AIS data, a mine of information on trawling fleet mobility in the Mediterranean Sea

Published Version:
Armelloni, E.N., Tassetti, A.N., Ferrà, C., Galdelli, A., Scanu, M., Mancini, A., et al. (2021). AIS data, a mine of information on trawling fleet mobility in the Mediterranean Sea. MARINE POLICY, 129, 1-9 [10.1016/j.marpol.2021.104571].

Availability:
This version is available at: https://hdl.handle.net/11585/856625 since: 2022-02-11

Published:
DOI: http://doi.org/10.1016/j.marpol.2021.104571

Title

AIS data, a mine of information on trawling fleet mobility in the Mediterranean Sea

Authors

Enrico Nicola Armelloni[1,2, *], Anna Nora Tassetti[1], Carmen Ferrà[1], Alessandro Galdelli[3], Martina Scanu[1,2], Adriano Mancini[3], Gianna Fabi[1], Giuseppe Scarcella[1]

Affiliations

[1] Institute of Marine Biological Resources and Biotechnologies, National Research Council, 60125 Ancona, ITALY

[2]Department of Biological, Geological and Environmental Sciences, University of Bologna, 40126 Bologna, Italy.

[3] Dipartimento di Ingegneria dell'Informazione, Università Politecnica delle Marche, 60131 Ancona, ITALY

* Corresponding author: Enrico Nicola Armelloni (mail address: enrico.armelloni@irbim.cnr.it, phone number: +39 333 5088078). Institute of Marine Biological Resources and Biotechnologies, National Research Council, 60125 Ancona, ITALY.

Abstract

In the Mediterranean Sea, fishing vessels often operates throughout the geographical subdivisions adopted for statistical data collection (Geographical Sub-Areas; GSAs), causing a potential mismatch between catches site and reporting site. This paper provides a quantitative assessment of the fluxes of fishing activity of bottom trawlers across the Mediterranean Sea, by analyzing the Automatic Identification System (AIS) data broadcasted in 2017. Fishing activity was analyzed from three perspectives: fishing site, port of arrival and registration site of the vessel. For each GSA, a "fidelity score" was calculated to quantify the proportion of fishing time spent in the home GSA; an "intrusion score" was computed to quantify the effort deployed by vessels registered elsewhere. Major vessel fluxes were detected between GSAs, and fleets were classified based on their mobility. Areas showing fleet overlaps were identified and those characterized by the largest overlaps were selected as case studies. The most mobile trawling fleets were those from the central Mediterranean (GSAs 11.2, 15, 16 and 18), while the highest intrusion score was recorded in the southern

Mediterranean and around Crete. The fleets most frequently engaged in long range mobility were from GSAs 16, 18, and 6. The case studies included: GSAs 23, where several fleets exploited narrow slope areas; GSA 13, where multiple fleets overlapped in a relatively wide area; and GSA 17, where two fleets overlapped in a wide platform area. Mobility was distinguished in short-range – involving platform areas of contiguous GSAs – and long-range – involving slope areas of non-contiguous GSAs.

Key-words

AIS data; Fleet mobility; Fishing effort; Mediterranean Sea, Geographical Sub-Areas

1 Introduction

Analysis of fleet mobility can provide valuable support for a wide range of studies, such as the drafting of management plans for the sustainable exploitation of fishery resources [1,2], the detection of possible conflicts among different fishing activities [3], the monitoring of effort displacement [4,5], and the identification of mismatches between catch and registration site [6,7]. The introduction of systems providing high-resolution fishing vessel position data, such as the Vessel Monitoring System (VMS) and the Automatic Identification Systems (AIS), has revolutionized the study of the fleet mobility and many patterns have been described worldwide [8,9]. As a matter of fact, the Mediterranean Sea is a basin bordered by more than 20 countries and three continents (Figure 1), where the virtual absence of Exclusive Economic Zones (EEZs) [10] allows fleets from different countries to operate far from their home port to exploit shared stocks [11,12]. A number of studies revealed that some Mediterranean fishers routinely operate at a limited distance from their home port, whereas others exploit grounds that are far removed from their own territorial waters [5,7] and may gravitate around ports different from their registration site [13]. This dynamism is not properly caught by the geographical sub-division system used to collect fishery statistical data, including vessels landing, which may appear too rigid [7]. In fact, the units adopted for the collection of fishery statistical data and stock assessment in the Mediterranean Sea (Geographical Sub-Areas; GSAs) [14] are a division that actually reflects less the actual geographical distribution of stocks and fleet exploitation patterns than the geopolitical borders, potentially undermining the accuracy of fishery statistics [6,11]. EU and non-EU

Mediterranean countries often fail to provide catch statistics for their fleets operating in remote areas, releasing only those based on GSAs (for an example see [15,16]). Such poor knowledge of mobility fleet dynamics is capable of leading to local depletion of stocks and/or destruction of sensitive habitats, which would escape direct detection. Available studies addressing the correspondence between the registration site and the exploitation patterns of fishing vessels in the Mediterranean Sea are limited to national scale [7], or focuses on the port usage of the European fleet [13]. A comprehensive assessment of Mediterranean fleet mobility in respect to the actual management areas is still lacking. Since transboundary cooperation is essential for the conservation of marine resources, especially where internationally shared stocks are concerned [17], there is the need to investigate fleet mobility patterns including also non-European fleets, and to assess its consistency with the in-force management areas.

To provide a quantitative description of fleet mobility dynamics in the Mediterranean Sea, in respect to the actual management units, we analyzed the AIS data transmitted in one entire year (2017) by bottom otter trawlers operating throughout the basin. The decision to focus only on bottom otter trawlers was mostly dictated by the need to reduce noise in the analysis: the mobility of beam and pelagic mid-water trawlers is limited because they are allowed only in specific areas of the basin, depending on national laws (*e.g.*: Italian beam trawlers [18], Spanish pelagic mid-water trawlers [19]). Spatial relationships were investigated at GSA level, by individuating three layers of information: where fishing activity was observed, where the fishing trips finished and where the vessels where registered. Vessels identifier where cross-matched with official registers to identify their registration port, and the corresponding GSA of registration, defined as "home-GSA". Fishing tracks (FTs) were subjected to spatial analysis allowing to identify where the trawling activity was conducted and to which port the fishing trips finished (port of arrival). The first objective of the analysis was to develop quantitative metrics describing fidelity of vessels to their home GSA and amount of fishing effort attributed to non-home fishing vessels in each area: this analysis will serve to identify the most mobile fleets and the areas mostly exploited by non-local fleets. The second objective was to reconstruct the main fluxes of bottom trawling activity between GSAs: this section will allow to disaggregate the exploitation patterns also in relation to the use of ports in distant areas. The third objective was to characterize fleets registered in the GSAs basing on the frequency of activity conducted beyond their home area borders: this information serves to figure out the percentage of the fleet responsible of the activity conducted in distant areas. The last objective was to increase the spatial detail for individuating the fishing grounds where vessels with different origin showed the maximum interaction, also providing detailed zooms. This last part will permit to identify the areas where it may be more urgent to consider fleet interaction within the management plans.

2 Material and methods

2.1 Data overview and pre-processing

Terrestrial AIS (t-AIS) data from fishing vessels operating throughout the Mediterranean Sea in 2017 were purchased from a private provider [20]. The dataset consisted of 5-minute resolution spatial points (or pings) accompanied by information on date, time, speed, International Maritime Organization (IMO) number, and Maritime Mobile Service Identity (MMSI) code. Data were pre-processed according to Ferrà et al. [21], to remove incorrect pings (speed outliers and repeated points), and according to Galdelli et al. [22], to classify vessel trips (VTs) as "Bottom trawl" or "Other". Once the bottom trawlers' VTs had been identified, their FTs were extracted and associated to the following attributes: towing speed (knots), towing duration (hours), timestamp, MMSI code, and port of departure and arrival. The ability of AIS data to provide exhaustive information on the number and identity the vessels fishing in the Mediterranean Sea was evaluated by comparing the AIS dataset to the list of bottom trawlers reported in the GFCM Fleet Register [23] as "Single Boat Bottom otter trawls", "Multiple Bottom otter trawls", "Bottom trawls (not either identified)", "Trawls (not either identified)" and reported in the EU Fleet Register [24] as Bottom otter trawls, Otter twin trawls or Bottom pair trawls based on the main or subsidiary fishing gear (vessels with the trawl gear as the subsidiary gear and Purse seine or Boat dredges as the main gear were excluded).

2.2 GSA of registration (home GSA) and GSA of arrival

Each FT was associated to two GSAs: (1) the GSA of the port where the VT ended, defined as "GSA of arrival" and (2) the GSA of the port where the vessel was registered, defined as "home GSA". Information regarding

GSA of arrival was derived from the port of arrival contained within VT attributes, while several techniques and information sources where used to identify the GSA of registration:

i. automatic match between AIS and European Union (EU) Fleet Register data and between AIS and GFCM Fleet Register data, where the port of registration is provided [23,24]. The AIS dataset supplied the MMSI code, IMO number, vessel name, and callsign attributes, whereas the EU Fleet Register provided the Community Fleet Register (CFR) number, IMO number, vessel name, and callsign attributes, and the GFCM fleet register, at the time of writing, provided registration number and vessel name. The EU fleet register was used for the EU fleet, because the EU Community Fleet Register (CFR) number allowed tracking the history of vessels and updating the registration port of those that had changed GSA during the period of observation. Matching was based on MMSI code, IMO number, vessel name, and vessel callsign. For matches based on the MMSI code and the IMO number, only perfect matches were considered as valid. Matches based on vessel name and callsign were performed by a stepwise procedure [25] that uses a Levenshtein and Jaro strings matching distances function [26] provided in the R library *stringdist* [27]. The matching procedure was run using first the vessel name and then the callsign (thresholds: 0.05 for names and 0.03 for callsigns), thus creating two different matrices. The MMSI code-CFR number pairs yielding a perfect match in both matrices were immediately validated. Problems due to minor misspellings were resolved using a nested distance function. The function was applied to the name matrix to assess the difference between callsigns (match validation threshold, 0.15) and to the callsign matrix to assess differences between names (match validation threshold, 0.1). For non-EU vessels the match was based on the GFCM Fleet register and involved application of the Levenshtein and Jaro strings matching distance function just on the vessels name.

ii. *the port of arrival based on VTs*: if approach described in step 1 failed, the VT records were used to calculate the frequency of the arrival GSA; a value > 0.9 involved assignation to a GSA also as registration site.

iii. *manual match with official registers after searching on fleet monitoring websites*: remaining vessels were manually assigned to a GSA of registration by searching on the web any information that could be used to obtain a match with official registers, including the use of pictures and fleet tracking websites.

Basing on this information, fleets observed to exploit their home area where defined as the "home-fleets", while fleet exploiting fishing ground in areas different from their home site were defined as "non-home fleets".

2.3 Statistics

FTs were intersected with three different feature layers: (1) GSA polygons (see 2.3.1); (2) GFCM statistical grid (0.5° x 0.5°; [28]); (3) 1 km x 1 km grid (see 2.3.2). For each intersection, the length of the FTs related to the fishing operations straddling one or more polygon or grid cell boundaries was re-calculated. All the spatial overlay operations were computed using *sf* R library [29]. The output features of intersection 1 (GSA polygons) were aggregated in three different manners:

i. by home GSA and GSA of fishing. Resulting fishing time was collected into a square matrix, where the cell value $T_{i,j}$ represented the fishing hours spent in GSA_j by vessels registered in GSA_i. The overall fishing time spent in GSA_j by any vessel was calculated by adding the elements in column j ($\sum_i T_{ij}$), whereas the row sums provided the overall fishing time spent by these vessels in their GSA of registration ($\sum_j T_{ij}$). The matrix was summarized to obtain the number of vessels fishing in their GSA of registration; the number of non-home vessels in each GSA; a Fidelity Score (FS), i.e. the proportion of fishing activity conducted by home vessels within the borders of their GSA of registration, calculated as $FS_i = \frac{T_{i=j}}{\sum_j T_{ij}}$; and an Intrusion Score (IS), i.e. the proportion of fishing activity attributable to non-home vessels, calculated as $IS_i = \frac{\sum_{i \neq j} T_{ij}}{\sum_i T_{ij}}$. Number of home and non-home vessels were also divided by the area of the GSA of fishing to calculate a vessel density statistic. Correlation between FS and registered vessel density was tested by a Spearman rank correlation test.

ii. By GSA of registration, GSA of arrival and GSA of fishing. Resulting fishing time represented the flux of fishing effort from the site of fishing to the site of registration, passing by the site of arrival. Fluxes larger than 1000 hours were represented by a Sankey diagram (*networkD3* R library; [30]), where the size of the flux was proportional to the amount of fishing time.

iii. By vessel identifier, GSA of registration, VT, Fishing Day (FD), and GSA of fishing. Based on the spatial information, those FDs spent by any vessel beyond its home GSA borders were considered as “positive”. Then, for each VT an outflow percentage was calculated as the number of positive FDs out of the total number of FDs; its mean value allowed dividing vessels into 6 outflow categories: 0%, 1-20%, 21-40%, 41-60%, 61-80%, 81-100%. The number of vessels falling into each category was calculated for each GSA and standardized to one.

The output features of intersection 2 (0.5° x 0.5° grid) were aggregated by cell and by GSA of registration to calculate, by grid cell, the total number of fishing hours attributable to each GSA. To minimize the influence of the occasional presence of vessels, values < 50 hours were discarded. Calculation of the number of fleets attributable to each GSA allowed analyzing their overlap. The areas showing maximum fleet overlap were selected for case studies, and the operations described just above were repeated on the output features of the intersection 3 (1km x 1km grid). In this case, values < 1 hour were discarded to minimize the influence of the occasional presence of vessels in the grid cells.

3 Results

3.1 Data overview

A total number of 2,060, 4,559 and 2,491 bottom trawlers were listed in the AIS database, the GFCM Fleet Register (both EU and non-EU vessels) and the EU Register (only EU vessels), respectively (Table 1). The fleet coverage was 0.45 based on the GFCM Register and 0.76 based on the EU Fleet Register. Regarding non-EU vessels detected in the AIS data, 160 vessels in total, 143 were from Turkey and 14 from Israel, while for other non-EU countries the coverage was close to 0, as no vessels broadcasted AIS data (Syria, Montenegro, Egypt, Morocco) or just a few did it (Albania, Algeria, Tunisia). A better coverage was observed for EU countries, with the highest values for Spain (0.88), France (0.83) and Slovenia (0.80).

3.2 GSA of registration and GSA of arrival

For 1,530 EU vessels the port of registration was identified based on the EU Fleet Register; 295 vessels were assigned to a GSA based on their VTs and 30 were assigned by searching on fleet monitoring websites. The registration GSA, during the year 2017, was changed by 34 vessels that remained in the same country (3 in Spain, 1 in Greece, and 30 in Italy), whereas one vessel changed GSA as well as country (from GSA 25, Cyprus, to GSA 15, Malta). Manual inspection of the AIS dataset demonstrated that some vessels had begun exploiting a new fishing area sometime before changing their registration GSA; this discrepancy influenced the analysis described in 2.3.2 and it is there commented. For non-EU countries, 140 vessels showed a match with the GFCM Fleet Register, 18 were assigned to a GSA based on VTs, while 2 were assigned by searching on the web.

3.3 Statistics

Non-zero FS values (Figure 2) ranged from 0.56 (GSA 18) to 1 (GSAs 4, 7, 27), with the highest values (FS > 0.9) largely concentrated in the western Mediterranean (GSAs 1 to 8). The density (n/km^2) of home vessels varied between 0.63 (GSA 16) and 0 (GSAs 2, 3, 11.1, 12, 14, 21). Spearman rank correlation coefficient between FS and vessel density, calculated after excluding GSAs where no registered vessels were detected, was -0.26 with a *p-value* of 0.25. The IS (Figure 2) ranged from 1 (GSAs 2, 3, 11.1, 12, 14, 21) to 0 (GSA 27), values being highest in the North African (GSAs 3, 12, 13, 14, 21), Maltese (GSA 15) and Cretan (GSA 23) areas. The density (n/km^2) of non-home vessels varied between 0.49 (GSA 2) and 0 (GSA 27). The fleets mostly fishing beyond their own GSA borders (Figure 3) were those registered in GSAs 16, 18, and 6 while the areas most exploited by non-home vessels were GSAs 17, 13 and 5. Regarding the three most proactive fleets, the vessels registered in GSA 16 returned to their home GSA when exploiting the neighboring GSAs 10, 12, 13, 15 and 19, while they temporarily based in ports of GSAs 9, 13, 22 and 23 when exploiting these distant areas. GSA 18 vessels frequently returned to their home GSA after having fished in GSA 17, while they often moored in the local harbors when fishing in GSA 19, and always when fishing in GSAs 9. The fleets of GSA 6 always returned to their home area after having exploited GSA 7, whereas they very often based in non-home harbors while fishing GSA 5. The outflow analysis (Figure 4) showed that the fleets based in the central Mediterranean (GSAs 11.2, 15, 18, 16, and 19) where those more prone to operate outside the GSA borders. The fleets registered in the western areas (GSAs 1 to 8) where those less frequently fishing in other areas. GSA 27 was the only area with sufficient AIS data coverage where the home vessels where never observed to fish outside their area borders. The mobility pattern for GSA 25 was influenced by the vessel that moved its registration site to GSA 15. The largest overlap between fleets in the 0.5 x 0.5 ° grid (Figure 5) was found in GSAs 22 and 23. In particular, in GSA 22 it involved one cell close to Rhodes, where the FTs belonged to vessels from 6 GSAs: 11.2, 16, 19, 22, 24 and 28. In GSA 23, Crete, FTs were also from vessels from 6 GSAs: 11.2, 16, 17, 19, 22, and 23. Overlap values up to 5 were computed in other cell grids of GSA 22 as well as in two cells in the Sicily Channel (GSA 13), where the analysis identified, respectively, FTs from vessels from GSAs 10, 11.2, 13, 16 and 19 and from GSAs 10, 13, 15, 16 and 25. Values up to 4 were computed in the Central Adriatic Sea (GSA 17), where FTs belonged to vessels from GSAs 9, 10, 17, and 18, in the Tyrrhenian Sea (GSA 9), where FTs were from vessels from GSAs 9, 10, 11.2, 16, 17, and 18. However, in the two latter cases the value may be overestimated by 1 in a few cells because some vessels had started operating in the area before their port GSA was changed in the official Registers. Values up to 4 were also found around Cyprus (GSA 25; vessels from GSAs 10, 11.2, 16, and 25) and in the Ionian Sea (GSA 19; vessels from GSAs 16, 17, 18, and 19). Values between 1 and 3 were computed for all the other areas. The Northern Adriatic Sea (GSA 17), the Sicily Channel (GSA 13) and the Crete island (GSA 23) were selected as case studies and analyzed at a resolution of 1 x 1 km (Figure 5). Analysis of the case study A (Northern Adriatic Sea, GSA 17) showed a wide overlap area of two fleets, those from GSA 17 and neighboring GSA 18. In the case study B (Sicily Channel, GSA 13) was highlighted an extensive overlap area, containing a narrower path where up to 3 fleets (GSAs 10, 11.2 and 16) fished in the same 1 x 1 km grid cell. Analysis of the case study C (Crete island) demonstrated that FTs were concentrated in narrow strips on the slope areas exploited by up to 5 fleets (GSAs 10, 11.2, 16, 17 and 19).

4 Discussion and conclusions

AIS data are a valuable instrument for fleet monitoring, even though the amount of vessels broadcasting the signal may vary among areas and countries [31,32]. Assessing the coverage of analyzed AIS data by comparisons with official registers can help to understand whether the results are representative of the reality. In the present analysis the coverage was generally poor for the non-European countries: the large discrepancy observed with the GFCM register, used for the non-European fleets, was unsurprising and in line with literature, due to the poor implementation of AIS transmitters on fishing vessels flagging northern African countries [33]. Slightly better results were observed for some Middle East countries, namely Turkey and Israel, which fleets showed AIS coverage values comparable to EU fleets. In addition, the GFCM register does not provide details on the vessel history, therefore it was not possible to know with certainty if the information coincides with the time of the analysis, reducing the accuracy of the results. Higher representation within AIS data was demonstrated by EU vessels, achieving a coverage that was also in line with literature [13]. Based on the coverage assessment, the results of this paper are likely to be representative of the dynamic of EU fleets as well as of the fleets of some Middle eastern countries such as Turkey and Israel, while the patterns of the northern-African fleets remain partially unsolved. The FS and IS analysis highlighted heterogeneous patterns in fleet dynamics. The FS was observed to be generally high for the western GSAs, while lower values were observed in the GSAs of the central Mediterranean and of the southern Adriatic Sea. Although some of the lowest values were observed in areas with high density of home vessels, a correlation between vessel density and FS was not demonstrated, suggesting that the competition for space is not a sufficient explanation for the fluxes of fishing activity. The IS was not mirroring the FS, since in the western Mediterranean Sea were observed some of the highest values. Notably, the outputs indicating that some GSAs hosted no fishing activity by home vessels (IS=1) were correct for GSAs 2 and 11.2, which lack fishing harbors, whereas those for GSA 3, 12, 14, and 21 merely depended on the absence of home vessels broadcasting AIS signal. A number of factors, such as fishing ground accessibility, time at sea restrictions and differences in vessel technology and size [16], as well as market prices [13], contribute to shape the fishing strategies adopted by Mediterranean fleets. AIS data *per se* cannot give information on vessels landings, and only logbook data [34] may confirms if the harbor of arrivals was used for bunkering or for unloading the catches [6]. Nevertheless, literature may be used for hypothesize on the factors driving the mobility patterns described. The analysis of the fluxes confirmed a high degree of heterogeneity between Mediterranean fishers' behavior. Fleet mobility was widespread, while in quantitative terms just three GSAs (16, 18 and 6) account for almost 70% of the activity conducted beyond the GSA of registration borders. The outflow analysis (Figure 3) set the two most active fleets apart from the third, since a large proportion of their vessels fell in the categories > 40%, whereas only a small proportion of the fleets registered in GSA 6 was often involved in fishing elsewhere. A wide spectrum of short- and long-range mobility was observed. Short-range mobility (*i.e.*, fishing activity conducted in neighboring GSAs) was common: in some cases, it involved numerous vessels that returned to their home-port at the end of the trip (such as the GSA 18 fleets exploiting the contiguous GSA 17), whereas in others only a few vessels regularly exploited and moored in a particular area (e.g. GSA 6 vessels operating in GSAs 5). EU and national management measures such as those regulating the access to fishing grounds [35,36] and time at sea [37] are likely to be the main factors that shape short-range mobility patterns; for instance, Italian vessels from GSA 18 are free to exploit Italian coastal waters in other GSAs, while France may limit the access of Spanish vessels within its territorial waters (GSA 7). In addition, Italian trawlers are allowed to fish for some consecutive days a week whereas their Spanish counterparts can only fish 12 hours a day [37]; as a result, GSA 18 vessels may undertake fishing trips spread over several days to exploit the Central Adriatic Sea, whereas fishing in the Gulf of Lion may be profitable only for some vessels registered in the northernmost part of GSA 6. Fluxes to the Spanish GSA 5 are also hampered by other restrictions, since the blue and red shrimp fishery in the Ibiza Channel is regulated by national laws that precisely define the number of vessels that are allowed to fish there [38]. Long-range mobility, entailing the exploitation of non-contiguous GSAs for a period during which the vessels based in the local ports, involved a smaller number of fleets. Most important fluxes were from GSA 16 vessels operating in the Ionian and Aegean Seas (GSAs 19, 22, and 23) and GSA 11.2 vessels exploiting GSA 23. Nevertheless, the analysis described in 2.3.1 identified several vessels from distant GSAs other than GSAs 16 and 11.2 (namely, GSAs 10, 13, 17, 19, 28) fishing in GSAs 22, 23 and 25, suggesting the existence of a number of minor fluxes of vessels involved in long-range mobility to the eastern Mediterranean. Profitability is likely to be the key driver of long-range mobility, and some evidences support this hypothesis: literature reports that the southern Aegean and Crete island slopes are particularly rich in deep-water shrimps [39] and still largely unexploited at the beginning of the 2000's [40], making them potentially highly attractive. The fishing patterns highlighted by the fleet overlap assessment may give additional information on the role of attractivity and accessibility in shaping the fleet mobility patterns. In the western Mediterranean (GSAs 1-7 and 11.1), the overlap pattern was neither intensive nor extensive, and was attributable to short-range mobility; here a small number of fleets (maximum 3) overlapped in some specific areas: the Iberian continental platform (GSA 6), the Gulf of Lion (GSA 7), the Ibiza channel (GSA 5), and the Sardinian slope (GSA 11.1). As mentioned above, Spanish and French fleets are subject to regulations that are likely to reduce their range of action. In the Tyrrhenian Sea (especially in GSA 9) and the Adriatic Sea (GSAs 17 and 18), the pattern was extensive but not intensive (rarely exceeding 2 fleets) and it was mostly attributable to short-range mobility of Italian vessels that are free to move along the Italian coast. The Sicily Channel (GSAs 12-16) was the only area in the Mediterranean Sea where the overlap was both extensive and intensive, and short-range and long-range mobility concomitantly occurred. This pattern was detected almost throughout the trawlable area, where up to 5 fleets exploited the deep bottoms between the offshore banks, which are known to be highly productive [41,42]. Finally, some areas in the eastern Mediterranean were characterized by an intensive but not extensive overlap pattern, with up to 6 long-range mobile fleets concentrating in a small number of cells where literature reports high densities of deep-water shrimps [39]. In the overall, the trawling fleet mobility patterns suggest that platform areas (e.g. the Northern Adriatic Sea and the Gulf of Lion) are exploited by neighboring fleets, whose fishing effort is spread over a relatively broad area, thus involving high exploitation values that may be greatly confounded in the catch reporting. Slope areas attract fleets from remote harbors that operate in very limited spaces, involving a high probability of spatial conflicts and an additional difficulty to link landing and fishing sites. Notably, the areas combining offshore banks and slopes, such as the Sicily Channel, attract vessels from neighboring and distant areas, which may also result in competition for space and confusion of catch reporting. The high degree of mixing between Mediterranean fleets and the long range of action of trawl fisheries, whose activity may span through several management areas, may increase if fishing continues to move to ever deeper grounds [43,44]. This perspective raises environmental concern, linked to the exploitation of important Essential Fish Habitats in deep-sea areas [45], as well as fishery statistics considerations. Considering the typically mixed nature of Mediterranean fisheries

[11,12,46], cooperation among flag States is crucial to regulate stocks and achieve sustainable fishery exploitation [11,17]. Improvements in fishery management in the region could be achieved by analyzing successful examples; for instance, in the North Atlantic, ad hoc management units straddling different exclusive economic zones (EEZs) and statistical areas have been adopted for several fisheries, for pelagic [47] and demersal [40] resources, basing on biological data and fishing effort patterns [48,49]. Revision of boundaries for the collection of fishery statistics is a topic already on the GFCM agenda and a dedicated trans-disciplinary EU project is ongoing [50]. Nevertheless, the present paper, in line with other valuable researches [5,13], describes a so complex fleet dynamic pattern that fluxes between statistical areas will be hardly eliminated. Monitoring fleet mobility remains therefore a critical step to ensure a sustainable exploitation, also through the creation of lists of authorized vessels targeting specific resources as already encouraged by the GFCM in the recommendations for the management of deep-water shrimps (GFCM/42/2018/3; GFCM/43/2019/6). The creation of fleet segment categories also including the spatial range of vessels activity, coupled with a systematic fishing operation tracking by AIS/VMS [6] and the analysis of spatial overlaps with species distribution [51] may contribute to identify with more precision the areas requiring management actions.

Funding

This work received no specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] D.R. Goethel, T.J. Quinn, S.X. Cadrin, Incorporating Spatial Structure in Stock Assessment: Movement Modeling in Marine Fish Population Dynamics, Rev. Fish. Sci. 19 (2011) 119–136. https://doi.org/10.1080/10641262.2011.557451.

[2] J.M. Cope, A.E. Punt, Drawing the lines: resolving fishery management units with simple fisheries data, Can. J. Fish. Aquat. Sci. 66 (2009) 1256–1273. https://doi.org/10.1139/F09-084.

[3] S.K. Chang, From subsidy evaluation to effort estimation: Advancing the function of voyage data recorders for offshore trawl fishery management, Mar. Policy. 74 (2016) 99–107. https://doi.org/10.1016/j.marpol.2016.09.017.

[4] D. Vaughan, Fishing effort displacement and the consequences of implementing Marine Protected Area management – An English perspective, Mar. Policy. 84 (2017) 228–234. https://doi.org/10.1016/j.marpol.2017.07.007.

[5] P. De Angelis, L. D'Andrea, S. Franceschini, S. Cataudella, T. Russo, Strategies and trends of bottom trawl fisheries in the Mediterranean Sea, Mar. Policy. 118 (2020) 104016. https://doi.org/10.1016/j.marpol.2020.104016.

[6] T. Russo, E.B. Morello, A. Parisi, G. Scarcella, S. Angelini, L. Labanchi, M. Martinelli, L. D'Andrea, A. Santojanni, E. Arneri, S. Cataudella, A model combining landings and VMS data to estimate landings by fishing ground and harbor, Fish. Res. 199 (2018) 218–230. https://doi.org/10.1016/J.FISHRES.2017.11.002.

[7] T. Russo, P. Carpentieri, L. D'Andrea, P. De Angelis, F. Fiorentino, S. Franceschini, G. Garofalo, L. Labanchi, A. Parisi, M. Scardi, S. Cataudella, Trends in Effort and Yield of Trawl Fisheries: A Case Study From the Mediterranean Sea, Front. Mar. Sci. 6 (2019) 1–19. https://doi.org/10.3389/fmars.2019.00153.

[8] R.O. Amoroso, C.R. Pitcher, A.D. Rijnsdorp, R.A. McConnaughey, A.M. Parma, P. Suuronen, O.R. Eigaard, F. Bastardie, N.T. Hintzen, F. Althaus, S.J. Baird, J. Black, L. Buhl-Mortensen, A.B. Campbell, R. Catarino, J. Collie, J.H. Cowan, D. Durholtz, N. Engstrom, T.P. Fairweather, H.O. Fock, R. Ford, P.A. Gálvez, H. Gerritsen, M.E. Góngora, J.A. González, J.G. Hiddink, K.M. Hughes, S.S. Intelmann, C. Jenkins, P. Jonsson, P. Kainge, M. Kangas, J.N. Kathena, S. Kavadas, R.W. Leslie, S.G. Lewis, M. Lundy, D. Makin, J. Martin, T. Mazor, G. Gonzalez-Mirelis, S.J. Newman, N. Papadopoulou, P.E. Posen, W. Rochester, T. Russo, A. Sala, J.M. Semmens, C. Silva, A. Tsolos, B. Vanelslander, C.B. Wakefield, B.A. Wood, R. Hilborn, M.J. Kaiser, S. Jennings, Bottom trawl fishing footprints on the world's continental shelves, Proc. Natl. Acad. Sci. 115 (2018) E10275–E10282. https://doi.org/10.1073/pnas.1802379115.

[9] D. Tickler, J.J. Meeuwig, M.-L. Palomares, D. Pauly, D. Zeller, Far from home: Distance patterns of global fishing fleets, Sci. Adv. 4 (2018) eaar3279. https://doi.org/10.1126/sciadv.aar3279.

[10] S. Katsanevakis, N. Levin, M. Coll, S. Giakoumi, D. Shkedi, P. Mackelworth, R. Levy, A. Velegrakis, D. Koutsoubas, H. Caric, E. Brokovich, B. Öztürk, S. Kark, Marine conservation challenges in an era of economic crisis and geopolitical instability: The case of the Mediterranean Sea, Mar. Policy. 51 (2015) 31–39. https://doi.org/10.1016/J.MARPOL.2014.07.013.

[11] M. Cardinale, G.C. Osio, G. Scarcella, Mediterranean Sea: A Failure of the European Fisheries Management System, Front. Mar. Sci. 4 (2017) 72. https://doi.org/10.3389/fmars.2017.00072.

[12] F. Colloca, M. Cardinale, F. Maynou, M. Giannoulaki, G. Scarcella, K. Jenko, J.M. Bellido, F. Fiorentino, Rebuilding Mediterranean fisheries: A new paradigm for ecological sustainability, Fish Fish. 14 (2013) 89–109. https://doi.org/10.1111/j.1467-2979.2011.00453.x.

[13] S. Holmes, F. Natale, M. Gibin, J. Guillen, A. Alessandrini, M. Vespe, G.C. Osio, Where did the vessels go? An analysis of the EU fishing fleet gravitation between home ports, fishing grounds, landing ports and markets, PLoS One. 15 (2020). https://doi.org/10.1371/journal.pone.0230494.

[14] FAO, Report of the First Session of the Scientific Advisory Committee. Rome, Italy, 23-26 March 1999. FAO Fisheries Report No. 601., Rome, 1999.

[15] STECF, Scientific, Technical and Economic Committee for Fisheries (STECF) – The 2018 Annual Economic Report on the EU Fishing Fleet (STECF-18-07), Publications Office of the European Union, Luxembourg, 2018. https://doi.org/10.2760/56158.

[16] FAO, The State of Mediterranean and Black Sea Fisheries, General Fisheries Commission for the Mediterranean, Rome, 2018. http://www.fao.org/3/ca2702en/CA2702EN.pdf.

[17] S.F. McWhinnie, The tragedy of the commons in international fisheries: An empirical examination, J. Environ. Econ. Manage. 57 (2009) 321–333. https://doi.org/10.1016/j.jeem.2008.07.008.

[18] MIPAAF, Decreto ministeriale 26 luglio 1995 recante “Disciplina del rilascio delle licenze di pesca,” 1995. https://www.gazzettaufficiale.it/eli/id/1995/11/16/095A6726/sg.

[19] BOE-A-1999-20641, Real Decreto 1440/1999, de 10 de septiembre, por el que se regula el ejercicio de la pesca con artes de arrastre de fondo en el caladero nacional del Mediterráneo., Spain, 1999. https://www.boe.es/eli/es/rd/1999/09/10/1440.

[20] Astra Paging Ltd, T-AIS Data Mediterr. Sea. (2017). http://www.astrapaging.com/data-services.

[21] C. Ferrà, A.N. Tassetti, F. Grati, G. Pellini, P. Polidori, G. Scarcella, G. Fabi, Mapping change in bottom trawling activity in the Mediterranean Sea through AIS data, Mar. Policy. 94 (2018) 275–281. https://doi.org/10.1016/j.marpol.2017.12.013.

[22] A. Galdelli, A. Mancini, A.N. Tassetti, C. Ferrà Vega, E. Armelloni, G. Scarcella, G. Fabi, P. Zingaretti, A Cloud Computing Architecture to Map Trawling Activities Using Positioning Data, in: Vol. 9 15th IEEE/ASME Int. Conf. Mechatron. Embed. Syst. Appl., American Society of Mechanical Engineers, 2019. https://doi.org/10.1115/DETC2019-97779.

[23] FAO, GFCM fleet register, Public Data as Transm. by CPCs to GFCM Secr. Line with Requir. Set Recomm. GFCM/33/2009/5 Establ. GFCM Reg. Fleet Regist. (2019). http://www.fao.org/gfcm/data/fleet/register/en/ (accessed January 30, 2019).

[24] EU, European Union Fleet Register, (2020). https://webgate.ec.europa.eu/fleet-europa/search_en (accessed June 1, 2020).

[25] F. Natale, M. Gibin, A. Alessandrini, M. Vespe, A. Paulrud, Mapping fishing effort through AIS data, PLoS One. 10 (2015) 1–16. https://doi.org/10.1371/journal.pone.0130746.

[26] W.E. Winkler, String Comparator Metrics and Enhanced Decision Rules in the Fellegi-Sunter Model of Record Linkage, Proc. Sect. Surv. Res. Am. Stat. Assoc. (1990) 354–359. https://doi.org/10.1007/978-1-4612-2856-1_101.

[27] M.P.J. van der Loo, The stringdist package for approximate string matching, R J. 6 (2014) 111–122. https://doi.org/10.32614/rj-2014-011.

[28] FAO, GFCM Statistical grid, (2020). http://www.fao.org/gfcm/data/maps/grid/en/ (accessed April 28, 2020).

[29] E. Pebesma, Simple features for R: Standardized support for spatial vector data, R J. (2018).

[30] J.J. Allaire, P. Ellis, C. Gandrud, K. Kuo, B.W. Lewis, J. Owen, K. Russell, J. Rogers, C. Sese, C.J. Yetman,] Maintainer, Package “networkD3,” 2017. https://github.com/christophergandrud/networkD3/issues (accessed February 19, 2021).

[31] M. Taconet, D. Kroodsma, J. Fernandes, Global atlas of AIS-based fishing activity: Challenges and opportunities, (2019).

[32] C. Ferrà, A.N. Tassetti, E.N. Armelloni, A. Galdelli, G. Scarcella, G. Fabi, Using AIS to Attempt a Quantitative Evaluation of Unobserved Trawling Activity in the Mediterranean Sea, Front. Mar. Sci. 7 (2020) 1036. https://doi.org/10.3389/fmars.2020.580612.

[33] G. Merino, M. Coll, I. Granado, J. Gee, D. Kroodsma, N.A. Miller, J.A. Fernandes, FAO Area 37 - AIS-based fishing activity in the Mediterranean and Black Sea, in: M. Aconet, D. Kroodsma, J.A. Fernandes (Eds.), Glob. Atlas AIS-Based Fish. Act. - Challenges Oppor., FAO, Rome, 2019: pp. 185–198. www.fao.org/3/ca7012en/ca7012en.pdf.

[34] EC, COUNCIL REGULATION (EC) No 1224/2009 of 20 November 2009 establishing a 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 768/2, 2009. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009R1224&from=IT.

[35] EU, Regulation (EU) No 1380/2013 of the European Parliament and of the council of 11 December 2013 on the Common Fisheries Policy, 2013. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:354:0022:0061:EN:PDF.

[36] P. Cacaud, Fisheries laws and regulations in the mediterranean: a comparative study, GFCM. Stud, FAO, Rome, 2005. https://epub.sub.uni-hamburg.de/epub/volltexte/2011/11880/pdf/752005y5880e00.pdf (accessed March 11, 2021).

[37] STECF, Scientific, Technical and Economic Committee for Fisheries (STECF) – Fishing effort regime for demersal fisheries in the western Mediterranean Sea (STECF-18-09), Publications Office of the European Union, Luxembourg, 2018. https://doi.org/10.2760/94831.

[38] M. García Rodríguez, A. Esteban, On the biology and fishery of *Aristeus antennatus* (Risso, 1816), (Decapoda, Dendrobranchiata) in the Ibiza Channel (Balearic Islands, Spain), Sci. Mar. 63 (1999) 27–37. https://doi.org/10.3989/scimar.1999.63n127.

[39] A. Kallianiotis, K. Sophronidis, P. Vidoris, A. Tselepides, Demersal fish and megafaunal assemblages on the Cretan continental shelf and slope (NE Mediterranean): Seasonal variation in species density, biomass and diversity, Prog. Oceanogr. 46 (2000) 429–455. https://doi.org/10.1016/S0079-6611(00)00028-8.

[40] C.Y. Politou, S. Kavadas, C. Mytilineou, A. Tursi, R. Carlucci, G. Lembo, Fisheries resources in the deep waters of the eastern Mediterranean (Greek Ionian Sea), J. Northwest Atl. Fish. Sci. 31 (2003) 35–46. https://doi.org/10.2960/J.v31.a3.

[41] F. Fiorentino, G. Garofalo, M. Gristina, S. Gancitano, G. Norrito, Some relevant information on the spatial distribution of demersal resources, benthic biocoenoses and fishing pressure in the Strait of Sicily, Mar. Living Resour. Assess. (2004) 50–66. http://www.faomedsudmed.org/pdf/publications/td2/td2_fiorentino.pdf (accessed August 26, 2019).

[42] M. Gristina, T. Bahri, F. Fiorentino, M. Camilleri, G. Garofalo, T. Fortibuoni, Nursery and Spawning Areas of Deep-water Rose Shrimp, Parapenaeus longirostris (Decapoda: Penaeidae), in the Strait of Sicily (Central Mediterranean Sea), J. Crustac. Biol. 30 (2010) 167–174. https://doi.org/10.1651/09-3167.1.

[43] T. Morato, R. Watson, T.J. Pitcher, D. Pauly, Fishing down the deep, Fish Fish. 7 (2006) 24–34. https://doi.org/10.1111/j.1467-2979.2006.00205.x.

[44] P. Puig, M. Canals, J.B. Company, J. Martín, D. Amblas, G. Lastras, A. Palanques, A.M. Calafat, Ploughing the deep sea floor, Nature. 489 (2012) 286–289. https://doi.org/10.1038/nature11410.

[45] F. Maynou, J.E. Cartes, Effects of trawling on fish and invertebrates from deep-sea coral facies of Isidella elongata in the western Mediterranean, J. Mar. Biol. Assoc. United Kingdom. 92 (2012) 1501–1507. https://doi.org/10.1017/S0025315411001603.

[46] F. Colloca, G. Scarcella, S. Libralato, Recent Trends and Impacts of Fisheries Exploitation on Mediterranean Stocks and Ecosystems, Front. Mar. Sci. 4 (2017) 244. https://doi.org/10.3389/fmars.2017.00244.

[47] NMFS (National Marine Fishery Service), Final consolidated Atlantic highly migratory species fishery management plan, MD National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Silver Spring, 2006.

[48] S.X. Cadrin, M. Bernreuther, A.K. Danielsdottir, E. Hjorleifsson, T. Johansen, L. Kerr, K. Kristinsson, S. Mariani, K. Nedreaas, C. Pampoulie, B. Planque, J. Reinert, F. Saborido-Rey, T. Sigurthsson, C. Stransky, Population structure of beaked redfish, *Sebastes mentella*: evidence of divergence associated with different habitats, ICES J. Mar. Sci. 67 (2010) 1617–1630. https://doi.org/10.1093/icesjms/fsq046.

[49] D.H. Secor, The Unit Stock Concept, in: S. Cadrin, L. Kerr, S. Mariani (Eds.), Stock Identif. Methods, 2nd ed., Elsevier, 2014: pp. 7–28. https://doi.org/10.1016/B978-0-12-397003-9.00002-3.

[50] FAO, General Fisheries Commission for the Mediterranean. Report of the twenty-first session of the Scientific Advisory Committee on Fisheries, Cairo, Egypt, 24–27 June 2019 / Commission générale des pêches pour la Méditerranée. Rapport de la vingt-et-unième se, FAO Fisheries and Aquaculture Report/FAO Rapport sur les pêches et l'aquaculture No., Rome, 2019. https://doi.org/10.1007/978-3-030-50032-0_213.

[51] G. Coro, L. Fortunati, P. Pagano, Deriving fishing monthly effort and caught species from vessel trajectories, in: Ocean. 2013 MTS/IEEE Bergen Challenges North. Dimens., 2013. https://doi.org/10.1109/OCEANS-Bergen.2013.6607976.

TABLES

Table 1: Number of bottom trawlers reported in the GFCM Fleet Register, the EU Fleet Register and the AIS dataset, listed by country and LOA category. The GFCM Fleet Register categories include Bottom otter trawls, Bottom shrimp trawls, Bottom trawls, Otter trawls (not specified) and Other trawls (not specified). The EU Fleet Register categories include Bottom otter trawls, Multi-rig otter traw and pair trawl bottom based on the main or subsidiary gear (vessels with purse seine or dredge as the main fishing gear were excluded). Coverage: number of GFCM vessels divided by the number of AIS vessels. NA: not assigned.

COUNTRY	GFCM Reg.	EU Reg.	15-18 m	18-24 m	24-40 m	40-85 m	NA m	AIS_ vessels	GFCM coverage	EU coverage
Albania	151	0	0.32	0.45	0.23	0.01	0	1	0.01	nd
Algeria	483	0	0.35	0.51	0.14	0	0	1	0	nd
Croatia	85	135	0.54	0.24	0.21	0	0	64	0.75	0.47
Cyprus	7	9	0	0.33	0.56	0	0.11	5	0.71	0.56
Egypt	967	0	0.25	0.72	0.03	0	0	0	0	nd

France	32	63	0.1	0.4	0.51	0	0	52	1.63	0.83
Greece	250	283	0.03	0.38	0.58	0.02	0	187	0.75	0.66
Georgia	2	0	0	1	0	0	0	0	0	nd
Israel	13	0	0.62	0.38	0	0	0	14	1.08	nd
Italy	1185	1424	0.29	0.47	0.22	0.02	0	1105	0.93	0.78
Malta	15	15	0	0.6	0.4	0	0	7	0.47	0.47
Montenegro	10	0	0.3	0.5	0.2	0	0	0	0	nd
Morocco	137	0	0.13	0.82	0.04	0	0	0	0	nd
Slovenia	5	5	1	0	0	0	0	4	0.8	0.8
Spain	516	557	0.25	0.53	0.22	0	0	476	0.92	0.85
Syrian Arab Republic	18	0	0.06	0.5	0.44	0	0	0	0	nd
Tunisia	432	0	0.02	0.66	0.32	0	0	1	0	nd
Turkey	251	0	0.3	0.55	0.13	0.02	0	143	0.57	nd
Total	4559	2491	-	-	-	-	-	2060 (1900*)	0.45	0.76

IMAGES

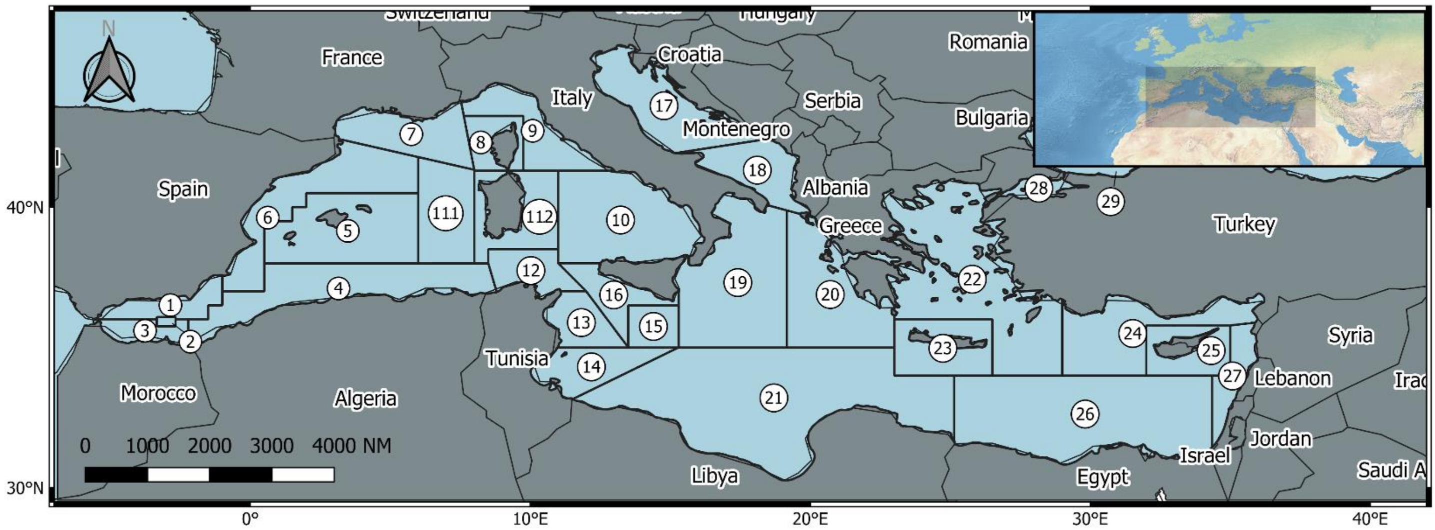

Figure 1: Map of the study area and GFCM Geographical Sub Areas: 1 Northern Alboran Sea; 2 Alboran Island; 3 Southern Alboran Sea; 4 Algeria; 5 Balearic Islands; 6 Northern Spain; 7 Gulf of Lion; 8 Corsica; 9 Ligurian Sea and Northern Tyrrhenian Sea; 10 Southern and Central Tyrrhenian Sea; 11.1 Western Sardinia; 11.2 Eastern Sardinia; 12 Northern Tunisia; 13 Gulf of Hammamet; 14 Gulf of Gabes; 15 Malta; 16 Southern Sicily; 17 Northern Adriatic Sea; 18 Southern Adriatic Sea; 19 Western Ionian Sea; 20 Eastern Ionian Sea; 21 Southern Ionian Sea; 22 Aegean Sea; 23 Crete; 24 Northern Levant Sea; 25 Cyprus; 26 Southern Levant Sea; 27 Eastern Levant Sea; 28 Marmara Sea; 29 Black Sea. GSA 30 (Azov Sea) is not showed.

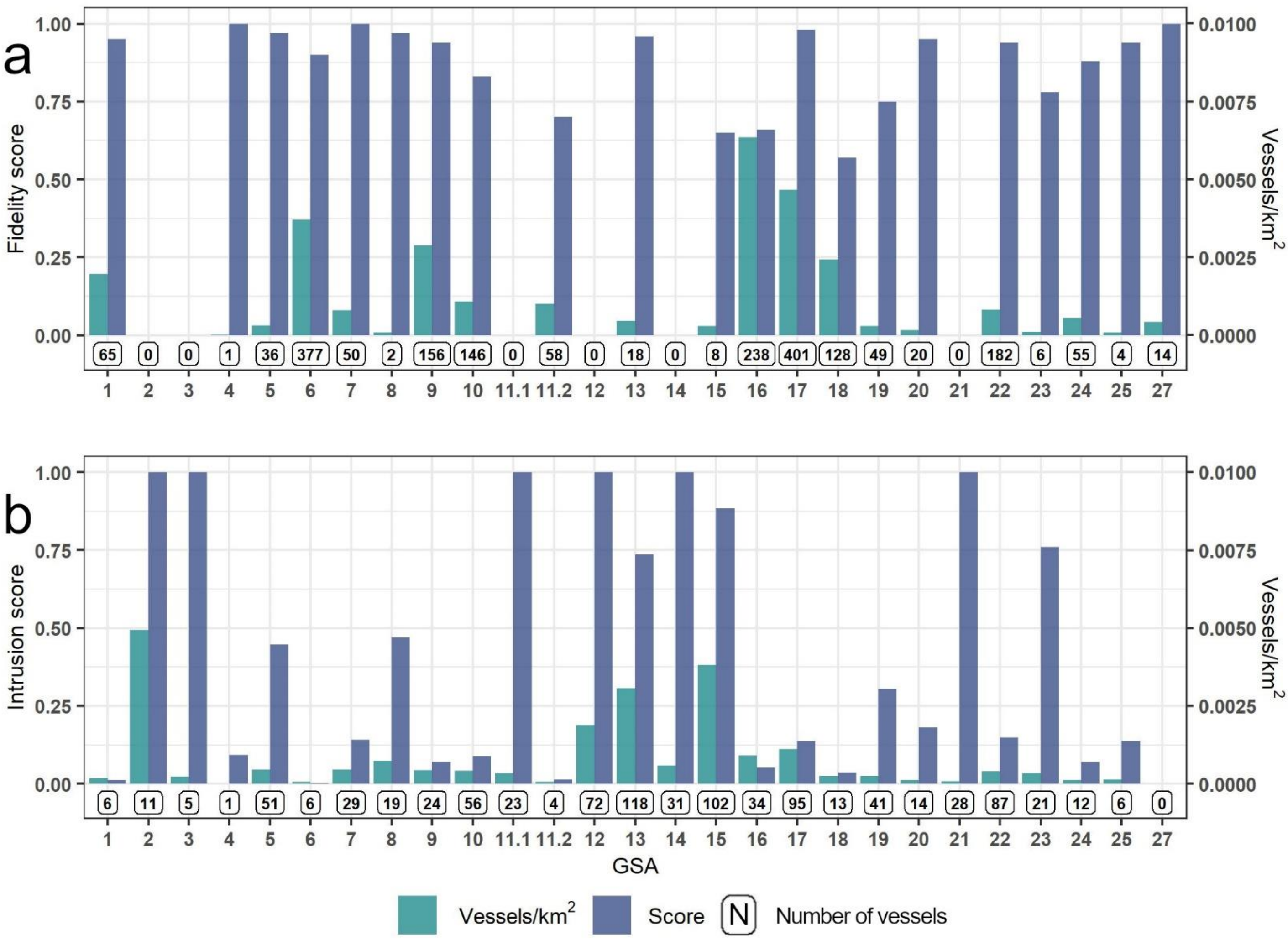

Figure 2: a) Fidelity score (blue bat) indicating the proportion of fishing hours that home-vessels (number of vessels in the boxes at the bottom of the figure) spent in their GSA, and density of home-vessels (turquoise bar); b) ,Intrusion score (blue bar) indicating the proportion of fishing hours that was attributable to non-home vessels (number of vessels in the boxes at the bottom of the figure) and density of non-home vessels (turquoise bar).

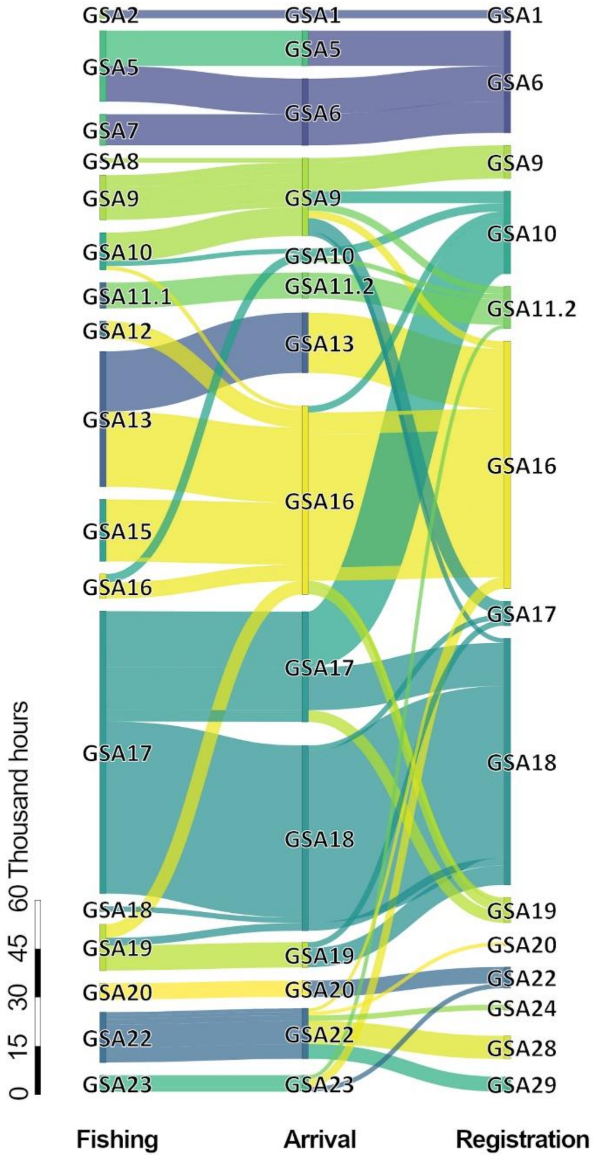

Figure 3: Fluxes of fishing effort (only those exceeding 1000 hours) between GSAs. Column "Fishing" indicates where the fishing activity was observed; column "Arrival" indicates the location of the harbor reached at the end of the fishing trip; column "Registration" refers to the GSA of registration of the vessel that has carried out the fishing trip. The width of the fluxes is proportional to the fishing activity.

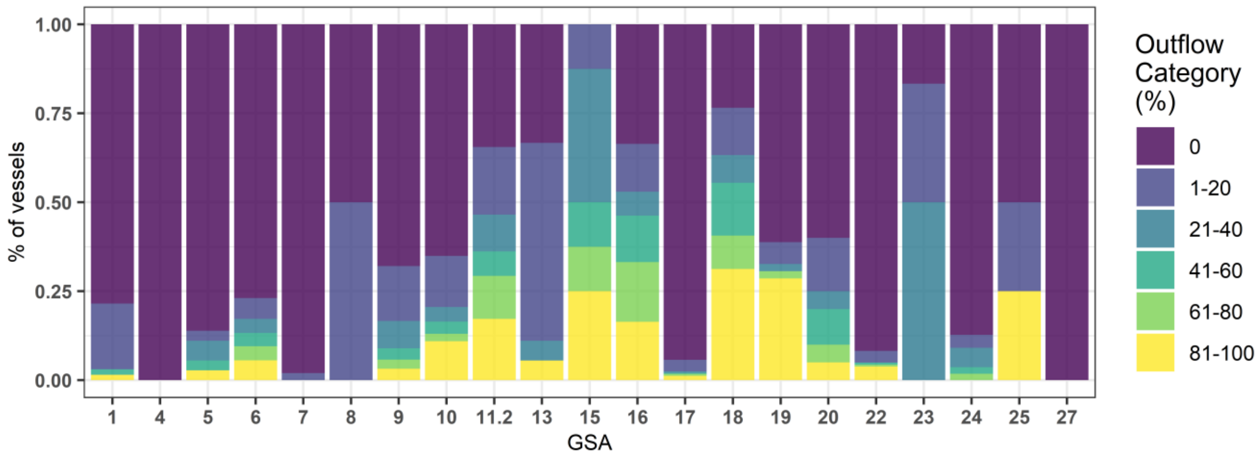

Figure 4: Percentage of vessels falling into each outflow category, aggregated on the GSA of registration. Outflow categories describe the proportion of fishing trips during which some fishing activity was observed beyond the borders of the GSA of registration.

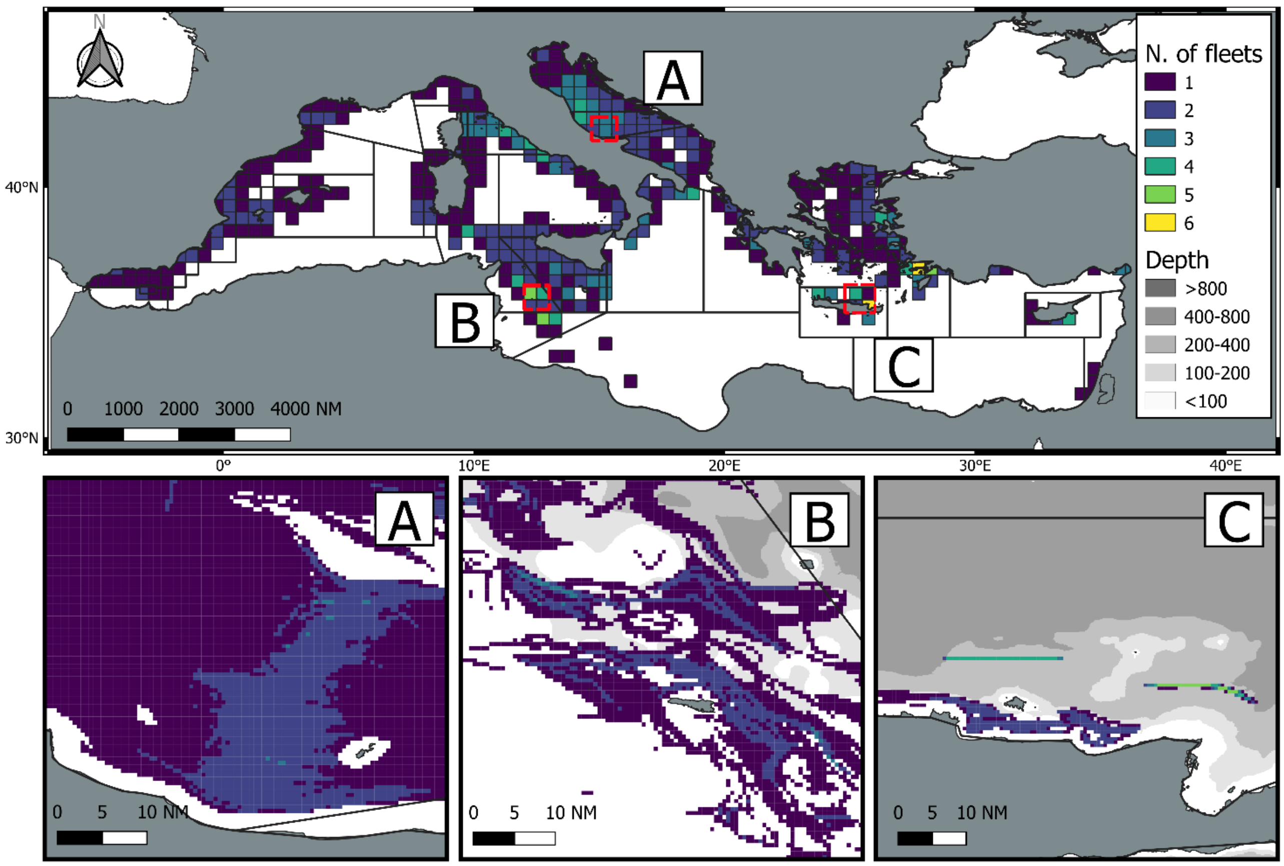

Figure 5: Number of fleets fishing > 50 hours a year detected in each cell of the GFCM grid. Insets maps show case studies in greater detail (1kmx1km grid): A) Adriatic Sea; B) Sicily Channel; C) Crete.