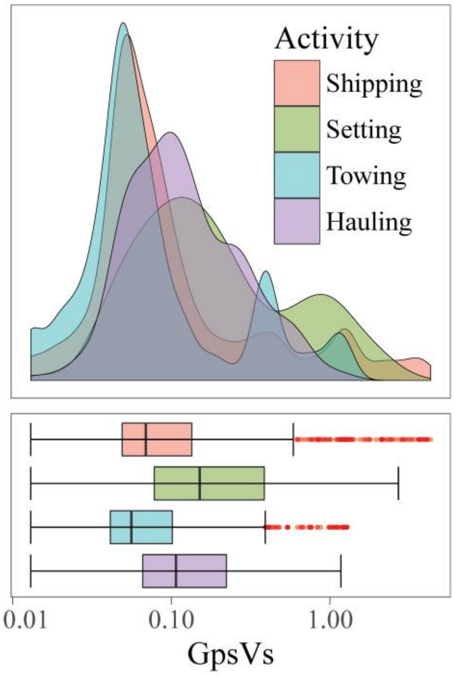

Figure 15. Tukey boxplots and density by activity of the variable $GpsV_s$. Logarithmic scale was used on the OX axis.

(Single column)