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

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1 Title

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

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16 **Abstract**

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

28 Mediterranean and around Crete. The fleets most frequently engaged in long range mobility were from GSAs
29 16, 18, and 6. The case studies included: GSAs 23, where several fleets exploited narrow slope areas; GSA 13,
30 where multiple fleets overlapped in a relatively wide area; and GSA 17, where two fleets overlapped in a
31 wide platform area. Mobility was distinguished in short-range – involving platform areas of contiguous GSAs
32 – and long-range – involving slope areas of non-contiguous GSAs.

33 **Key-words**

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

35 **1 Introduction**

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

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

63 To provide a quantitative description of fleet mobility dynamics in the Mediterranean Sea, in respect to the
64 actual management units, we analyzed the AIS data transmitted in one entire year (2017) by bottom otter
65 trawlers operating throughout the basin. The decision to focus only on bottom otter trawlers was mostly
66 dictated by the need to reduce noise in the analysis: the mobility of beam and pelagic mid-water trawlers is
67 limited because they are allowed only in specific areas of the basin, depending on national laws (*e.g.*: Italian
68 beam trawlers [18], Spanish pelagic mid-water trawlers [19]). Spatial relationships were investigated at GSA
69 level, by individuating three layers of information: where fishing activity was observed, where the fishing
70 trips finished and where the vessels where registered. Vessels identifier where cross-matched with official
71 registers to identify their registration port, and the corresponding GSA of registration, defined as “home-
72 GSA”. Fishing tracks (FTs) were subjected to spatial analysis allowing to identify where the trawling activity
73 was conducted and to which port the fishing trips finished (port of arrival). The first objective of the analysis
74 was to develop quantitative metrics describing fidelity of vessels to their home GSA and amount of fishing
75 effort attributed to non-home fishing vessels in each area: this analysis will serve to identify the most mobile
76 fleets and the areas mostly exploited by non-local fleets. The second objective was to reconstruct the main
77 fluxes of bottom trawling activity between GSAs: this section will allow to disaggregate the exploitation
78 patterns also in relation to the use of ports in distant areas. The third objective was to characterize fleets

79 registered in the GSAs basing on the frequency of activity conducted beyond their home area borders: this
80 information serves to figure out the percentage of the fleet responsible of the activity conducted in distant
81 areas. The last objective was to increase the spatial detail for individuating the fishing grounds where vessels
82 with different origin showed the maximum interaction, also providing detailed zooms. This last part will
83 permit to identify the areas where it may be more urgent to consider fleet interaction within the
84 management plans.

85 **2 Material and methods**

86 *2.1 Data overview and pre-processing*

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

101 *2.2 GSA of registration (home GSA) and GSA of arrival*

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

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

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

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

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

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

136 2.3 Statistics

137 FTs were intersected with three different feature layers: (1) GSA polygons (see 2.3.1); (2) GFCM statistical
138 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
139 the fishing operations straddling one or more polygon or grid cell boundaries was re-calculated. All the spatial
140 overlay operations were computed using *sf* R library [29]. The output features of intersection 1 (GSA
141 polygons) were aggregated in three different manners:

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

- 153 ii. By GSA of registration, GSA of arrival and GSA of fishing. Resulting fishing time represented the flux of
154 fishing effort from the site of fishing to the site of registration, passing by the site of arrival. Fluxes larger
155 than 1000 hours were represented by a Sankey diagram (*networkD3* R library; [30]), where the size of
156 the flux was proportional to the amount of fishing time.
- 157 iii. By vessel identifier, GSA of registration, VT, Fishing Day (FD), and GSA of fishing. Based on the spatial
158 information, those FDs spent by any vessel beyond its home GSA borders were considered as “positive”.
159 Then, for each VT an outflow percentage was calculated as the number of positive FDs out of the total
160 number of FDs; its mean value allowed dividing vessels into 6 outflow categories: 0%, 1-20%, 21-40%,
161 41-60%, 61-80%, 81-100%. The number of vessels falling into each category was calculated for each GSA
162 and standardized to one.

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

170

171 **3 Results**

172 *3.1 Data overview*

173 A total number of 2,060, 4,559 and 2,491 bottom trawlers were listed in the AIS database, the GFCM Fleet
174 Register (both EU and non-EU vessels) and the EU Register (only EU vessels), respectively (Table 1). The fleet
175 coverage was 0.45 based on the GFCM Register and 0.76 based on the EU Fleet Register. Regarding non-EU
176 vessels detected in the AIS data, 160 vessels in total, 143 were from Turkey and 14 from Israel, while for
177 other non-EU countries the coverage was close to 0, as no vessels broadcasted AIS data (Syria, Montenegro,

178 Egypt, Morocco) or just a few did it (Albania, Algeria, Tunisia). A better coverage was observed for EU
179 countries, with the highest values for Spain (0.88), France (0.83) and Slovenia (0.80).

180

181 *3.2 GSA of registration and GSA of arrival*

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

191 *3.3 Statistics*

192 Non-zero FS values (Figure 2) ranged from 0.56 (GSA 18) to 1 (GSAs 4, 7, 27), with the highest values (FS >
193 0.9) largely concentrated in the western Mediterranean (GSAs 1 to 8). The density (n/km^2) of home vessels
194 varied between 0.63 (GSA 16) and 0 (GSAs 2, 3, 11.1, 12, 14, 21). Spearman rank correlation coefficient
195 between FS and vessel density, calculated after excluding GSAs where no registered vessels were detected,
196 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),
197 values being highest in the North African (GSAs 3, 12, 13, 14, 21), Maltese (GSA 15) and Cretan (GSA 23)
198 areas. The density (n/km^2) of non-home vessels varied between 0.49 (GSA 2) and 0 (GSA 27). The fleets mostly
199 fishing beyond their own GSA borders (Figure 3) were those registered in GSAs 16, 18, and 6 while the areas
200 most exploited by non-home vessels were GSAs 17, 13 and 5. Regarding the three most proactive fleets, the
201 vessels registered in GSA 16 returned to their home GSA when exploiting the neighboring GSAs 10, 12, 13,
202 15 and 19, while they temporarily based in ports of GSAs 9, 13, 22 and 23 when exploiting these distant areas.
203 GSA 18 vessels frequently returned to their home GSA after having fished in GSA 17, while they often moored

204 in the local harbors when fishing in GSA 19, and always when fishing in GSAs 9. The fleets of GSA 6 always
205 returned to their home area after having exploited GSA 7, whereas they very often based in non-home
206 harbors while fishing GSA 5. The outflow analysis (Figure 4) showed that the fleets based in the central
207 Mediterranean (GSAs 11.2, 15, 18, 16, and 19) where those more prone to operate outside the GSA borders.
208 The fleets registered in the western areas (GSAs 1 to 8) where those less frequently fishing in other areas.
209 GSA 27 was the only area with sufficient AIS data coverage where the home vessels were never observed
210 to fish outside their area borders. The mobility pattern for GSA 25 was influenced by the vessel that moved
211 its registration site to GSA 15. The largest overlap between fleets in the 0.5 x 0.5 ° grid (Figure 5) was found
212 in GSAs 22 and 23. In particular, in GSA 22 it involved one cell close to Rhodes, where the FTs belonged to
213 vessels from 6 GSAs: 11.2, 16, 19, 22, 24 and 28. In GSA 23, Crete, FTs were also from vessels from 6 GSAs:
214 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
215 two cells in the Sicily Channel (GSA 13), where the analysis identified, respectively, FTs from vessels from
216 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
217 Central Adriatic Sea (GSA 17), where FTs belonged to vessels from GSAs 9, 10, 17, and 18, in the Tyrrhenian
218 Sea (GSA 9), where FTs were from vessels from GSAs 9, 10, 11.2, 16, 17, and 18. However, in the two latter
219 cases the value may be overestimated by 1 in a few cells because some vessels had started operating in the
220 area before their port GSA was changed in the official Registers. Values up to 4 were also found around
221 Cyprus (GSA 25; vessels from GSAs 10, 11.2, 16, and 25) and in the Ionian Sea (GSA 19; vessels from GSAs 16,
222 17, 18, and 19). Values between 1 and 3 were computed for all the other areas. The Northern Adriatic Sea
223 (GSA 17), the Sicily Channel (GSA 13) and the Crete island (GSA 23) were selected as case studies and analyzed
224 at a resolution of 1 x 1 km (Figure 5). Analysis of the case study A (Northern Adriatic Sea, GSA 17) showed a
225 wide overlap area of two fleets, those from GSA 17 and neighboring GSA 18. In the case study B (Sicily
226 Channel, GSA 13) was highlighted an extensive overlap area, containing a narrower path where up to 3 fleets
227 (GSAs 10, 11.2 and 16) fished in the same 1 x 1 km grid cell. Analysis of the case study C (Crete island)
228 demonstrated that FTs were concentrated in narrow strips on the slope areas exploited by up to 5 fleets
229 (GSAs 10, 11.2, 16, 17 and 19).

230 **4 Discussion and conclusions**

231 AIS data are a valuable instrument for fleet monitoring, even though the amount of vessels broadcasting the
232 signal may vary among areas and countries [31,32]. Assessing the coverage of analyzed AIS data by
233 comparisons with official registers can help to understand whether the results are representative of the
234 reality. In the present analysis the coverage was generally poor for the non-European countries: the large
235 discrepancy observed with the GFCM register, used for the non-European fleets, was unsurprising and in line
236 with literature, due to the poor implementation of AIS transmitters on fishing vessels flagging northern
237 African countries [33]. Slightly better results were observed for some Middle East countries, namely Turkey
238 and Israel, which fleets showed AIS coverage values comparable to EU fleets. In addition, the GFCM register
239 does not provide details on the vessel history, therefore it was not possible to know with certainty if the
240 information coincides with the time of the analysis, reducing the accuracy of the results. Higher
241 representation within AIS data was demonstrated by EU vessels, achieving a coverage that was also in line
242 with literature [13]. Based on the coverage assessment, the results of this paper are likely to be
243 representative of the dynamic of EU fleets as well as of the fleets of some Middle eastern countries such as
244 Turkey and Israel, while the patterns of the northern-African fleets remain partially unsolved. The FS and IS
245 analysis highlighted heterogeneous patterns in fleet dynamics. The FS was observed to be generally high for
246 the western GSAs, while lower values were observed in the GSAs of the central Mediterranean and of the
247 southern Adriatic Sea. Although some of the lowest values were observed in areas with high density of home
248 vessels, a correlation between vessel density and FS was not demonstrated, suggesting that the competition
249 for space is not a sufficient explanation for the fluxes of fishing activity. The IS was not mirroring the FS, since
250 in the western Mediterranean Sea were observed some of the highest values. Notably, the outputs indicating
251 that some GSAs hosted no fishing activity by home vessels ($IS=1$) were correct for GSAs 2 and 11.2, which
252 lack fishing harbors, whereas those for GSA 3, 12, 14, and 21 merely depended on the absence of home
253 vessels broadcasting AIS signal. A number of factors, such as fishing ground accessibility, time at sea
254 restrictions and differences in vessel technology and size [16], as well as market prices [13], contribute to
255 shape the fishing strategies adopted by Mediterranean fleets. AIS data *per se* cannot give information on
256 vessels landings, and only logbook data [34] may confirms if the harbor of arrivals was used for bunkering or
257 for unloading the catches [6]. Nevertheless, literature may be used for hypothesize on the factors driving the

258 mobility patterns described. The analysis of the fluxes confirmed a high degree of heterogeneity between
259 Mediterranean fishers' behavior. Fleet mobility was widespread, while in quantitative terms just three GSAs
260 (16, 18 and 6) account for almost 70% of the activity conducted beyond the GSA of registration borders. The
261 outflow analysis (Figure 3) set the two most active fleets apart from the third, since a large proportion of
262 their vessels fell in the categories > 40%, whereas only a small proportion of the fleets registered in GSA 6
263 was often involved in fishing elsewhere. A wide spectrum of short- and long-range mobility was observed.
264 Short-range mobility (*i.e.*, fishing activity conducted in neighboring GSAs) was common: in some cases, it
265 involved numerous vessels that returned to their home-port at the end of the trip (such as the GSA 18 fleets
266 exploiting the contiguous GSA 17), whereas in others only a few vessels regularly exploited and moored in a
267 particular area (e.g. GSA 6 vessels operating in GSAs 5). EU and national management measures such as those
268 regulating the access to fishing grounds [35,36] and time at sea [37] are likely to be the main factors that
269 shape short-range mobility patterns; for instance, Italian vessels from GSA 18 are free to exploit Italian coastal
270 waters in other GSAs, while France may limit the access of Spanish vessels within its territorial waters (GSA
271 7). In addition, Italian trawlers are allowed to fish for some consecutive days a week whereas their Spanish
272 counterparts can only fish 12 hours a day [37]; as a result, GSA 18 vessels may undertake fishing trips spread
273 over several days to exploit the Central Adriatic Sea, whereas fishing in the Gulf of Lion may be profitable
274 only for some vessels registered in the northernmost part of GSA 6. Fluxes to the Spanish GSA 5 are also
275 hampered by other restrictions, since the blue and red shrimp fishery in the Ibiza Channel is regulated by
276 national laws that precisely define the number of vessels that are allowed to fish there [38]. Long-range
277 mobility, entailing the exploitation of non-contiguous GSAs for a period during which the vessels based in the
278 local ports, involved a smaller number of fleets. Most important fluxes were from GSA 16 vessels operating
279 in the Ionian and Aegean Seas (GSAs 19, 22, and 23) and GSA 11.2 vessels exploiting GSA 23. Nevertheless,
280 the analysis described in 2.3.1 identified several vessels from distant GSAs other than GSAs 16 and 11.2
281 (namely, GSAs 10, 13, 17, 19, 28) fishing in GSAs 22, 23 and 25, suggesting the existence of a number of minor
282 fluxes of vessels involved in long-range mobility to the eastern Mediterranean. Profitability is likely to be the
283 key driver of long-range mobility, and some evidences support this hypothesis: literature reports that the
284 southern Aegean and Crete island slopes are particularly rich in deep-water shrimps [39] and still largely

285 unexploited at the beginning of the 2000's [40], making them potentially highly attractive. The fishing
286 patterns highlighted by the fleet overlap assessment may give additional information on the role of
287 attractivity and accessibility in shaping the fleet mobility patterns. In the western Mediterranean (GSAs 1-7
288 and 11.1), the overlap pattern was neither intensive nor extensive, and was attributable to short-range
289 mobility; here a small number of fleets (maximum 3) overlapped in some specific areas: the Iberian
290 continental platform (GSA 6), the Gulf of Lion (GSA 7), the Ibiza channel (GSA 5), and the Sardinian slope (GSA
291 11.1). As mentioned above, Spanish and French fleets are subject to regulations that are likely to reduce their
292 range of action. In the Tyrrhenian Sea (especially in GSA 9) and the Adriatic Sea (GSAs 17 and 18), the pattern
293 was extensive but not intensive (rarely exceeding 2 fleets) and it was mostly attributable to short-range
294 mobility of Italian vessels that are free to move along the Italian coast. The Sicily Channel (GSAs 12-16) was
295 the only area in the Mediterranean Sea where the overlap was both extensive and intensive, and short-range
296 and long-range mobility concomitantly occurred. This pattern was detected almost throughout the trawlable
297 area, where up to 5 fleets exploited the deep bottoms between the offshore banks, which are known to be
298 highly productive [41,42]. Finally, some areas in the eastern Mediterranean were characterized by an
299 intensive but not extensive overlap pattern, with up to 6 long-range mobile fleets concentrating in a small
300 number of cells where literature reports high densities of deep-water shrimps [39]. In the overall, the trawling
301 fleet mobility patterns suggest that platform areas (e.g. the Northern Adriatic Sea and the Gulf of Lion) are
302 exploited by neighboring fleets, whose fishing effort is spread over a relatively broad area, thus involving
303 high exploitation values that may be greatly confounded in the catch reporting. Slope areas attract fleets
304 from remote harbors that operate in very limited spaces, involving a high probability of spatial conflicts and
305 an additional difficulty to link landing and fishing sites. Notably, the areas combining offshore banks and
306 slopes, such as the Sicily Channel, attract vessels from neighboring and distant areas, which may also result
307 in competition for space and confusion of catch reporting. The high degree of mixing between Mediterranean
308 fleets and the long range of action of trawl fisheries, whose activity may span through several management
309 areas, may increase if fishing continues to move to ever deeper grounds [43,44]. This perspective raises
310 environmental concern, linked to the exploitation of important Essential Fish Habitats in deep-sea areas [45],
311 as well as fishery statistics considerations. Considering the typically mixed nature of Mediterranean fisheries

312 [11,12,46], cooperation among flag States is crucial to regulate stocks and achieve sustainable fishery
313 exploitation [11,17]. Improvements in fishery management in the region could be achieved by analyzing
314 successful examples; for instance, in the North Atlantic, ad hoc management units straddling different
315 exclusive economic zones (EEZs) and statistical areas have been adopted for several fisheries, for pelagic [47]
316 and demersal [40] resources, basing on biological data and fishing effort patterns [48,49]. Revision of
317 boundaries for the collection of fishery statistics is a topic already on the GFCM agenda and a dedicated trans-
318 disciplinary EU project is ongoing [50]. Nevertheless, the present paper, in line with other valuable researches
319 [5,13], describes a so complex fleet dynamic pattern that fluxes between statistical areas will be hardly
320 eliminated. Monitoring fleet mobility remains therefore a critical step to ensure a sustainable exploitation,
321 also through the creation of lists of authorized vessels targeting specific resources as already encouraged by
322 the GFCM in the recommendations for the management of deep-water shrimps (GFCM/42/2018/3;
323 GFCM/43/2019/6). The creation of fleet segment categories also including the spatial range of vessels
324 activity, coupled with a systematic fishing operation tracking by AIS/VMS [6] and the analysis of spatial
325 overlaps with species distribution [51] may contribute to identify with more precision the areas requiring
326 management actions.

327

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331

332 **References**

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496 TABLES

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

502

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

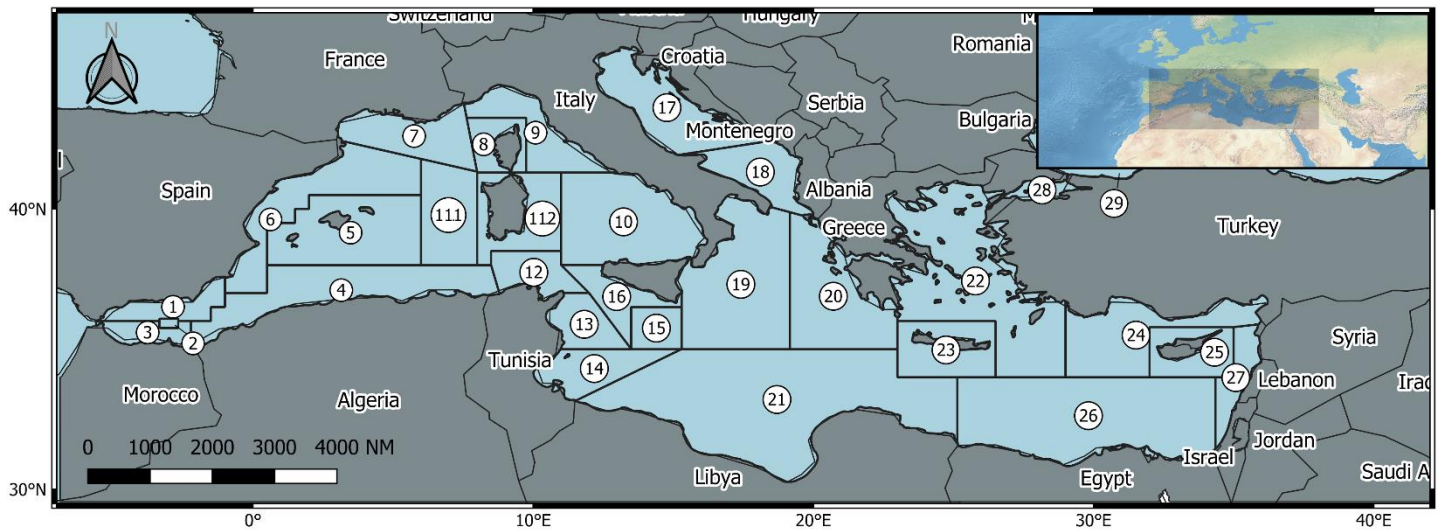


Figure 1: Map of the study area and GFCM Geographical Sub Areas: 1 Northern Alboran Sea; 2 Alboran Island; 3 Southern Alboran Sea; 4 Algeria; 5 Balearic Islands; 6 Northern Spain; 7 Gulf of Lion; 8 Corsica; 9 Ligurian Sea and Northern Tyrrhenian Sea; 10 Southern and Central Tyrrhenian Sea; 11.1 Western 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.

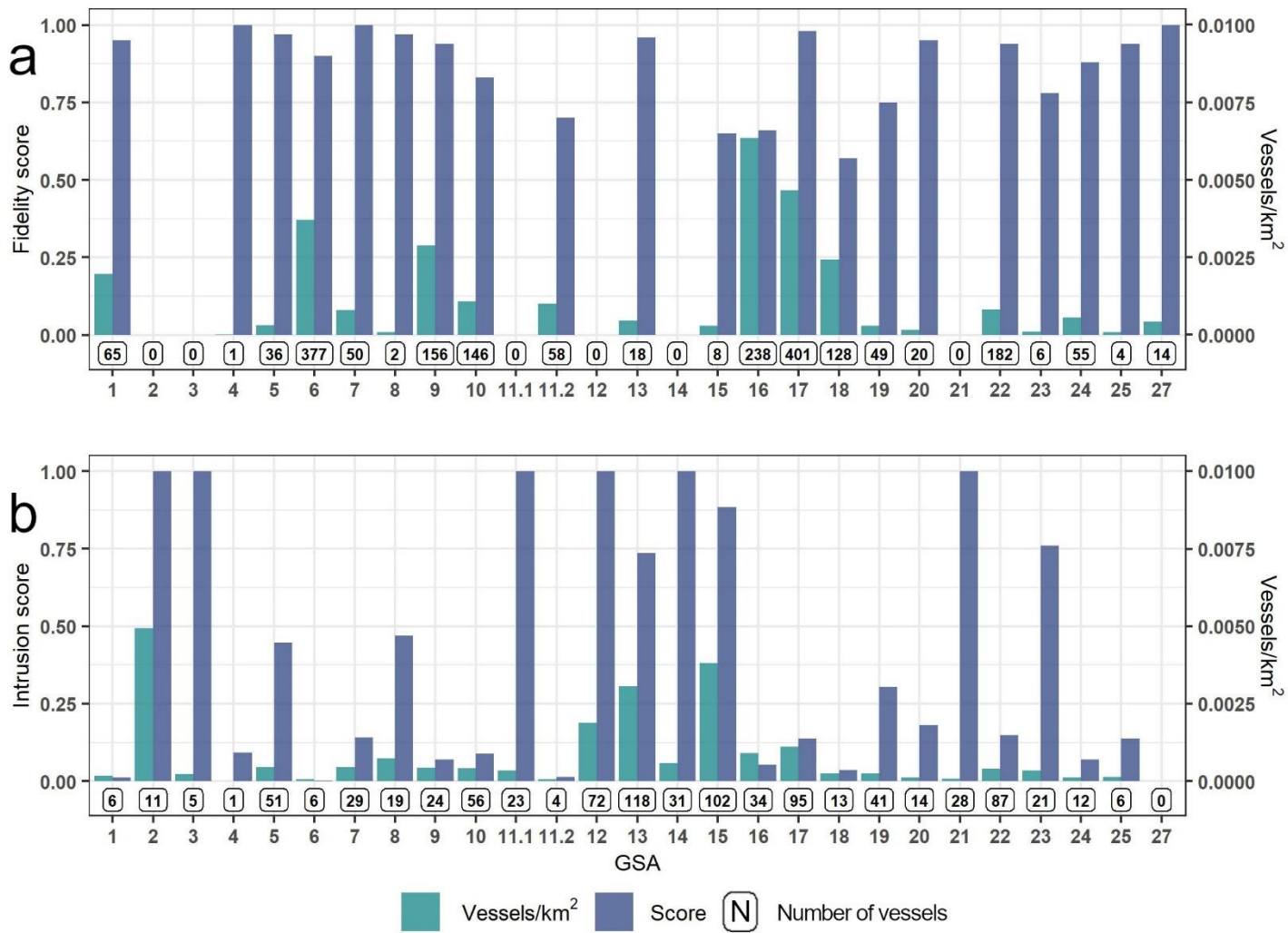


Figure 2: a) Fidelity score (blue bar) indicating the proportion of fishing hours that home-vessels (number of vessels in the boxes at the bottom of the figure) spent in their GSA, and density of home-vessels (turquoise bar); b) ,Intrusion score (blue bar) indicating the proportion of fishing hours that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

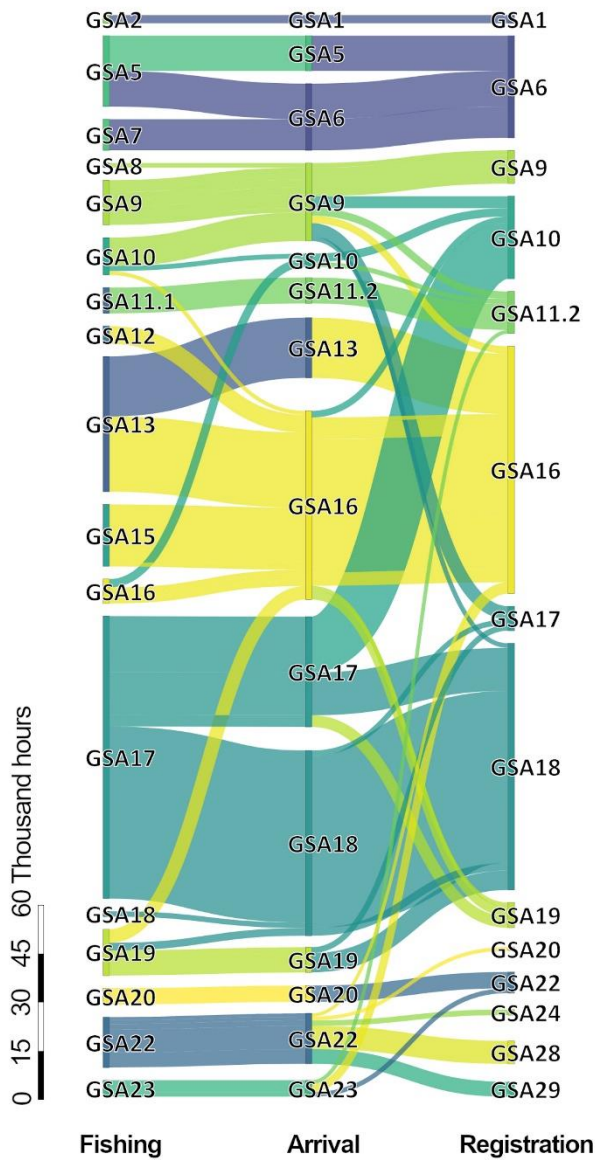


Figure 3: Fluxes of fishing effort (only those exceeding 1000 hours) between GSAs. Column “Fishing” indicates where the fishing activity was observed; column “Arrival” indicates the location of the harbor reached at the end of the fishing trip; column “Registration” refers to the GSA of registration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

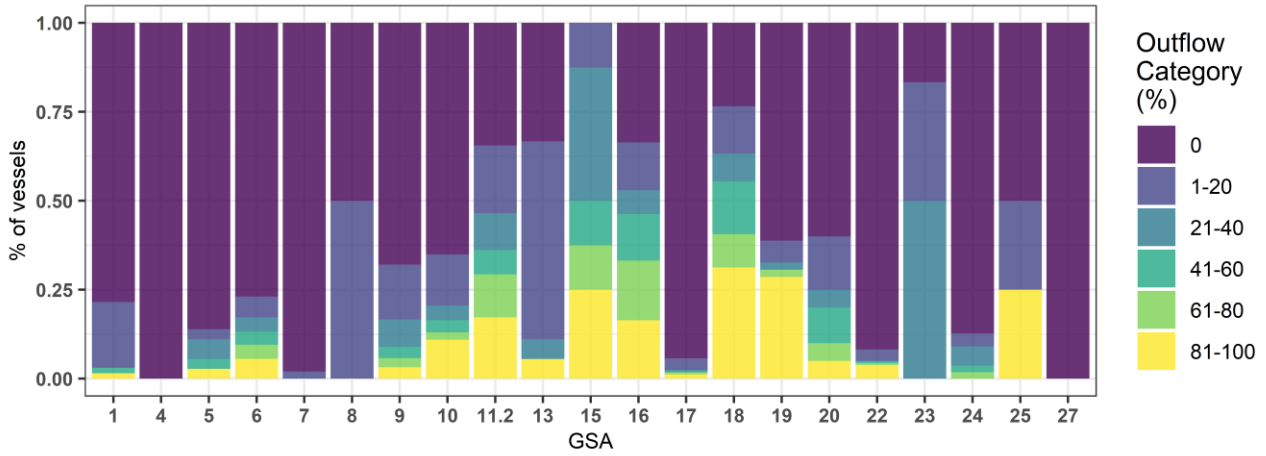


Figure 4: Percentage of vessels falling into each outflow category, aggregated on the GSA of registration. Outflow categories describe the proportion of fishing trips during which some fishing activity was observed beyond the borders of the GSA of registration.

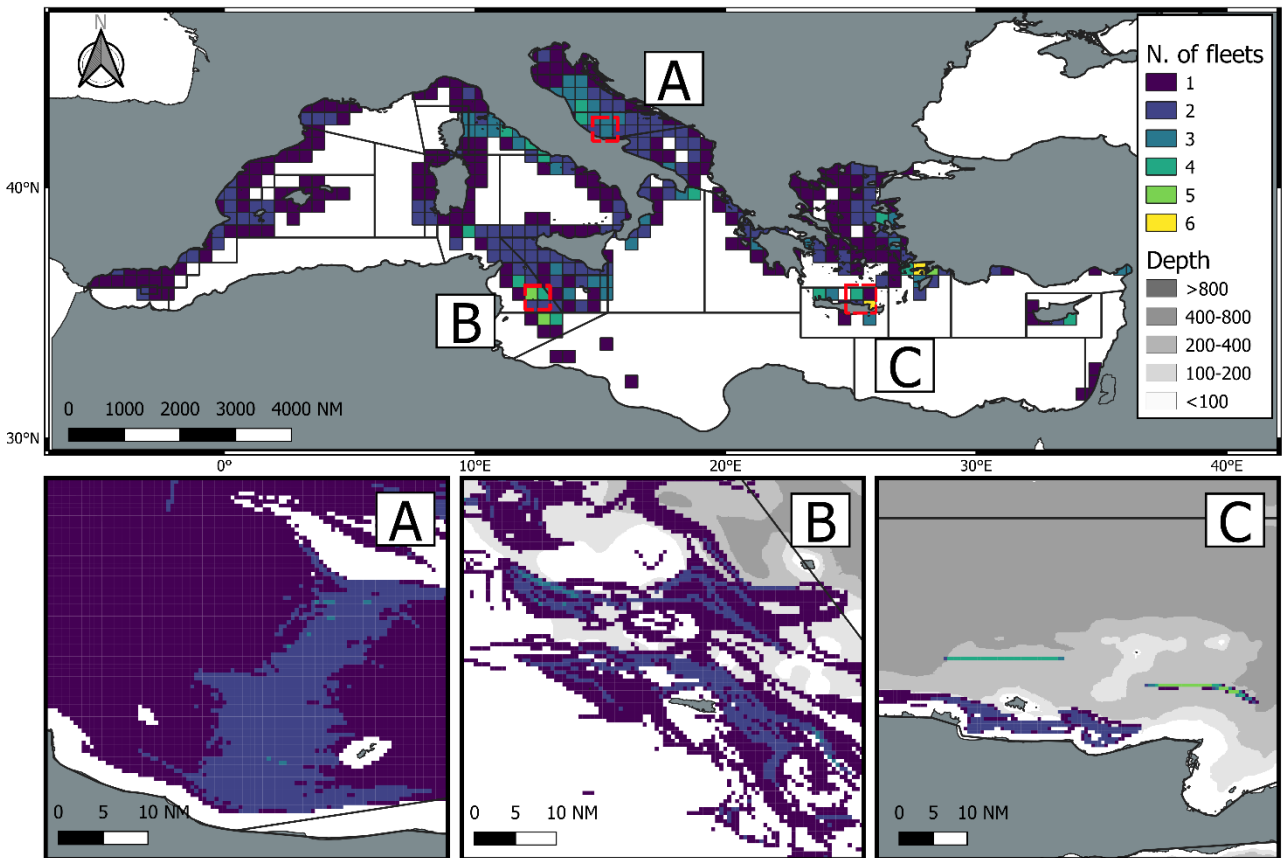


Figure 5: Number of fleets fishing > 50 hours a year detected in each cell of the GFCM grid. Insets maps show case studies in greater detail (1kmx1km grid): A) Adriatic Sea; B) Sicily Channel; C) Crete.