Description of the vessel traffic within the north Pelagos Sanctuary: Inputs for Marine Spatial Planning and management implications within an existing international Marine Protected Area

Frazer Guy Coomber [a,b], Massimo D'Incà [b,c], Massimiliano Rosso [a], Paola Tepsich [a,b], Giuseppe Notarbartolo di Sciara [d], Aurélie Moulins [a,*]

[a] CIMA Research Foundation, Savona, Italy
[b] DIBRIS, Università degli studi di Genova, Italy
[c] Logness S.r.l., Savona, Italy
[d] Tethys Research Institute, Milano, Italy

ABSTRACT

International shipping, although considered a safe and environment-friendly form of transportation, has many direct and indirect impacts on cetaceans in many ways, particularly in the Mediterranean Sea, one of the world's busiest waterways. An AIS receiver located at 44.30 °N and 8.45 °E, operating between 3 May 2013 and 31 October 2014, provided a detailed description of the distribution, number, type and operation of vessels within the Pelagos Sanctuary, an international protected area dedicated to the conservation of marine mammals. A total of 3,757,587 km of vessel traffic was recorded from 82,831 transits by 4205 distinct vessels. The spatial and temporal distribution of traffic was not uniform and dependent on vessel type ($0.00 < r < 0.7$); the level of shipping differed spatially between day and night. Passenger vessel traffic was predominant, with 20,853 transits totalling 1,385,361 km, followed by cargo (12,384 transits totalling 1,427,681 km). Transit speed significantly differed amongst vessel types ($F = 12621$, d.f. $= 5$, p-value < 0.0001) with passenger vessels the fastest (mean 15.47 ± 4.40 kn). Hazardous cargo transits accounted for 435,116 km. Vessels within the sanctuary navigated under the flags of 90 different states, in variable proportion depending on vessel type ($X^2 = 1231$, d.f. $= 10$, p-value < 0.0001). The data presented in this study on high density shipping corridors and hazardous cargo supplies information for the identification of areas at higher risk from shipping. This data once integrated with available ecological data, can be used to inform ecosystem based management within a Marine Spatial Planning framework.

1. Introduction

The Mediterranean Sea is one of the busiest waterways in the world, despite covering less than 1% of the world's oceans; it accounts for around 15% of the global shipping activity by number of port calls, 10% by vessel deadweight tonnes [1] and 8% of the global fleet underway at any given point [2]. Although considered a safe and environmental form of goods transport, the impacts from maritime traffic are recognised as an anthropogenic threat to cetaceans in the Mediterranean Sea [3]. In February 2002, an agreement between France, Italy and Monaco: the "International Sanctuary for the Protection of Mediterranean Marine Mammals" also known as the "Pelagos Sanctuary" entered into force, with the

specific goal to protect marine mammals and their habitats from negative impacts [4]. However, the conservation goals of the Pelagos Sanctuary are impeded by the international nature of the agreement and the few mitigation measures in place do not directly address the anthropogenic threats posed by marine traffic to cetaceans.

Marine Spatial Planning (MSP) is recognised as an important management tool that provides a comprehensive framework for managing multiple activities within the marine environment [5]. It is defined by UNESCO as a "public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social objectives that are typically specified through the political process". MSP is one of the key tools in Ecosystem Based Management (EBM), an approach which is widely accepted as a key framework for delivering sustainable development in the marine environment [6]. During the planning phase of MSP, the spatial and temporal data of

* Corresponding author.
E-mail address: aurelie.moulins@cimafoundation.org (A. Moulins).

the biological aspects and the anthropogenic pressures should be mapped and their interactions understood [7]. Many anthropogenic stressors on cetaceans in the Mediterranean Sea are directly or indirectly associated with the activities of maritime traffic [3] and most activities in the marine environment are in some way linked to shipping.

Automatic Identification System (AIS) is a ship-to-ship and ship-to-shore system intended to enhance the safety of life at sea [8], the efficiency of navigation and the protection of the marine environment under the International Maritime Organization's (IMO) 1974 International Convention for the Safety of Life at Sea (SOLAS). Since December 2004, it has been mandatory that all vessels over 299 gross tonnage and all passenger vessels must carry an AIS transponder. AIS data is used to track vessel movements in real time and represents a powerful ship monitoring and surveillance tool. It is now recognised that AIS can form an integral part of MSP [9] and there are several examples of its use for this purpose [9–13].

There already exist several studies that have recorded the maritime traffic in the Mediterranean Sea [1,2,14–16]. However, their primary objective was not MSP and as such these studies and their data may be limited in their applicability for this purpose. For instance, the recorded shipping levels do not represent the actual spatial distribution of the maritime traffic [1]or the spatial resolution used may be too large (100 km in [2]) or the temporal scale too small (63 days in [16]). Several works did not consider all vessel types [1,15,16], did not analyse the density by different vessel types [16] or consider any spatio-temporal analyses [14,15]. Thus this study aims to supply detailed information relating to the level and spatio-temporal distribution of shipping in the Pelagos Sanctuary for incorporation within a MSP framework.

2. Methods

2.1. Raw data tables

An AIS receiver was installed at the geographic coordinates of 44.30 °N and 8.45 °E at a height of approximately 25 m above sea level. The raw NMEA data packets and their associated database timestamp were parsed using an *ad hoc* service written in C# language following the NMEA AIVDM/AIVDO protocol decoding[1]. The analyses within this article represent the data parsed from the 3rd of May 2013 to the 31st of October 2014. Not all the data encoded in the 27 AIS message types was considered essential or desirable and only the dynamic, static and voyage related data encoded in message types 1, 2, 3, 5, 18, 19 and 24 were incorporated (see Refs. [8,17] for message descriptions and details). The raw data were amalgamated into two separate tables, the *"Raw dynamic messages"* table of every recorded Position Report Class (PRC) and the *"Raw static and voyages"* table that contained all vessel specific and voyage related data for both type A and B AIS transponders (Fig. 1).

2.2. Vessels table

The reliability of the static and voyage related data from AIS was considered to be moderate to poor but of desirable usefulness [9] and the creation of a vessel information table was considered for quality control. The *"Vessels"* table was created from the *"Raw static and voyages"* table and based on the unique identification of each vessel: Maritime Mobile Service Number (MMSI) and contained its dimension (width and length) and vessel classification

(Fig. 1). All fields were double checked against online databases[2]. Seven vessel types: passenger, cargo, tanker, fishing, service, pleasure and unclassified were considered and passenger, cargo and tanker were combined into a commercial vessel category. Additional information not present in the AIS message was added for every ship pertaining to its flag state, build year, gross tonnage and dead weight from the previously mentioned online databases and data relating to a vessel's activity (number of filtered PRCs recorded and, maximum, mean and modal vessel speeds over all PRCs). This data through the unique MMSI can be linked to the other tables.

2.3. Filtered positions table

AIS data is notoriously unreliable due to faulty equipment, human related errors or omitted values [18–20] and as such requires data quality control procedures. Only the PRCs within the extent of the Pelagos Sanctuary from the *"Raw dynamic messages"* table were inserted into the *"Filtered positions"* table. Geometric calculations were then conducted between consecutive PRCs (pgAdminIII POSTGIS extension) to obtain a PRC's heading in degrees, time in seconds, distance in metres and speed in kilometres per hour (Fig. 1). These calculations provided an additional value to the *"Raw dynamic messages"* that could be used to identify ambiguous or missing data.

A quality control procedure adapted from the Marine Management Organization [12] was used to remove and filter erroneous PRCs. The first step was to remove any vessel and their corresponding PRCs with an erroneous MMSI number from the *"Vessels"* table; these included MMSIs with more or less than 9 digits and those with repetitive or sequential number strings (i.e. 111,111,111 or 123,456,789 according to Ref. [21]). Unique vessels with a low number (< 5) of recorded PRCs were also removed as these were considered as data noise [22]. The second step of the quality control was to remove from the *"Filtered positions"* table the moored or anchored vessels and PRCs with erroneous locations. PRCs relating to moored or at anchor vessels, i.e. any vessels that had both a recorded and calculated speed less than 1 knot (1.852 km/h) and a subsequent PRC within 1 km were removed. Erroneous PRCs were removed by deleting any subsequent PRC that had a geometrically calculated speed that exceeded the *"Vessels table"* maximum speed and whose geometrically calculated heading differed from the AIS recorded heading by 30°.

2.4. Transits table

The *"Filtered positions"* table was connected to a Quantum GIS platform (QGIS) to create the *"Transits"* table, that contains the individual transits created from the PRCs using the QGIS PointsToPaths plugin. The transits' start time and end time, the duration in minutes and the length in kilometres were added using the raster calculator. The *"Raw static and voyages"* table and *"Filtered positions"* table were used where possible to update the *"Transits"* table with information on the transit's destination, the hazardous classification of its' cargo and the mean, modal and maximum speeds (Fig. 1).

2.5. Polygon grids table

The spatial and temporal shipping density was calculated as the number of vessels, number of transits and covered distance of transit per grid cell area per unit time. This was done by summarizing the *"Transits"* table into numerous composite *"Polygon*
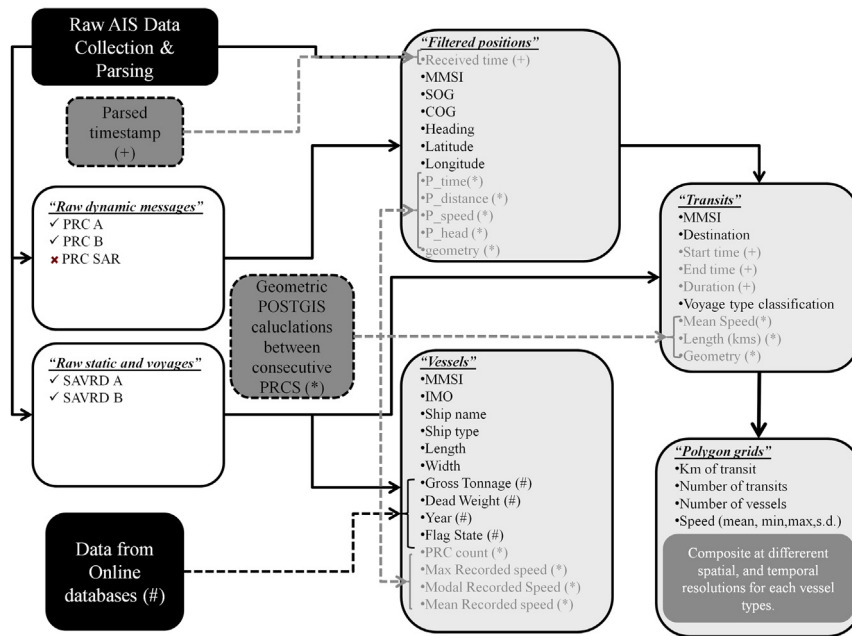

Fig. 1. Schematic representation of the AIS data processing. The raw data sources (black), the combined raw data tables (white), the clean data tables (grey) and the geometric calculations (*), parsed data inputs (+) and online database additions (# and hatched lines).

grids" table using the sum line lengths and zonal statistics tools in QGIS at various spatial and temporal resolutions for each vessel composite. The 1 km European Environmental Agency's (EEA) INSPIRE compliant reference grid[3] was used for this study. Moreover, an additional 5 km-grid was created following the INSPIRE compliancy guidelines [23] to compute the nested ANOVA for the temporal analyses.

2.6. Statistics

Various statistical analyses were conducted to test if the observed differences between vessel types, spatial distributions and temporal distributions were significant. All statistical analyses were conducted in R version 3.1.0 (R Core Team 2014). Differences between the vessel dimensions, their mean transiting speeds and number of vessels present during the different hours of the day were conducted using the parametric one-way analysis of variance (ANOVA) or non-parametric equivalent Kruskal-Wallis tests. A chi-Squared goodness of fit test was used to assess for the proportional differences between a vessels' type category and its' member flag state.

The spatial and temporal distributions were analyzed using spatial correlations over a reduced extent. The reduced extent, from hence forth "Genoa Canyon System" was considered as all grid cells located within 55 km of the receiver, as the referenced terrestrial receiver coverage at sea level is 55 km [8] and was used to eliminate the bias caused by reception. Temporal gaps in the operation of the AIS receiver required the use of a temporal sub-sample (the same 8 d time frame within a month). Temporal analyses were conducted using a nested ANOVA on a random sample of 10 5 km-grid cells, to avoid violating the independence assumption caused by spatial autocorrelation, with month as the nested factor. Model assumptions were validated by refitted the data as a linear mixed model with month as a random effect. If the residuals did not validate the response, variable transformations were conducted. The temporal differences in fishing and service

vessels were conducted on selected 6 cells due to the highly localized nature of these vessel types.

3. Results

3.1. Raw tables

From the 3rd of May 2013 to the 31st of October 2014, a total of 42,354,450 NMEA data packets were collected and parsed and the majority inserted into to the *"Raw dynamic messages"* table (78.6%) and the *"Raw static and voyages"* table (5.1%). After quality control a third (33.3%) of *"Raw dynamic messages"* PRCs (11,084,553) were available within the *"Filtered positions"* table that related to 4268 *"Vessels"* table records, 82,831 *"Transits"* table records and 3,757,587 km of vessel traffic amalgamated into the *"Polygon grids"* table.

The receiver has been in continuous operation throughout this time frame; however, logistical problems resulted in 16 temporal gaps, i.e. when the receiver was non-operational and no new NMEA data packets were received for thirty minutes. The temporal gaps ranged from just over 1 h to 57days with a total accumulated missing reception time of 183 days. The effects of these gaps did not affect the overall conclusions of the analysis but resulted in an incomplete temporal coverage for 12 of the 17 months.

3.2. Vessel table

All 4268 vessels within the *"Vessels"* table were classified to one of the seven vessel types. Sixty three (1.5%) vessels and their associated PRCs (924,223: 8%) were excluded from further analysis as they were unclassified. The predominant remaining vessel types were cargo (41.8%) and pleasure vessels (31.8%) and over half (62.9%) of the unique vessels were classed as commercial vessels (Table 1). The dimensions, transit speed and number of the vessels were found to be dependent on the vessel type classification (Table 1). All vessel types were found to be significantly different (1) in length except between tanker and cargo vessels; (2) in gross tonnage and dead weight except between fishing and service

Table 1
Summary statistics of the level, number and mean values of the shipping data from the "Vessels (v), Transits (t)" tables. The final three rows of passenger, cargo and tanker combined relate to the commercial vessel classification (c).

Vessel type	Number of vessel (v)	Mean vessel length (v)	Mean vessel width (v)	Mean gross tonnage (v)	Mean dead weight (v)	Vessel modal speed km.h^{-1} (v)	Vessel modal age (v)	Vessel mean age (v)	Mean transit speed km.h^{-1} (t)	Number of transits (t)	Total transit (km) (t)
Fishing	117	21	5	279	45	6		1997	9	7501	212,858
Pleasure	1340	40	8	944	208	3 & 21	2010	2002	20	8587	289,006
Service	106	37	10	2908	2197	9	2005	1997	11	8401	73,716
Passenger (c)	286	156	22	41,380	5139	24	2001	1996	28	26,264	1,385,361
Cargo (c)	1759	174	25	27,416	29,858	19	2010	2002	21	21,753	1,427,618
Tanker (c)	597	171	28	28,100	48,434	17 & 18	2009	2005	16	10,325	369,026

vessels (Appendix Table A.1 for full K-W tests) and (3) in mean vessel speed (F=185, d.f.=5, p-value < 0.0001).

There were 3069 (73%) vessels in the Pelagos Sanctuary that had information relating to the year in which they were built. The build date of all vessels ranged from 1896 to 2014 with an overall mean build date of 2002 and modal date of 2008. The majority of all the vessels (68%) were built in the last 15 years, a trend that is most apparent in tankers (90%), pleasure (78%) and cargo (69%) vessels (Appendix Fig. A.1).

There were a total of 4105 (97.6%) vessels that were classified to a countries state flag and they were comprised of the flags from 90 different countries. The top 5 countries with the most vessels under their flag were, in order Italy, Cayman Islands, Malta, United Kingdom (UK) and Panama (Appendix Fig. A.2). The classification to member state indicates that from the vessels in the Pelagos Sanctuary, the majority (74%) were represented by countries outside of the Mediterranean bordering states. About half (51%) of the vessels recorded in the Pelagos Sanctuary were found to be navigating under a Flag Of Convenience (FOC); an "open registry" used to avoid financial charges or restrictive regulations in the owner's country [24]. Vessels under the jurisdiction of one of the Pelagos states represented 19% of the total unique vessels in the Sanctuary. The proportion of the flag state was dependent on the vessel type (X^2=1231, d.f.=10, p-value < 0.0001), with fishing, service and passenger vessels predominantly Pelagos states and cargo, tanker and pleasure vessels were predominantly non-Mediterranean states.

3.3. Transit table

Due to the number of transits conducted by each vessel, the previous findings relating to the unique vessels differed dramatically when considered as the number of transits or the kilometres of transits. There were a large number of unique cargo vessels, but each unique vessel had on average a low number of transits (12). The same can be said for tankers (17) and pleasure craft (6), while passenger, service and fishing vessels had a much greater number of transits for each unique vessel (92, 79 and 64 mean respectively). Considering transits, passenger and cargo vessels are the most predominant vessel types in respect to the number of transits (30% and 26% respectively) and the total kilometres of transits (37% and 38% respectively). The overall proportion of commercial transits is around 70% of all the transits and 85% of the total kilometres (Table 1). The total number and kilometres of transits operating under a FOC vessel is 25% and 31% respectively and the portion of transits under a Pelagos state flag are the majority (60% and 50% respectively).

In 31,029 (37%) transits, it was possible to determine the presence or absence of hazardous materials and 5654 transits were found to be carrying hazardous cargo, that is 18% of the know voyage type transits and 7% of all transits. There was a total of 435,116 km of hazardous cargo transits which represents roughly a third of all the cargo and tanker transits of known voyage type (Table 1). The mean speeds of hazardous cargo and non-hazardous cargo were similar but were found to be significantly different between hazardous and non-hazardous cargo vessels (F=166.8, d.f.=1, p-values < 0.0001) and tanker vessels (F=35.7, d.f.=1, p-value < 0.0001: Table 20.2).

The identification of a transits' destination was successful in 28,978 (35%) transits. A total of 329 different destinations were found from 61 distinct countries. There were 69 destinations (21%) located within the Pelagos Sanctuary, 121 destinations (37%) within a Pelagos member state country and 250 destinations (76%) within a Mediterranean state country. The most recorded destination was Genoa and the majority of the most visited ports lie within the Pelagos Sanctuary or belong to one of the Pelagos

Table 2
The hazardous cargo within the separate vessel types (Percentages calculated from the total number of known transit classification).

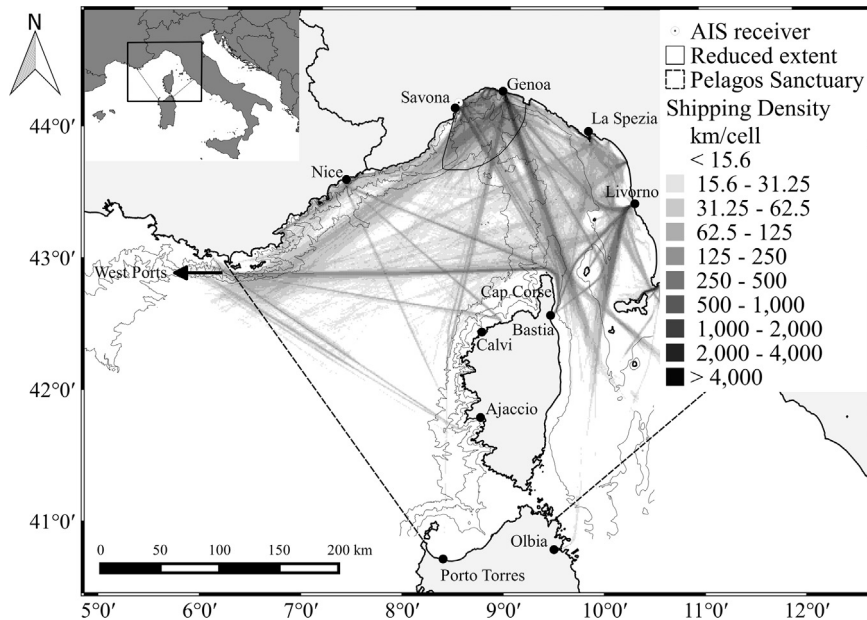|	Number of unique vessels carrying hazardous cargo	Number of hazardous cargo transits	% hazardous transits respective to transits with information on carriage	Distance covered of hazardous transits (km)	Mean calculated hazardous transit speed (km/h)	Mean calculated non hazardous transit speed (km/h)
Passenger	6	35	00.1	2693	28.2	28.5
Cargo	424	4246	35.8	354,667	22.6	21.2
Tanker	211	1373	30.0	77,756	16.5	15.6

Fig. 2. The spatial distribution of the total combined shipping in the Pelagos Sanctuary, recorded by the Savona AIS receiver during the total sampling period as the summed kilometres of shipping transits within a 1 km-grid cell. Map presented in a ETRS89 Lambert Azimuthal Equal Area (EPSG: 3035) with the 200, 1000 and 2000 m isobaths. The reduced level of shipping in the southern Pelagos Sanctuary is caused by receiver reception.

member states (Appendix Table A.2).

3.4. Polygon grid spatial analysis

The "Polygon grids" table, with transit distance per grid cell per total time frame, clearly displayed that the spatial distribution of shipping traffic is not uniform (Fig. 2). The spatial distribution of shipping density was found to be vessel type dependent, with different vessel types localized to specific areas or utilising different shipping corridors (Fig. 3). The analyses on the reduced extent clearly demonstrated that the spatial distribution of passenger and cargo vessels was similar to each other (R=0.70) but different to the other vessel types (0.01 < R < 0.48) with passenger and cargo vessels contributing most to the overall spatial distribution of the shipping levels in the area (R=0.89 & R=0.88 respectively). Despite their similarities, there were several distinct corridors used by passenger vessels and not by cargo: for instance, passenger vessels had a high density corridor between Genoa in the direction of West Corsica and Porto Torres (northwest Sardinia: Fig. 3(b) and Fig. 2 for port labels). There was also found a distinct corridor used solely by pleasure vessels travelling between Portofino and the Western Mediterranean ports (Fig. 3(c) and Fig. 2 for port labels). The spatial distribution of hazardous cargo transits did not display any distinct spatial distribution and followed the spatial distribution of cargo (R=0.92) and to some extent tankers (Fig. 3(g)) vessels (R=0.59).

The spatial distribution of the vessel transit speeds were also found to not to be uniform and the areas of fast and slow speeds were dependent on vessel type (Fig. 4). It highlights a clear

difference in the operational characteristics of each vessel type. Passenger vessels once again have been shown to be the fastest vessels type, with the fastest mean speeds localized within distinct corridors. To a similar degree but not quite as dramatic are the other two commercial vessel types, (cargo and tanker). Cargo and tanker vessels displayed slower speeds close to the coast and near ports, where passenger vessels did not. Despite not being a strong correlation, the commercial vessels contributed most to the overall spatial distribution of mean speed in the area (R=0.61, R=0.57 & R=0.58 for passenger, cargo and tanker respectively).

The non-commercial vessels were, with the exception of pleasure craft, much slower on average than their commercial counterparts. Service vessels were found to be faster in coastal areas (less than 200 m deep) than further offshore. Fishing displayed distinct areas of slow transits between the 200 and 1000 m isobaths, perhaps indicative of trawling grounds. Most interestingly was the almost homogenous distribution of fast travelling pleasure craft, which were slower in the vicinity of the coast and port areas.

3.5. Polygon grid temporal analysis

The spatial distribution of the shipping density was found to differ at several temporal scales. The inter-annual analysis was conducted on the total kilometres of vessel transits located within the reduced temporal and spatial extent. May, June, August and September have data from both years and were used to test for inter-annual differences. The spatial correlation (R > 0.873) and overall shipping density was not found to differ significantly between the years of 2013 and 2014 (nested ANOVA: F=0.091, d.
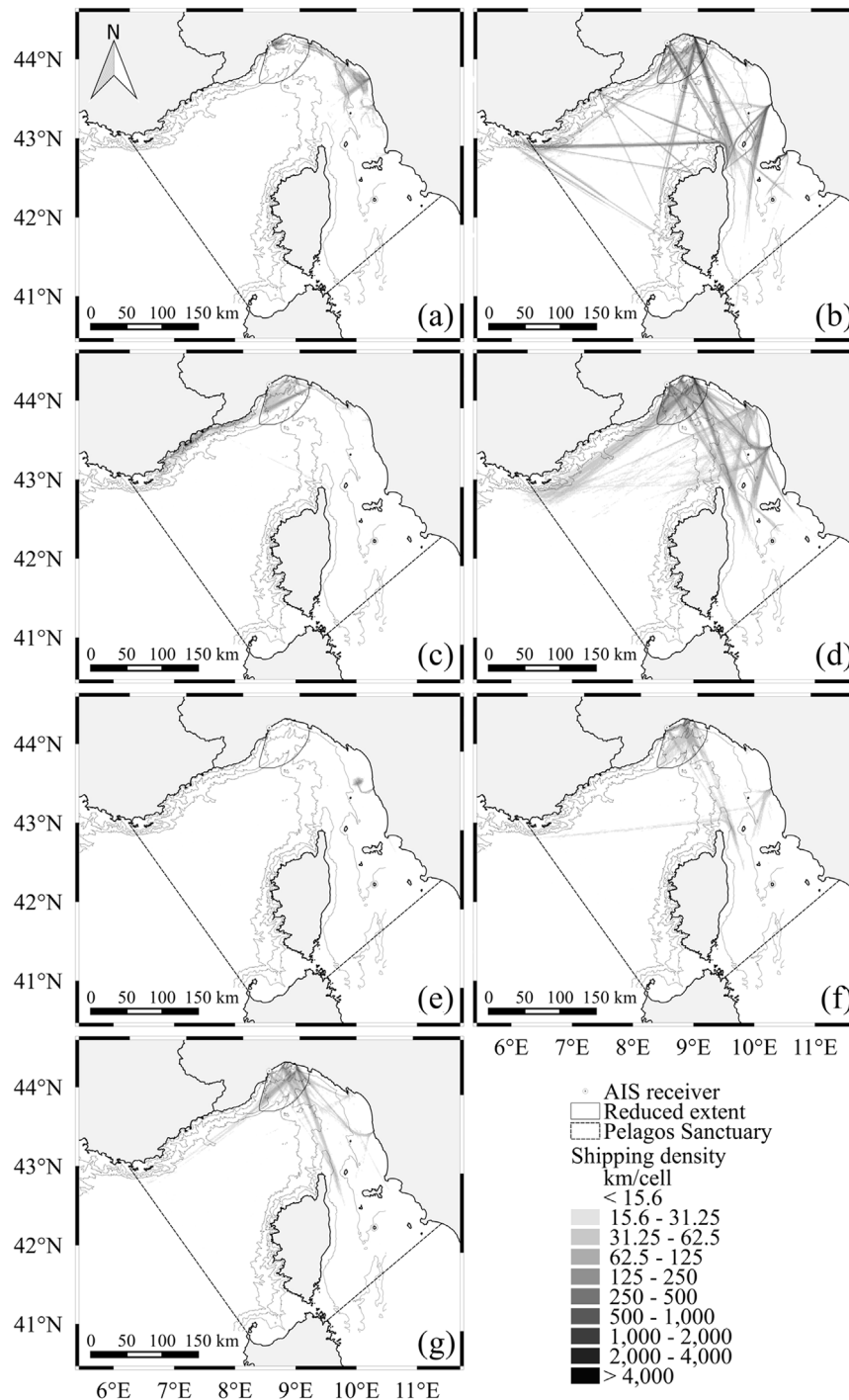
Fig. 3. The spatial distribution of the different vessel types (a) fishing, (b) passenger, (c) pleasure, (d) cargo, (e) service, (f) tanker and (g) total hazardous cargo within the Pelagos Sanctuary at 1 km-grid cell resolution within the whole timeframe of this study. Map presented in a ETRS89 Lambert Azimuthal Equal Area (EPSG: 3035) with the 200, 1000 and 2000 m isobaths.

f.=1, p-value=0.76). However, there appears to be monthly and seasonal differences within a year (Figs. 5 and, 7). When comparing the two seasons: summer (June, July & August 2013) and winter (December 2013, January & February 2014) the nested ANOVA indicated that the difference was significant for the pleasure (F=17.7, d.f.=1, p-value=0.014), passenger (F=6.5, d.f.=1, p-value=0.0135) and fishing vessels (F=37.5, d.f.=1, p-value < 0.001) but not for the cargo (F=0.151, d.f.=1, p-value=0.7), tanker (F=0.137, d.f.=1, p-value=0.9) and service vessels (F=2.874, d.f.=1 p-value=0.11).

The spatial distribution and level were also found to differ between the daylight and night time (Figs. 6 and, 2 for port labels) and also between the individual hours of the day (Fig. 7). The most noticeable night time daytime spatial change was that of the Genoa–Porto Torres and the Cape Corsica–West Ports corridors, where a higher night time level of shipping was found compared with the daylight hours (Fig. 6). Within the daylight hours, the number of boats recorded in the reduced extent were found to be significantly different between the hours of the day (F=39.66, d. f.=14, p < 0.0001). Post-hoc analysis found 3 temporal groupings that were not significantly different between themselves but distinctly different from the other groupings. The early morning (6–8
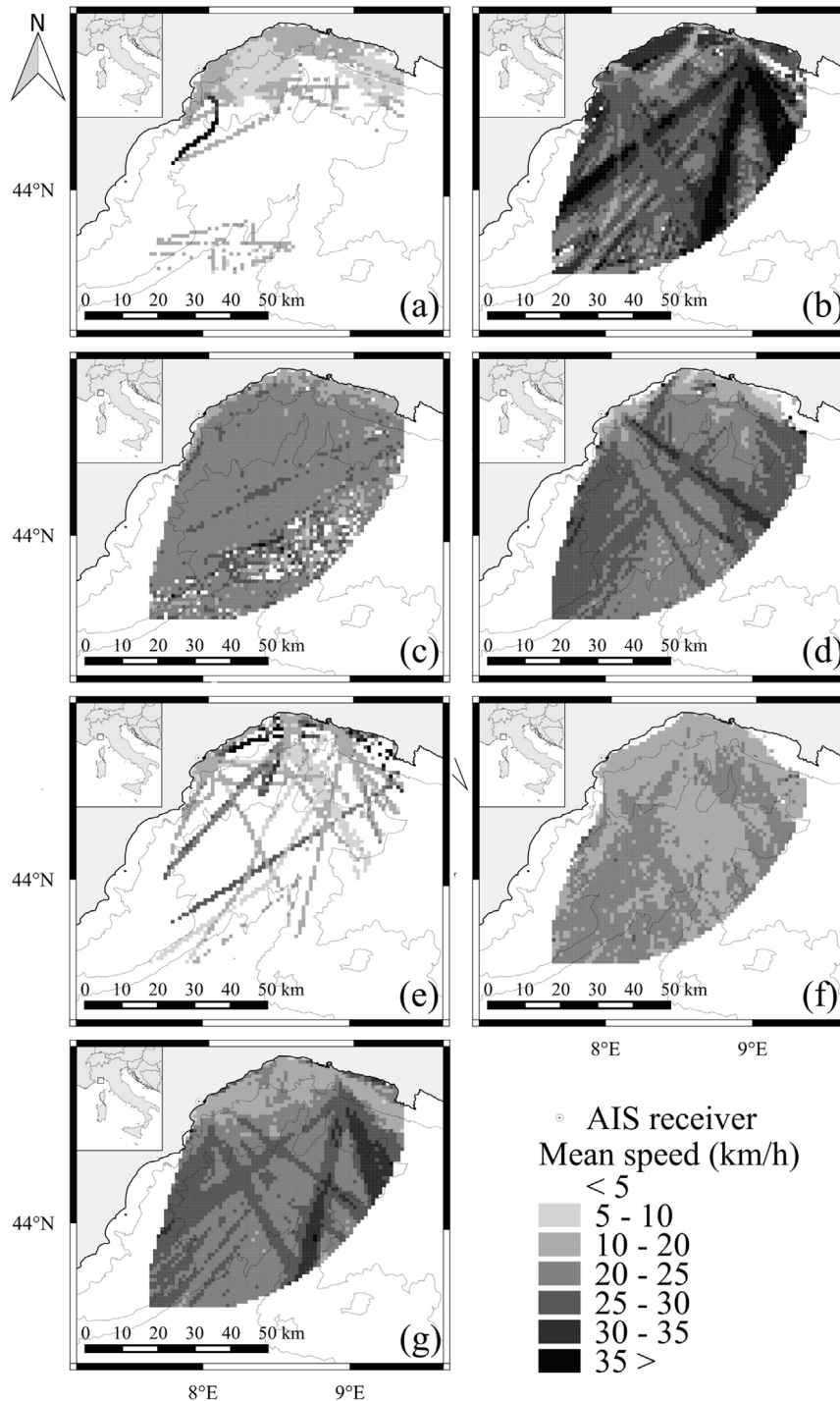
Fig. 4. Mean speed in kilometres per hour of the different vessel types: (a) fishing, (b) pleasure, (c) service (d) passenger, (e) cargo and (f)tanker and the (g) overall vessels mean speed per 1 1 km-grid cell within 55 km of the Savona AIS receiver. Map presented in a ETRS89 Lambert Azimuthal Equal Area (EPSG: 3035) with the 200, 1000 and 2000 m isobaths.

UTC+2) that was significantly higher than the other 2 with a median number of 12 boats, morning to midday (9–12 UTC+2) with significantly less vessels, median 8 and the rest of the daylight hours (13–20 UTC+2) with a median of 10 vessels; a pattern that can be seen in all the months analyzed (Fig. 7).

4. Discussion

The Pelagos Sanctuary is bordered by coastlines that are densely inhabited, and where urban, industrial, touristic and agricultural activities carry significant economic importance. As a consequence, and as demonstrated in this study, its waters are crisscrossed by intense maritime traffic from a variety of vessel types. Considering that the presence of traffic in this Marine Protected Area is unavoidable, the only option available is to develop and implement traffic impact mitigation measures. This approach can be effectively implemented through the use of a Marine Spatial Planning framework to identify the spatial overlap between cetacean distributions and anthropogenic pressures [25].
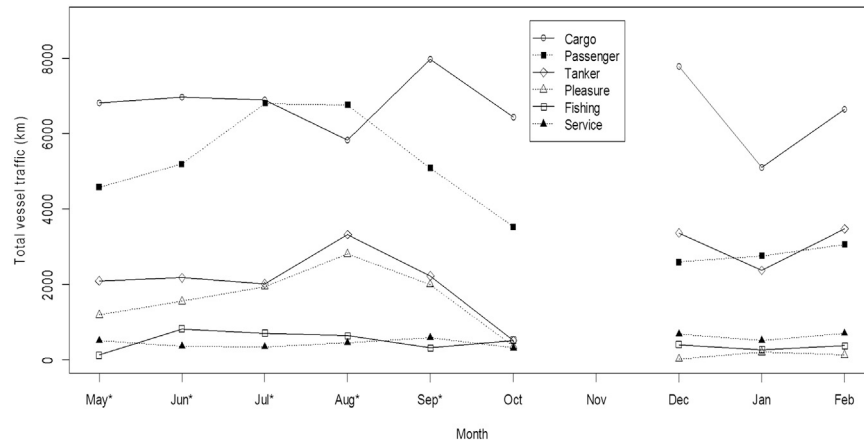
Fig. 5. The monthly covered distances in kilometres in the Genoa Canyon System where the AIS antenna is receiving perfectly for each vessel types (data from all sub-sampled months were exhaustive and expressed by the average when the sub-sampled was available from both years(*)).
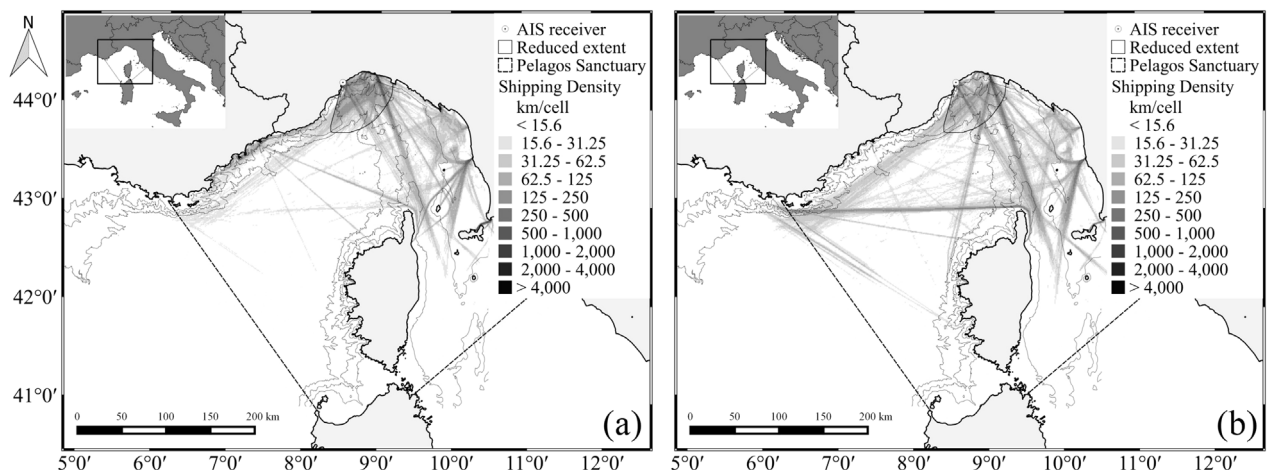

Fig. 6. The spatial distribution of the shipping levels between the (a) day light and (b) night time hours at 1 km-grid cell spatial resolution and presented in a ETRS89 Lambert Azimuthal Equal Area (EPSG: 3035) with the 200, 1000 and 2000 m isobaths.

4.1. Shipping impacts and possible mitigation measures

Maritime shipping traffic is known to have many direct and indirect impacts on marine life, and in particular can be a source of anthropogenic pressures on cetaceans. These include disturbance, noise, collisions and chemical pollution in these mammals' critical habitat. Two of the main threats to marine mammals from maritime traffic are the increasing anthropogenic noise pollution [26] and the direct mortality through ship whale collisions [27]. Underwater noise pollution is known to have several detrimental effects on marine mammals [26,28–32] and their prey [33]. Collisions with ships are also a known cause of cetacean mortality [34] and it is a special concern in the Pelagos Sanctuary [47] where 1–1.7 fin whale hits per year were estimated [35].

Knowledge of the ecology of cetaceans found in the Pelagos Sanctuary has made significant progress in recent decades. Information is available on the modelled spatial distributions [36,37] and the oceanographic and topographic relationships on the presence and abundance of many of the regularly occurring cetacean species [38,39]. This existing knowledge on cetacean habitat, soon to be mapped as Important Marine Mammal Areas (IMMA: [40]), can be combined with the shipping data to identify the spatial overlap of the environmental and anthropogenic conflicts in the Sanctuary and determine the priority management areas [41]. This is especially important for vessels carrying dangerous cargo which should avoid ecologically Sensitive Areas.[4]

Several regulatory measures exist that can be implemented and numerous nations have previously applied to the IMO to reduce the risk from maritime shipping on cetaceans. (1) A slight displacement of a Traffic Separation Scheme (TSS) in the Stellwagen Bank National Marine Sanctuary in the north-eastern USA to induce ship traffic to and from the Boston harbour to avoid crossing high density whale areas [42]. (2) An area specific ship speed reductions implemented within a security area in the Strait of Gibraltar to avoid hitting sperm whales [43]. (3) The establishment of Areas To Be Avoided (ATBAs) such as the voluntary ATBA in the Roseway Basin area, which was found to reduce the risk of collisions with right whales by 82% [44]. The declaration of the IMO's Particularly Sensitive Sea Area (PSSA) would allow for several mitigation measures to be put in place. The straight of Bonifacio in the Pelagos Sanctuary, between Sardinia and Corsica, has already been designated as a PSSA and has TSS, mandatory pilotage, ATBA around reefs and vessel traffic system measures in place [45].

---

[4] IMO Resolution A.927(22): "*MARPOL 73/78, in Annexes I, II and V, defines certain sea areas as Special Areas in relation to the type of pollution covered by each Annex. A Special Area is defined as "a sea area where for recognised technical reasons in relation to its oceanographical and ecological conditions and to the particular character of its traffic, the adoption of special mandatory methods for the prevention of sea pollution by oil, noxious liquid substances, or garbage, as applicable, is required.*"
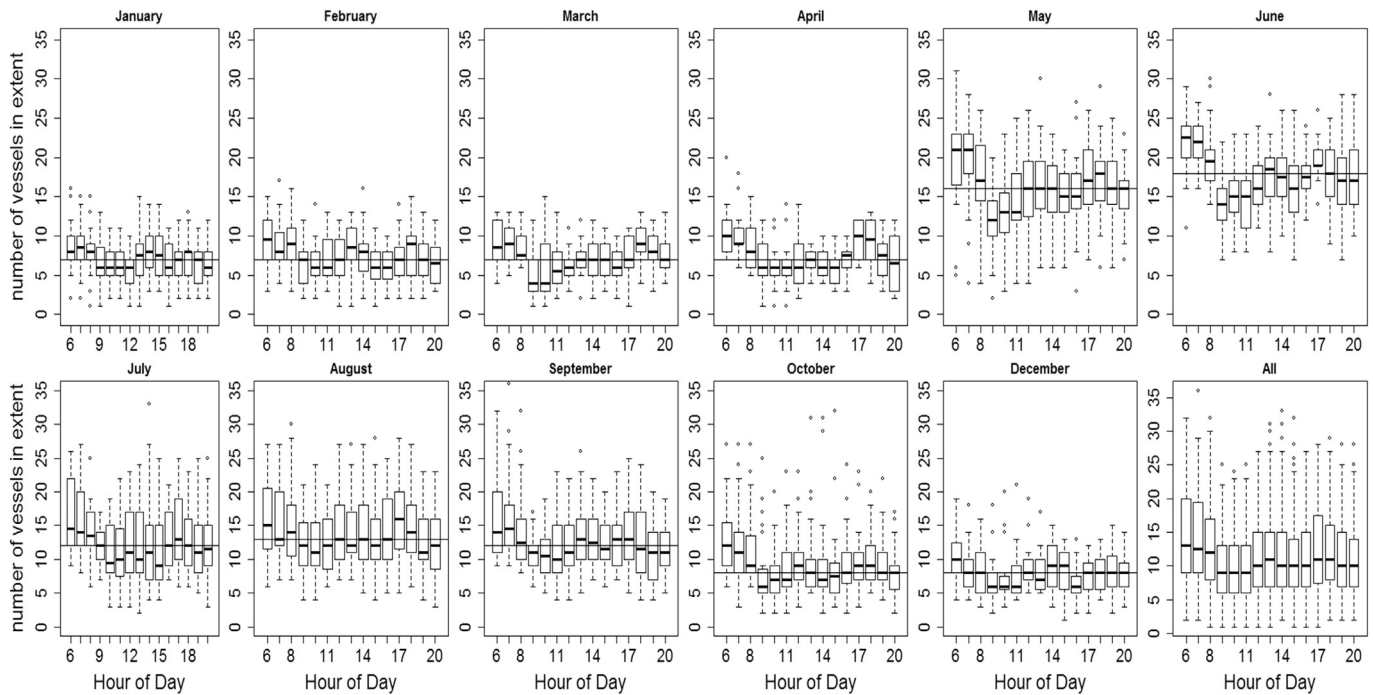http://www.gc.noaa.gov/documents/gcil_sad_imo_927.pdf

Fig. 7. The number of vessels found in the Genoa Canyon System where the AIS antenna is receiving perfectly during the different daylight hours for each month and combined total.

4.2. Findings

This study highlights the heterogeneous spatial distribution of the shipping density in the Pelagos Sanctuary, with the majority of the vessel transits localized within distinct shipping corridors. Moreover, the speeds at which the vessels navigate within them, the time of day they are used and the vessel types which predominantly use them has been shown to differ. This includes a corridor predominantly used by pleasure vessels and one mostly used during the hours of darkness. This study has also identified the spatial distribution of the vessels transiting with hazardous cargo and areas frequented by fishing vessels. Thus the high resolution spatio-temporal distribution and characteristics of one of the most influential marine activities within the Sanctuary is a main asset for integration into a MSP framework for effect EBM.

Despite the global and Mediterranean trend towards increasing shipping with time [1,46] and its close link with global economic effects [47] the temporal distribution of the shipping density in the area was not found to differ significantly between the studied years. This is likely due to the short time frame and the current global economic situation. However, this work displayed a significant seasonal trend which is in concordance with the finding of [16]. It also confirms their assumption that it is primarily due to the increase of summer passenger vessel transits in the area. Moreover, this study has also found a summer increase in fishing and pleasure vessels. The other vessel types were found to remain relatively constant between seasons indicating at a consistent level of trade traffic and associated service vessel traffic throughout the year.

The vessel transiting speeds in the Pelagos Sanctuary were found to be high and dependent on vessel type with specific spatial distributions. A similar result was found by [16,48] whom both found that the Pelagos Sanctuary was transited by an abundant number of high speed vessels. They attributed this finding to the numerous high speed ferries in the area, despite not separating shipping densities into type. This work confirms their finding as passenger vessels were the fastest navigating vessel type and

contributed the most to the overall spatial speed distribution. On another hand, this study gives for the first time indications about pleasure vessel speed: they have an almost spatially uniform distribution of fast vessels (20–25 km/h) across the entire reduced extent.

Globally, the proportion of the cargo and tanker vessels found in this study were similar to that of the world fleet, however, the proportion of passenger vessels was found to be much higher (6.8% relative to 0.3%: [46]). This coincides with the description of the Mediterranean Sea as a global cluster of passenger vessels [2]. Moreover, the proportion of the commercial transits made by cargo (37%) and tanker vessels (18%) were lower (72% and 20% respectively), and passenger transits much higher (45% relative to 6%), than what has previously been recorded in the whole Mediterranean Sea [1]. A large number of transits were found to be navigating under a Pelagos state or Mediterranean state flag (60% & 64% respectively) and this is also higher than what was reported previously in the Mediterranean Sea [1]. However, a large number of transits especially those of cargo, tanker and pleasure vessels were flagged to non-Mediterranean flag state and a quarter of the transits were found to be navigating under a FOC. It was also found that 76% of all transits were destined for a Mediterranean state, which again is higher than what was previously quoted [1].

The lesser studied vessel types: service, fishing and pleasure crafts have been found to contribute considerably to the overall shipping traffic in the area with 37% of all vessels, 30% of the total number of transits and 15% of the total kilometres of transits. As pointed out by [9] the contribution of these vessels, which have often been excluded from previous Mediterranean studies [1,15,16], are an important component of the shipping, especially considering that for both pleasure and fishing crafts are obviously underestimated due to the absence of AIS transmitters on high portion of crafts. Indeed, the spatial distribution of fishing and pleasure vessels have an important socioeconomic use of the marine environment.

4.3. Use of the findings for MSP and EBM

The findings of this study indicate that the shipping in the Pelagos Sanctuary is not representative of the Mediterranean as a whole. A large proportion of the transits were intra-Mediterranean passenger transits navigating under a Mediterranean state flag. Given that, a vessel is bound by the laws of its flag state, unless in the territorial waters of another flag state [24]. The majority of the vessels and a certain surface of the Sanctuary are already covered by the national jurisdiction of Mediterranean states and international agreements. Indeed, the Sanctuary lies within the jurisdictional boundaries of several national and international legal agreements, including: the Regional Activity Centre for Specially Protected Areas (RAC/SPA), the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and the contiguous Atlantic Area (ACCOBAMS), the French Exclusive Economic Zone, the Italian Ecological Protection Zone and the Pelagos Agreement itself. Agreements' whose combined objectives are to manage and improve the conservational status of marine life (including cetaceans) and their habitats from the detrimental effects of anthropogenic pressures.

However, a proportion of the shipping is under the flags of non-Mediterranean states (64%) particularly cargo and tanker vessels, which are also more likely to be carrying hazardous cargo and navigating beyond the 12 nautical mile territorial waters. This means that a proportion of the maritime traffic is beyond Mediterranean state jurisdiction, and are bound by the laws of the vessel's flag state due to freedom of navigation [49]. It is a fact that some flag states are "better" than others in their acceptance and ability to comply to safety and environmental conventions [50] and the reporting of incidences [51]. Thus an international body must be involved in order that all shipping traffic is to be targeted. The IMO represents this international governing body, as it is the primary authority responsible for all international maritime interests. Once an IMO shipping policy or environmental mitigation method is in place, all vessels, regardless of their flag state, fall under the jurisdiction of the IMO. Thus the IMO represents one of the key components in mitigating shipping and marine mammal mitigation methods [52]. However, once again the control falls upon the Mediterranean and Pelagos state governments as a formal proposal must be made to the IMO by member state governments only [43]. The proposal of mitigation actions requires documentation, supplied by this study, describing the problem caused by maritime traffic, the associated adverse affects, the associated nature of the vessel traffic [43].

The level of the impacts of both collisions and acoustic pollution are closely linked with the type and operational behaviour of the shipping. The level, spectral shape and frequencies of the emitted underwater noise from shipping has been directly linked to the type, age, size and speed of a vessel [53–55]. Moreover, the speed of a vessel affects directly the frequency of occurrence and the lethality of a whale ship collision [34,35,44,56]. Despite all vessel types being found to be linked with ship whale collisions [34,35,57] high speed passenger vessels have been implicated with a higher frequency of ship strikes [35].

Many cetacean species are also subject to diurnal behavioural changes [58–60] or changes in seasonal presence and abundance [61,62]. Thus the temporal overlap, for instance the coincidental increase of both fin whale and shipping during the summer, can be used to propose temporary management areas and indicate when it should be introduced. The identification of these priority management areas are fundamental in the Pelagos Sanctuary due to its large size (87,500 km^2) and will facilitate conservation efforts allowing to be more concentrated when and where it is needed and less restrictive when and where possible.

4.4. Implications about the methodology

The methods used in this study have several methodological implications towards previous studies on the distribution and levels of shipping. Firstly the clear differences found between the recorded levels of shipping as the number of vessels, transits and covered transit distance has distinct outcomes. These differences were caused by the multiple transits conducted by each unique vessel and it is of special importance because of the predominance of passenger vessels in the Sanctuary. For instance, [2] recorded the number of unique vessels in a 100 km^2 cell over 8 days, as a consequence, one vessel in this time and at this scale may conduct several, if not tens, of transits. Also the use of a "snap-shot", brief temporal windows, have been used in previous shipping studies [2,16], due to the amount of AIS data and the associated processing time but they may not be adequate to discover the small time scale or seasonal differences that were found in this study. Moreover, this study, along with [9] have demonstrated that AIS data processing times are not extensive and the benefits of this highly detailed data source are incredibly useful in shipping management. It has been seen in this study and previously stated by the [8] that the reception of terrestrial AIS receivers is limited beyond 55 km, due to unreceived PRCs. However, the inferred transit method of the [12] used here has allowed for a reliable description of the shipping beyond this distance. Providing confident descriptions and identification of high use areas beyond this referred distance that can be used in successful management purposes.

5. Conclusion

This long term AIS monitoring study has analyzed at a high resolution the spatial and temporal distribution of the shipping levels by type in an established MPA, information which is essential for the successful management of shipping [63]. Moreover, it has identified several key stakeholders (passenger vessel companies and fishermen) and managerial authorities (Mediterranean state governments and the IMO) that should be involved in future sanctuary decisions. Furthermore, these findings have provided the relevant authorities with a necessary component required for IMO's mitigation measure proposals [64] and the study's methods can be used to regulate, control and assess the proposed mitigation measures in the future. As such, the work of this study represents highly relevant information for future management of the Pelagos Sanctuary. However, the data provided cannot be used in isolation, and requires integration into a MSP framework with the available spatial distributions of the biological, ecological and socioeconomic data in the area. This will allow for coordinated decisions on managing multiple uses within this marine environment with the aim to minimize the user-user and user-environmental conflicts. In conclusion this study relates to the planning and future development of the EBM approach that the sanctuary authorities had in mind during its conception [65].

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.marpol.2016.04.013.

References

[1] M.I.U. Lloyds. Study of Maritime Traffic Flows in the Mediterranean Sea. Regional Marine Pollution Emerg. Response Cent. Mediterr. SEA (REMPEC), 2008, p. 39.

[2] G. Eiden, T. Martinsen, Technical Note 4.1 Vessel Density Mapping. Preparatory Action for Assessment of the Capacity of Spaceborne Automatic Identification System Receivers to Support EU Maritime Policy, 2010, p. 32. ⟨https://webgate.ec.europa.eu/maritimeforum/sites/maritimeforum/files/6039_PASTA%20MARE_GH_TN-004–1_Density_Plot_I4.pdf⟩.

[3] A. Abdulla, O. Linden, Maritime Traffic Effects on Biodiversity in the Mediterranean Sea, (Volume 1, Review) Of Impacts, Priority Areas and Mitigation Measures, IUCN Centre for Mediterranean Cooperation, Malaga, Spain 2008, p. 168, ISBN:978–2–8317–1079–2.

[4] G. Notarbartolo di Sciara, T. Agardy, D.K. Hyrenbach, T. Scovazzi, P. Van Klaveren, The Pelagos Sanctuary for Mediterranean marine mammals, Aquat. Conserv.: Mar. Freshw. Ecosyst. 17 (5) (2008) 367–391, http://dx.doi.org/10.1002/aqc.855.

[5] N. Schaefer, V. Barale, Maritime Spatial Planning: Opportunities & challenges in the framework of the EU integrated maritime policy, J. Coast. Conserv. 15 (2) (2011) 237–245, http://dx.doi.org/10.1007/s11852–011–0154–3.

[6] F. Douvere, The importance of Marine Spatial Planning in advancing ecosystem-based sea use management, Mar. Policy 32 (5) (2008) 762–771, http://dx.doi.org/10.1016/j.marpol.2008.03.021.

[7] C.N. Ehler, F. Douvere, Visions for a Sea Change, Report of the First International Workshop on Marine Spatial Planning, UNESCO, Paris, France 2006, p. 84 ⟨http://www.belspo.be/belspo/northsea/publ/sea%20change%20vision%20.pdf⟩.

[8] IMO. Guideline for the Onboard Operational use of Shipborne Automatic Identification Systems (AIS). ASSEMBLY/22/RES/917, 2002, p. 14. ⟨http://www.navcen.uscg.gov/pdf/AIS/IMO_A_917(22)_AIS_OPS_Guidelines.pdf⟩.

[9] R.L. Shelmerdine, Teasing out the detail: how our understanding of marine AIS data can better inform industries, developments, and planning, Mar. Policy 54 (2015) 17–25, http://dx.doi.org/10.1016/j.marpol.2014.12.010.

[10] C. Erbe, A. MacGillivray, R. Williams, Mapping cumulative noise from shipping to inform Marine Spatial Planning, Acoust. Soc. Am. 132 (5) (2012) 423–428, http://dx.doi.org/10.1121/1.4758779.

[11] J.V. Redfern, M.F. McKenna, T.J. Moore, J. Calambokidis, M.L. DeAngelis, E.A. Becker, J. Barlow, K.A. Forney, P.C. Fiedler, S.J. Chivers, Assessing the risk of ships striking large whales in Marine Spatial Planning, Conserv. Biol. 27 (2) (2012) 292–302, http://dx.doi.org/10.1111/cobi.12029.

[12] MMO. Spatial trends in shipping activity. ABP) Marine Environmental Research Ltd MMO. Project NO:1042, 2013, p. 46. ISBN:978–1–909452–12–1.

[13] R. Shucksmith, L. Gray, C. Kelly, J.F. Tweddle, Regional Marine Spatial Planning – The data collection and mapping process, Mar. Policy 50 (2014) 1–9, http://dx.doi.org/10.1016/j.marpol.2014.05.012.

[14] B.S. Halpern, S. Walbridge, K.A. Selkoe, C.V. Kappel, F. Micheli, C. D'Agrosa, J.F. Bruno, K.S. Casey, C. Ebert, H.E. Fox, R. Fujita, D. Heinemann, H.S. Lenihan, E.M.P. Madin, P.T. Perry, E.R. Selig, M. Spalding, R. Steneck, R. Watson, A global map of human impact on marine ecosystems, Science 319 (5865) (2008) 948–952, http://dx.doi.org/10.1126/science.1149345.

[15] L. David, S. Alleaume, C. Guinet, Evaluation of the potential of collision between fin whales and maritime traffic in the north-western Mediterranean Sea in summer, and mitigation solutions, J. Mar. Anim. Ecol. 4 (1) (2011) 17–28 ⟨http://www.oers.ca/journal/volume4/issue1/Lea_Galley.pdf⟩.

[16] T. Vaes, J.N. Druon, Mapping of Potential Risk of Ship Strike with Fin Whales in the Western Mediterranean SEA, Publications Office of the European Union, Luxembourg 2013, p. 28, ISBN:978–92–79–28851–7.

[17] Z. Ou, J. Zhu, AIS database powered by GIS technology for maritime safety and security, J. Navig. 61 (4) (2008) 655–665, http://dx.doi.org/10.1017/S0373463308004888.

[18] A.A.I.S. Graveson, An inexact science, J. Navig. 57 (3) (2004) 339–343, http://dx.doi.org/10.1017/S0373463304002759.

[19] A. Norris, AIS implementation – success or failure? J. Navig. 60 (1) (2006) 1–10, http://dx.doi.org/10.1017/S0373463307004031.

[20] A. Harati-Mokhtari, A. Wall, P. Brooks, J. Wang, Automatic Identification System (AIS): data reliability and human error implications, J. Navig. 60 (3) (2007) 373–389, http://dx.doi.org/10.1017/S0373463307004298.

[21] R. Bošnjak, L. Šimunović, Z. Kavran, Automatic identification system in maritime traffic and error analysis. transactions on maritime, Sciences 1 (2) (2012) 77–84, http://dx.doi.org/10.7225/toms.v01.n02.002.

[22] HELCOM. Inaccuracies in Ais Data - Effects on usability. Helsinki Commission Expert Working Group for Mutual Exchange and Deliveries of Ais DATA, 2008, p. 4. ⟨https://portal.helcom.fi/Archive/Shared%20Documents/AIS%20EWG%2017–2008_9–1%20AIS%20data.pdf⟩.

[23] H. Peifer, About the EEA reference grid, Eea (2011) 2 ⟨http://www.eea.europa.eu/data-and-maps/data/eea-reference-grids-1#tab-additional-information⟩.

[24] I.M. Sinan, UNCTAD and flags of convenience, J. World Trade 18 (2) (1984) 95–109 ⟨https://www.kluwerlawonline.com/abstract.php?area=Journals&id=TRAD1984011⟩.

[25] Ehler & Douvere, Marine Spatial Planning: a Step-by-step Approach Toward Ecosystem-based Management. Intergovernmental Oceanographic Commission and Man and the Biosphere Programme. IOC Manual and Guides No. 53, ICAM Dossier No. 6, UNESCO, Paris 2009, p. 99 ⟨http://unesdoc.unesco.org/images/0018/001865/186559e.pdf⟩.

[26] W.J. Richardson, Jr.C.R. Greene, C.I. Malme, D.H. Thomson, Marine Mammals and Noise, Academic press, San Diego, 1995, ISBN: 978–0–08–057303–8.

[27] IWC, Report of the Joint IWC-ACCOBAMS Workshop on Reducing Risk of Collisions Between Vessels and Cetaceans, International Whaling Commission, Beaulieu-sur-Mer 2010, p. 42 ⟨https://iwc.int/private/downloads/KCt_NslZ5ORAGm37c9Z-Yg/Ship%20strikes%20workshop%20report%20final.pdf⟩.

[28] C. Perry, SC/50/E9 A review of the impact of anthropogenic noise on cetaceans. SC50 Documents, International Whaling Commission, 1998, p. 27.

[29] T.M. Cox, T.J. Ragen, A.J. Read, E. Vos, R.W. Baird, K. Balcomb, J. Barlow, J. Caldwell, T. Cranford, L. Crum, A. D'Amico, G. D'Spain, A. Fernandez, J. Finneran, R. Gentry, W. Gerth, F. Gulland, J. Hildebrand, D. Houser, T. Hullar, P.D. Jepson, D. Ketten, C.D. MacLeod, J.G. Mead, P. Miller, S.E. Moore, D.C. Mountain, D.L. Palka, P. Ponganis, S. Romme, T Rowles, B. Taylor, P. Tyack, D. Wartzok, R. Gisiner, J. Meads, L. Benner, Understanding the impacts of anthropogenic sound on beaked whales, J. Cetacean Res. Manag. 7 (3) (2006) 177–187.

[30] L.S. Weilgart, The impacts of anthropogenic ocean noise on cetaceans and implications for management, Can. J. Zool. 85 (11) (2007) 1091–1116, http://dx.doi.org/10.1139/Z07–101.

[31] D.P. Nowacek, L.H. Thorne, D.W. Johnston, P. Tyack, Responses of cetaceans to anthropogenic noise, Mammal. Rev. 37 (2) (2007) 81–115, http://dx.doi.org/10.1111/j.1365–2907.2007.00104.x.

[32] B.L. Southall, A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, Jr.C.R. Greene, D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, P.L. Tyack, Marine mammal noise exposure criteria: initial scientific recommendations, Aquat. Mamm. 33 (4) (2007) 411–509, http://dx.doi.org/10.1578/AM.33.4.2007.411.

[33] C. Peng, X. Zhao, G. Liu, Noise in the sea and its impacts on marine organisms international, J. Environ. Res. Public Health 12 (10) (2015) 12304–12323, http://dx.doi.org/10.3390/ijerph121012304.

[34] D.W. Laist, A.R. Knowlton, J.G. Mead, A.S. Collet, M. Podesta, Collisions between ships and whales, Mar. Mammal. Sci. 17 (1) (2001) 35–75, http://dx.doi.org/10.1111/j.1748–7692.2001.tb00980.x.

[35] S. Panigada, G. Pesante, M. Zanardelli, F. Capoulade, A. Gannier, M.T. Weinrich, Mediterranean fin whales at risk from fatal ship strikes, Mar. Pollut. Bull. 52 (10) (2006) 1287–1298, http://dx.doi.org/10.1016/j.marpolbul.2006.03.014.

[36] S. Panigada, M. Zanardelli, M. MacKenzie, C. Donovan, F. Mélin, P.S. Hammond, Modelling habitat preferences for fin whales and striped dolphins in the Pelagos Sanctuary (Western Mediterranean Sea) with physiographic and remote sensing variables, Remote Sens. Environ. 112 (8) (2008) 3400–3412, http://dx.doi.org/10.1016/j.rse.2007.11.017.

[37] A. Azzellino, S. Panigada, C. Lanfredi, M. Zanardelli, S. Airoldi, G. Notarbartolo di Sciara, Predictive habitat models for managing marine areas: Spatial and temporal distribution of marine mammals within the Pelagos Sanctuary (Northwestern Mediterranean sea), Ocean Coast. Manag. 67 (2012) 63–74, http://dx.doi.org/10.1016/j.ocecoaman.2012.05.024.

[38] A. Azzellino, S. Gaspari, S. Airoldi, B. Nani, Habitat use and preferences of cetaceans along the continental slope and the adjacent pelagic waters in the western Ligurian Sea, Deep Sea Res. Part I: Ocean. Res. Pap. 55 (3) (2008) 296–323, http://dx.doi.org/10.1016/j.dsr.2007.11.006.

[39] P. Tepsich, M. Rosso, P.N. Halpin, A. Moulins, Habitat preferences of two deep-diving cetacean species in the northern Ligurian Sea, Mar. Ecol. Progress. Ser. 508 (2014) 247–260, http://dx.doi.org/10.3354/meps10851.

[40] G. Notarbartolo di Sciara, E. Hoyt, R. Reeves, J. Ardron, H. Marsh, D. Vongraven, B. Barr Place-based approaches to marine mammal conservation. Aquatic Conservation: Marine and Freshwater Ecosystems, 2016, http://dx.doi.org/10.1002/aqc.2642 (In press).

[41] M.E. Portman, G. Notarbartolo di Sciara, T. Agardy, S. Katsanevakis, H. Possingham, G. Di-Carlo, Who hesitates is lost: Why conservation in the Mediterranean Sea is necessary and possible now, Mar. Policy 42 (2013) 270–279, http://dx.doi.org/10.1016/j.marpol.2013.03.004.

[42] D. Wiley, L. Hatch, K. Schwehr, M. Thompson, C. Macdonald, Marine Sanctuaries and Marine Planning: Protecting Endangered Marine Life, National Ocean Policy Proceedings, Washington, DC 2013, pp. 10–15 ⟨http://uscgproceedings.epubxp.com/i/205896-fall-2013/12⟩.

[43] G.K. Silber, A.S.M. Vanderlaan, A.T. Arceredillo, L. Johnson, C.T. Taggart, M.W. Brown, S. Bettridge, R. Sagarminaga, The role of the International Maritime Organization in reducing vessel threat to whales: process, options, action and effectiveness, Mar. Policy 36 (6) (2012) 1221–1233, http://dx.doi.org/10.1016/j.marpol.2012.03.008.

[44] A.S.M. Vanderlaan, C.T. Taggart, Vessel collisions with whales: the probability of lethal injury based on vessel speed, Mar. Mammal. Sci. 23 (1) (2007) 144–156, http://dx.doi.org/10.1111/j.1748–7692.2006.00098.x.

[45] Marine Environment Protection Committee, Designation of the Strait of Bonifacio as a Particularly Sensitive Sea Area. Annex 22 Resolution MEPC.204(62) adopted on 15 july 2011. ⟨http://www.imo.org/blast/blastDataHelper.asp?data_id=30763&filename=204(62).pdf⟩.

[46] UNCTAD, Review of Maritime Transport, 2014, United Nations publication,

Geneva 2013, p. 120, ISBN:978–92–1-112878–9.

[47] G.V. Frisk, Noiseonomics: The relationship between ambient noise levels in the sea and global economic trends, Sci. Rep. 2 (437) (2012) 1–4, http://dx.doi.org/10.1038/srep00437.

[48] R. Leaper, S. Panigada, SC/63/BC4 Some considerations on the use of AIS data to estimate shipping density for ship strike risk assessment. SC63 Documents, International Whaling Commission, 2011, p. 8. ⟨https://iwc.int/private/downloads/1Y-RvFOUuX0FRWZs5RW9lA/SC-63-BC4.pdf⟩.

[49] J. Gisbon, L. Warren, Legislative requirements, in: S. Gubbay (Ed.), Marine Protected Areas: Principles and Techniques for Management. New York, Springer, Netherlands, 1995, pp. 32–60, ISBN:978–94–011–0527–9.

[50] E. Gold, Learning from disaster: lessons in regulatory enforcement in the maritime sector, Rev. Eur. Community Int. Environ. Law 8 (1) (1999) 16–20, http://dx.doi.org/10.1111/1467–9388.00173.

[51] N. Ellis, M. Bloor, H. Sampson, N. Ellis, M. Bloor, H. Sampson, Patterns of seafarer injuries, Marit. Policy Manag.: Flagship J. Int. Shipp. Port. Res. 37 (2) (2010) 121–128, http://dx.doi.org/10.1080/03088830903533742.

[52] C.K.A. Geijer, P.J.S. Jones, A network approach to migratory whale conservation: are MPAs the way forward or do all roads lead to the IMO? Mar. Policy 51 (2015) 1–12, http://dx.doi.org/10.1016/j.marpol.2014.06.002.

[53] B. Kipple, Glacial Bay Underwater Noise Technical Report NSWCCD-71-TR-2002/579, Naval Surface Warfare Center, Bremerton, Washington 2002, p. 66.

[54] M.F. McKenna, D. Ross, S.M. Wiggins, J.A. Hildebrand, Underwater radiated noise from modern commercial ships, Acoust. Soc. Am. 131 (1) (2012) 92–103, http://dx.doi.org/10.1121/1.3664100 ⟨http://www.nps.gov/glba/learn/nature/upload/GBAmbientNoiseInterimReport.pdf⟩.

[55] M.F. McKenna, S. Wiggins, J.A. Hildebrand, Relationship between container ship underwater noise levels and ship design, operational and oceanographic conditions. Scientific Reports, 2013, vol. 3 (1760), pp. 1–10, doi: 10.1038/srep01760.

[56] D.N. Wiley, M. Thompson, R.M. Pace III, J. Levenson, Modeling speed restrictions to mitigate lethal collisions between ships and whales in the Stellwagen Bank National Marine Sanctuary, USA, Biol. Conserv. 144 (9) (2011) 2377–2381, http://dx.doi.org/10.1016/j.biocon.2011.05.007.

[57] A.S. Jensen, G.K. Silber, Large Whale Ship Strike Database. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-OPR, 2003, p. 37. ⟨http://www.nmfs.noaa.gov/pr/pdfs/shipstrike/lwssdata.pdf⟩.

[58] R.W. Baird, F.J. Borsani, M.B. Hanson, P.L. Tyack, Diving and night-time behavior of long-finned pilot whales in the Ligurian Sea, Mar. Ecol. Progress. Ser. 237 (2002) 301–305, http://dx.doi.org/10.3354/meps237301.

[59] S. Panigada, G. Pesante, M. Zanardelli, S. Oehen, Day and Night-time Diving Behavior of Fin Whales in the Western Ligurian Sea. Proceedings of the Conference Oceans 2003, IEEE, San Diego, California 2003, pp. 466–471, http://dx.doi.org/10.1109/OCEANS.2003.178624.

[60] R.W. Baird, D.L. Webster, G.S. Schorr, D.J. McSweeney, Diel variation in beaked whale diving behavior, Mar. Mammal. Sci. 24 (3) (2008) 630–642, http://dx.doi.org/10.1111/j.1748–7692.2008.00211.x.

[61] G. Notarbartolo di Sciara, M. Zanardelli, M. Jahoda, S. Panigada, S. Airoldi, The fin whale *Balaenoptera physalus* (L 1758) in the Mediterranean Sea, Mammal. Rev. 33 (2) (2003) 105–150, http://dx.doi.org/10.1046/j.1365–2907.2003.00005.x.

[62] S. Laran, V. Drouot-Dulau, Seasonal variation of striped dolphins, fin- and sperm whales' abundance in the Ligurian Sea (Mediterranean Sea), J. Mar. Biol. Assoc. U. K. 87 (2007) 45–52, http://dx.doi.org/10.1017/S0025315407054719.

[63] H.D. Smith, The environmental management of shipping, Mar. Policy 19 (6) (1995) 503–508, http://dx.doi.org/10.1016/0308–597X(95)00033–3.

[64] IMO. Resolution A, 982(24) Revised guidelines for the identification and designation of Particularly Sensitive Sea Areas, 2006, p. 13. ⟨http://www.gc.noaa.gov/documents/982–1.pdf⟩.

[65] A. Barcelo, M. Peirache, D. Ody, Gouvernance et animation du Sanctuaire PELAGOS, la première aire marine protégée transfrontalière de haute *mer* destinée à la protection des mammifères marins (Méditerranée), Sci. Rep. Port.-Cros Natl. Park 27 (2013) 451–460 ⟨http://www.portcrosparcnational.fr/Documentations/Gouvernance-et-animation-du-Sanctuaire-PELAGOS-la-premiere-aire-marine-protegee-transfrontaliere-de-haute-*mer*-destinee-a-la-protection-des-mammiferes-marins-Mediterranee⟩.