SOME CONSIDERATIONS ON THE USE OF AIS DATA TO ESTIMATE SHIPPING DENSITY FOR SHIP STRIKE RISK ASSESSMENT

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Abstract

Data on shipping density are required for input into risk assessment of ship strikes. Automatic identification Systems (AIS) data have been used for estimation of shipping density in a number of studies. Several different measures of density exist and some methods are presented for converting these to comparable units. The limited range of terrestrial AIS complicates analysis and limits spatial coverage. New developments in AIS received from satellites (S-AIS) have allowed correction factors to be applied for vessels missed and provided the first quantitative estimates of average shipping density at a global scale. These highlight the concentrated nature of global shipping with the majority of under way vessels concentrated in 2% of the global sea area when shipping density is averaged over 1^o blocks. Although relatively coarse resolution these data provide new opportunities for comparative ship strike risk assessments and S-AIS data may be available at a finer spatial scale for areas of specific interest identified as high risk.

Introduction

Data on shipping density patterns are required for assessing ship strike risk and developing mitigation measures. There are several commercial and government initiatives to develop databases of data that could be used for analyses of shipping density.

The IWC-ACCOBAMS workshop (IWC, 2010) agreed that approaches to data holders of shipping data for access for research use may be facilitated by the support of organisations such as IWC, ACCOBAMS, IMO or UNEP. However, before the support of IWC or ACCOBAMS is given to any specific requests, the Workshop recommended that researchers requesting support, clearly specify the objectives of the work, the data required and the analytical methods proposed and that these are reviewed carefully (e.g. by the Scientific Committees of IWC and/or ACCOBAMS).

Following on from these recommendations, this paper aims to describe some of the issues associated with analysis of shipping density data from Automatic Identification System (AIS) transmissions. The intention is to promote discussion of some general considerations that should assist the Committee in reviewing proposals requesting support from IWC for data access.

There have been several studies that have used AIS data in the context of assessing risk of collisions between vessels and cetaceans. The general features and limitations of AIS and alternative systems are described in (IWC, 2010) and also in various papers using AIS or other sources of shipping data (e.g. Evans et al., 2011; Hatch et al., 2008; Leaper and Danbolt, 2008; Silber and Bettridge, 2010; Vanderlaan and Taggart, 2009; Williams and O'Hara, 2010). Key limitations of AIS are that many smaller fishing and recreational vessels do not use the system and the limited transmission range, typically around 50km depending on the height of the transmitting and receiving aerials. The limited and unpredictable transmission range of terrestrial AIS is one of the main factors that needs to be taken into account in analysis of AIS data to estimate shipping density. AIS transmissions can also be monitored by satellite (S-AIS). S-AIS allows monitoring over a wide geographical area but is complicated by saturation of the receiver in areas of high shipping density. The AIS system has a Time Division Multiplexing (TDM) transmission protocol which prevents ships operating within range of each other from transmitting simultaneously and interfering with each other's signals. This system does not work for a satellite receiving signals from over a much wider area and so many transmissions can be lost through interference. Hence analysis of S-AIS data needs to take account of the changes in detection probability in high density areas (Eiden and Martinsen, 2010). Nevertheless, there has been considerable interest in using S-AIS for monitoring global shipping (e.g. Høye et al., 2008) and a recent EU funded study has developed correction factors to produce the first quantitative global data set of shipping density estimates (Eiden and Martinsen, 2010) and to make these available on the internet (https://webgate.ec.europa.eu/maritimeforum/node/1603).

There are around 62,000 class A-vessels globally fitted with AIS transponders. The proportion by vessel type as identified in AIS transmissions is shown in Figure 1. Eiden and Martinsen (2010) found from a sample of AIS transmissions from around 20,000 vessels that 75% of the global fleet will be under way at any given time.

Methods for analysis of AIS data

Measures of shipping density
IWC (2010) recommended collaborative efforts with shipping experts to develop comparable density plots for cetaceans and vessels at appropriate geographical and temporal scales. Shipping density analyses are conducted for a number of reasons including collision risk between vessels (e.g. Min Mou et al., 2010) or with passive autonomous underwater gliders (Merckelbach, 2011). The collision risk with gliders is similar for that of a whale that makes no response to the vessel.

Shipping density may be defined in a number of different ways with three commonly used measures and their units listed in Table 1. Leaper and Danbolt (2008) suggest that the distance travelled density provides the most useful measure from the perspective of collision risk and to allow comparison between different studies. Number of transits can also be used in simple risk models but may be dependent on the size and shape of the area considered and so is less easy to compare between studies.

Table 1. Measures of shipping density

Measure	**Symbol**	**Units**
'Vessel density' expressed as the number of vessels per unit area	*P*	km^{-2}
'Distance travelled density' expressed as the total distance travelled per unit area per unit time	*D*	$km^{-1}year^{-1}$
'Vessel traffic density' expressed as the number of transits across an area per unit time	*R*	$year^{-1}$

Converting from transit rates to distance travelled density
If transit rates are given for any grid square in terms of numbers of crossing per unit time, these can be approximated to density in terms of distance travelled per unit area per unit time. This will depend on the orientation of the grid relative to the flow of ship traffic. If s is the size of the grid square then the average distance steamed $\bar{L}$ for a vessel crossing the grid at angle θ (for θ between 0 and 45^o) will be given by $\bar{L} = s \times \cos\theta$

The distance travelled density D could then be expressed as

$$D = \frac{R \times s \times \cos\theta}{s^2} = \frac{R \times \cos\theta}{s}$$

Where R is the rate of ships crossing the grid square. If there is no obvious shipping route and the direction of shipping can be assumed to be random then the average distance travelled for vessels that cross all or part of a grid square can be expressed as

$$\bar{L} = \frac{4s}{\pi}\int_0^{\pi/4} \cos\theta d\theta = 0.90 \times s$$

giving

$$D = \frac{R \times 0.9}{s}$$

Different options for analysis of terrestrial AIS data to estimate density
One option for the analysis of AIS data is to count transits for any grid square and to use these approximations to estimate density. This is illustrated in Figure 2. In this case, over a measured time for which any grid square was within the range of the receiving aerial the number of vessels which enter the grid square would be counted. This would give an estimate of the number of transits in that time period. For a fixed aerial this would just be the total monitoring period, for a mobile aerial on a vessel, this would be the time for which the vessel was close enough to the grid square of interest. A more precise, but analytically more complex method is to calculate the actual distance travelled by each vessel in each grid square from the series of positions given by multiple AIS transmissions.

An alternative is to use a snapshot approach. For the grid square the number of vessels within that area at any one instant gives the density of ships P. The AIS data stream also includes the vessel speed in knots. A point estimate from the snapshot of distance travelled density D will be the sum of the vessel speeds over all the vessels in the grid square adjusted for the reference period and whatever units are used. For example, if there are *n* vessels each with speed v_i knots then the distance travelled density in kilometres travelled per km^2 per year

$$D = 1.852 \times 24 \times 365 \times \frac{1}{s^2}\sum_{i=1}^{n} v_i$$

Estimates of mean speed of shipping allow conversion from vessel density to *D*. These appear consistent across different areas. For the southern North Sea, Min Mou et al. (2010) reported a mean vessel speed of 13.5 (s.d. = 3.7) knots. In the Mediterranean, mean vessel speeds were 13.9 knots (Leaper and Danbolt, 2008) and 13.8(s.d. = 3.2) knots (Scrimger and Heitmeyer, 1991).

Spatial scale and amount of data required

The choice of spatial scale, if a simple grid is used, will depend on the available data on cetaceans and on shipping. Since shipping data should be easier and cheaper to gather, it makes sense to base the spatial scale on the cetacean data. Leaper et al. (1997) describe a method based on the distances between pairs of sightings within grid squares that could be used to select the size of a grid. For any two random points within a square, the expected distance between them is $0.52 \times s$ where *s* is the length of the side of the square. If distances between sightings are significantly less than this, then information on the spatial pattern of whale distribution is being lost and a smaller grid size would be advantageous. For example, in a study of data from a whale watching operation on minke whales off the west coast of Scotland, Leaper et al. (1997) found that with a 5km grid, 40% of squares showed evidence of over-dispersion but this was reduced to 3% with a 4km grid. This suggests that in that study region spatial information on whale distribution would have been lost with a 5km grid size.

Shipping routes can be very concentrated with measurable differences in shipping density at scales of hundreds of metres, especially where there is some natural turning point such as a hazard or a headland. Traffic Separation Schemes are typically 4-10km wide although may be narrower in confined straits or approaches to ports. If spatial scale is determined on the basis of cetacean data then this can be used to estimate how much AIS data will be required to achieve adequate precision.

The number of ships crossing any grid square can generally be treated as a Poisson process which is a useful model to predict the amount of observation effort that could be required for a particular area to obtain estimates of shipping density with a desired level of precision. While traffic in some areas can be quite seasonal, for example summer ferry routes or seasonal fisheries, much of global shipping traffic operates in a similar way for 365 days a year. Thus in many cases, shipping data can be gathered over a short time period without having to take seasonal differences into account.

Satellite AIS derived estimates of shipping density

Eiden and Martinsen (2010) provide the first quantitative global estimates of vessel density (Figure 3). This was based on 10, eight day, sets of satellite data between 1st January 2010 and 5th March 2010. For each 8 day set, between 19,000 and 23,000 individual vessels based on unique MMSI number were located. This represents about 1/3 of the global fleet. Only the first location received for each vessel was used. Based on the proportion of the global fleet detected, a correction factor was applied. The results given represent corrected averages from the 10 data sets of the number of vessels by 1^o x 1^o block. At Latitude 36^o each such block covers 10,000km^2.

The results highlight the highly concentrated nature of shipping. Within each 1^o x 1^o block it would be expected that shipping would be highly concentrated into a few routes. Nevertheless, at a global scale, 38% of shipping is concentrated within 1%, and 80% within 10% of the sea area, when averaged over 1^o blocks (Figure 4).

The data shown by Eiden and Martinsen (2010) in Figure 3 can be shown at a regional scale for area of particular concern for ship strikes. The qualitative visualisation of main shipping routes for the Mediterranean from combined terrestrial data sets (with some gaps in coverage) shown in Figure 5 can be compared to the quantitative density estimates in Figure 6. Where comparsions of density can be made, the data sets appear broadly comparable. For example, along the main route across the eastern basin between the Strait of Sicily and the Suez Canal the S-AIS data suggest mean number of vessels per 1o block of 7-10. Assuming a mean speed of 13.5 knots this would correspond to values of *D* of 140-200 km^{-1}year^{-1}. Leaper and Danbolt (2008) estimated a mean *D* of 280 km^{-1}year^{-1} for this route. Given that the vessels are more concentrated than 1^o blocks, it would be expected that the density measured directly on the shipping route would be higher.

In busy shipping lanes in the southern North Sea approaching the port of Hamburg, Merckelbach (2011) reported 0.8-2.0 ships per hour per km^2. This would correspond to a distance travelled density *D* of approx 6000-15000 km^{-1}year^{-1}. For a mean speed of 13.5 knots (Min Mou *et al.*, 2010), a transit rate of 0.8-2.0 ships per hour per km^2 would correspond to an instantaneous density of approximately 0.03 – 0.07 vessels per km^2. Outside of the North Sea, only two 1^o blocks (approaches to Tokyo and Singapore) had densities within this range averaged over the whole block based on the S-AIS data from (Eiden and Martinsen, 2010). The densities in these limited areas are one or two orders of magnitude greater than the busiest shipping lanes in the open ocean.

Shipping densities west of the Iberian peninsula and approaches to the Channel are shown in Figure 7. This area holds about 6% of global shipping at any one time. For comparison, the same sized area around Japan had 9% or along the east coast of the USA (where there are a much greater number of ship strikes reported) 3%.

Discussion

The recent developments in space based AIS reception have allowed quantitative estimates of global shipping density at a spatial scale of 1^{o} blocks. These data should allow comparison with available whale data to predict areas of relatively high ship strike risk globally. The data available now (Eiden and Martinsen, 2010) are considerably more comprehensive than the situation at the time of the IWC/ACCOBAMS workshop in September 2010 (IWC, 2010). While the current data are of a fairly coarse resolution, there is now a large satellite data set that contains finer scale data including speed over ground that might allow finer scale analysis over specific areas (Gerd Eiden *pers. commn*.).

The global data have also emphasized the concentrated nature of shipping, with the majority of ships within 2% of the total sea area, suggesting that the areas with the greatest problem are likely to be quite limited in spatial extent.

Even without finer scale data the S-AIS data set will allow quantitative comparisons of risk models over large areas. For example, the fin whale is the species most commonly reported struck and estimates of ship strikes may also be needed for input into the RMP in the North Atlantic. There have been several surveys which have generated population estimates along the east coast of the USA from the Gulf of Maine up to Maine giving a best estimate of 2,269 (NOAA, 2009). The CODA survey also generated estimates in the North East Atlantic with. the total estimate for the CODA blocks 2,3,4 covering the northern Iberian peninsula, Biscay and SW Approaches to the UK and Ireland was 7,377 (Macleod et al., 2009). A series of aerial surveys has been conducted along the seas around Italy in 2009 and 2010, to provide significant baseline information on cetaceans distribution and abundance (Panigada et al., 2011). The covered areas included the Pelagos Sanctuary, the Central Tyrrhenian, the Corsica and Sardinia Seas, with an estimated abundance of 426 fin whales (CV=18%; 95% CI=298–609). Overall numbers of vessels along the US coast are about half of that in the CODA area which also had around three times the numbers of whales. Despite this, the reported rate of ship strikes is much higher in the US averaging 1.6 fin whales per year along the east coast between 2003 and 2007 (NOAA, 2009). Further analyses might indicate whether the differences in reported ship strikes could be explained by localised high co-occurrence of vessels and whales or by probability of a collision being detected and reported.

Although the S-AIS data have been reported in terms of vessel density, the overall mean speed of global ship traffic appears sufficiently consistent (13.5-13.9 knots) that vessel density can be reliably converted to distance travelled density, which is the most useful measure for risk assessment. However, ship strike mortality risk is known to increase with vessel speed (Vanderlaan and Taggart, 2007) and so additional data on vessel speed would be of considerable value. For example, Leaper and Danbolt (2008) found substantial differences in the mean speeds of vessels along different routes across the Mediterranean, which are frequented by different types of traffic.

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Figures

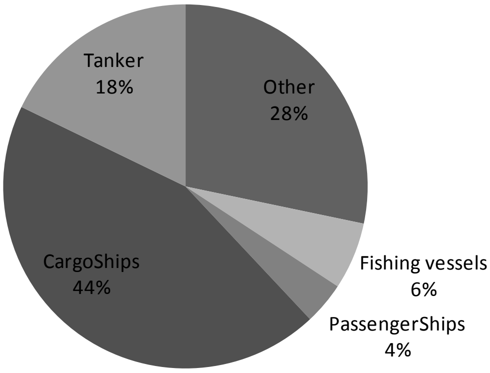

Figure 1. Relative proportion of class A-vessels as identified by AIS transmission codes for vessel type (data from Eiden and Martinsen (2010)).

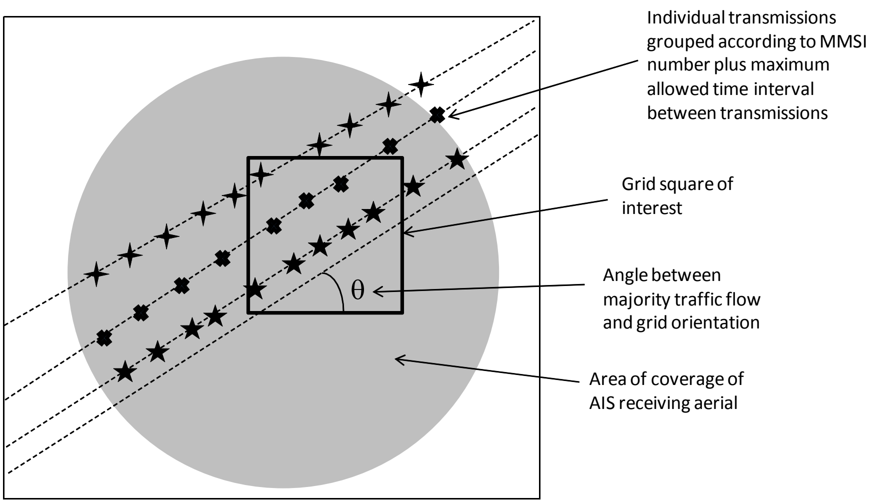

Figure 2. Example of grouping AIS transmission by vessel MMSI to estimate distance travelled density within a grid square from data from an AIS receiver covering the grey shaded area.

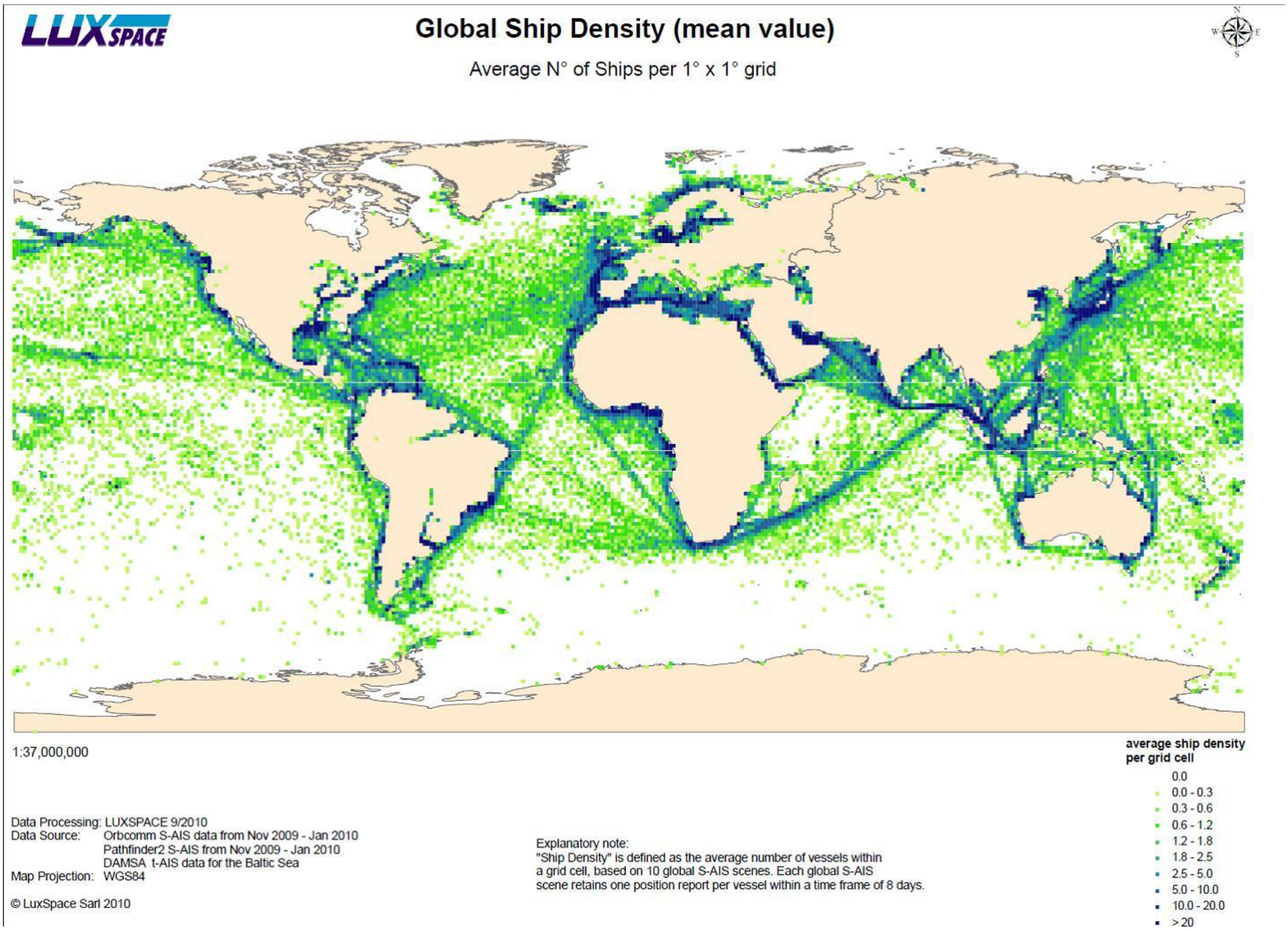

Figure 3. Density (vessels km^{-2}) from S-AIS data. Reproduced from Eiden and Martinsen (2010). Copyright European Commission.

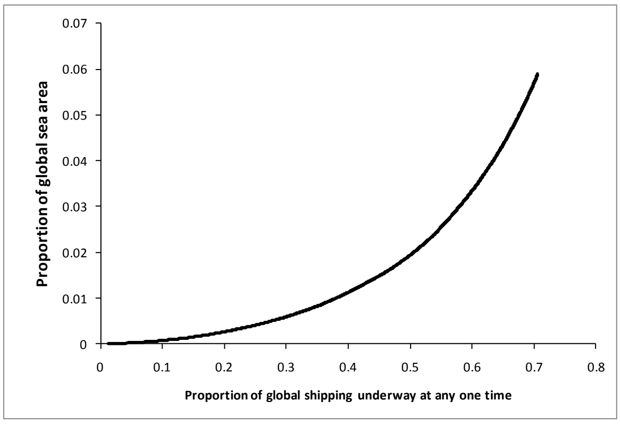

Figure 4. Proportion of global shipping concentrated within a proportion of the sea area (when shipping density is averaged over 1^o x 1^o blocks). For example, 50% of shipping is concentrated within 2% of the area. Data from Eiden and Martinsen (2010).

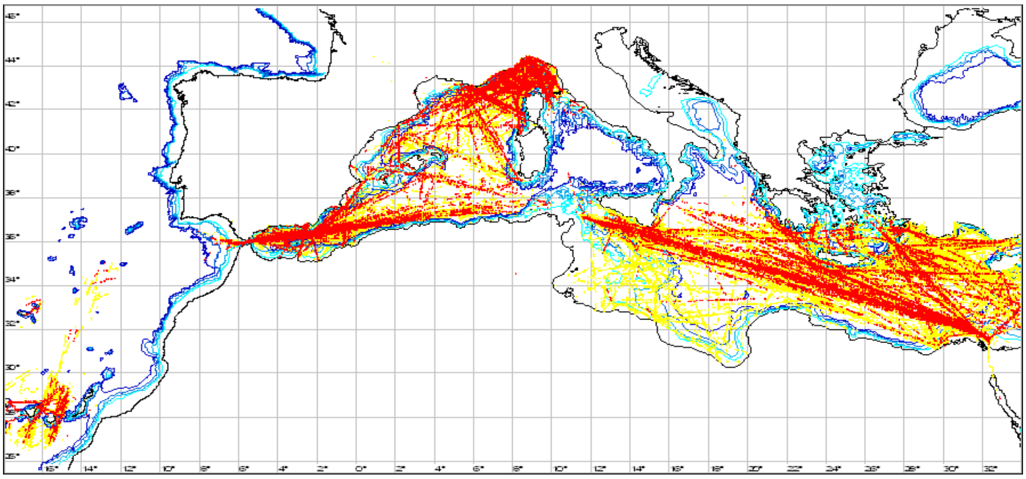

Figure 5. Major shipping routes across Mediterranean based on terrestrial AIS data received during cetacean surveys (data from IFAW, Tethys and Alnitak). Red indicates vessels travelling at >17 knots, yellow indicates slower vessels. Note there are several areas with gaps in coverage that do not necessarily indicate a lack of ship traffic.

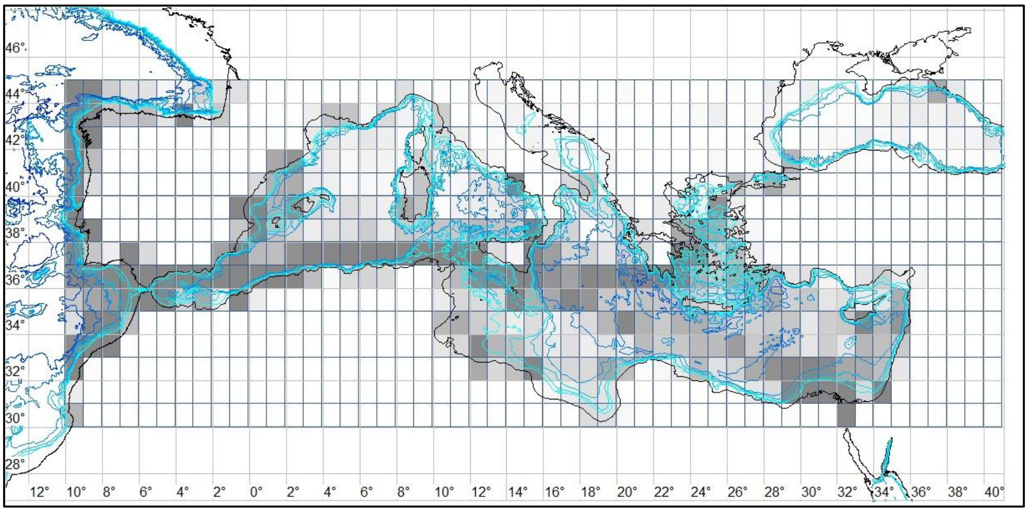

Figure 6. Density of shipping (vessels km^{-2}) by 1^{o} blocks from S-AIS data for the gridded area. Data from Eiden and Martinsen (2010). The average total number of vessels within the gridded area was 3494, corresponding to 8% of the vessels underway globally.

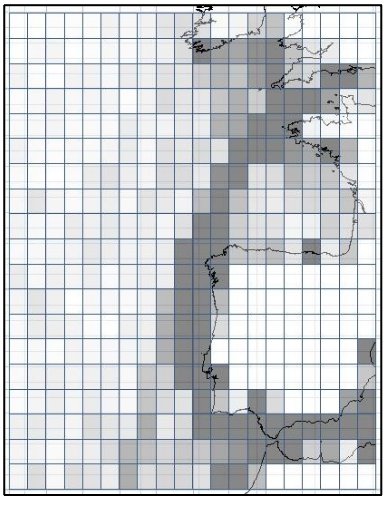

Figure 7. Density of shipping (vessels km^{-2}) by 1^{o} blocks from S-AIS data for the gridded area west of Europe (Lat 35^{o}-53^{o}N, Long 0^{o} to 20^{o}W). Data from Eiden and Martinsen (2010). The average total number of vessels within the area was 2464, corresponding to 5.6% of the vessels underway globally.