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Intra-gear variation in sea turtle bycatch: Implications for fisheries management

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ABSTRACT

In the Mediterranean Sea, bottom trawl, bottom longline and set nets are the fishing gears with the highest impact on marine turtle populations. These demersal gear types are characterised by a variety of *métiers* (fishing operations targeting a specific assemblage of species, using specific gear, during a precise period of the year and/or within a specific area). Data on fishing methods, target species and turtle bycatch were collected through interviews in three different study areas in the central Mediterranean. The results show that, even in the same fishing area, different *métiers* of the same gear can have a different impact on turtles. These findings have several implications. First, traditional turtle bycatch estimations and comparisons based on a fishing gear as a whole may be spatially or temporally biased by spatial and temporal differences in *métier* composition, respectively. Second, the efficiency of conservation measures may be different according to the *métiers* involved and caution is needed when measures developed in small areas with certain *métiers* are exported to a wider scale with possibly very different *métiers*. Third, conservation measures may induce shifts among *métiers* that may have an impact on other species, but such shifts are difficult to detect. All this suggests that, in the Mediterranean, a *métier*-based approach is needed to provide realistic estimates of turtle bycatch, to increase the efficiency of conservation measures by targeting only the most relevant *métiers* and to predict the changes in target species and effort distribution that can be driven by conservation measures. The variability of fishing methods and *métiers* implies that the most effective management strategies should be identified at relatively small geographical scales.

1. Introduction

Fisheries bycatch has been identified as a primary driver of population declines of long-lived marine megafauna; mitigating its impact is an important challenge worldwide (Kelleher, 2005; Lewison et al., 2004). Industrial shrimp trawlers have been the first fishing gear attracting significant and long-term scientific attention and conservation measures (e.g., Crowder et al., 1994; Epperly, 2003 and references therein). Since then, the interest in sea turtle bycatch increased rapidly, with great attention given to industrial pelagic longlines (e.g., Lewison and Crowder, 2007; Rees et al., 2016; Wallace et al., 2010). Although industrial fisheries are inherently easier to study, it has soon become evident that the more elusive small-scale demersal fisheries (e.g. set nets, demersal longlines and also small-scale pelagic longlines) probably have a high impact on sea turtle populations (Casale, 2011; FAO, 2009; Lewison et al., 2013; Rees et al., 2016; Wallace et al., 2010).

In the last decades numerous studies identified ways to reduce bycatch of marine megafauna, and differences in the technical features or in the use of a fishing gear were found to affect bycatch rate of sea turtles, sea mammals, sea birds and sharks (e.g., Clarke et al., 2014; Cosgrove et al., 2016; Gilman, 2011; Mangel et al., 2018; Melvin et al., 1999). Regarding turtles, it has been experimentally demonstrated that turtle catch rate can be affected by the specific technical features of a fishing gear (e.g. hook size, depth, lights, floats, net height) as well by fishing operational parameters (e.g. time of the day, soak time, bait) (e.g., Gilman et al., 2010; Gilman and Huang, 2017; Ortiz et al., 2016; Peckham et al., 2016). This suggests that the intra-gear variation associated with different *métiers* may result in different turtle catch rates.

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In the Mediterranean, interaction with fisheries represents the most important threat to sea turtles and quantifying and developing ways to reduce bycatch levels are listed among the top research priorities (Casale et al., 2018). Bottom trawl, bottom longline and set nets (gill and trammel nets) represent the fishing gears with the highest impact on turtle populations, due to the high mortality rate associated with these fisheries (20–60%), and because the turtles caught are usually large individuals with a high reproductive value (Casale, 2011; Lucchetti et al., 2017; Wallace et al., 2008). In addition, fishing gears such as set nets and bottom longline are widespread in small-scale fisheries (defined as fisheries carried out by vessels of an overall length of less than 12 m and using passive gears; European Commission, 2006), which represent about 71% of the EU Mediterranean fleet (Scientific Technical and Economic Committee for Fisheries (STECF), 2018). A growing literature describes the heterogeneity of the fishing operations of these demersal fishing gears. Within the same gear, groups of different fishing practices targeting different species assemblages can be identified and have been called with different terms such as fishing tactics or *métiers* (Marchal, 2008; Pelletier and Ferraris, 2000; Stergiou et al., 2006; Tzanatos et al., 2006).

The European Union Data Collection Framework (DCF; European Commission, 2008) has defined a *métier* as a group of fishing operations targeting a specific assemblage of species, using specific gear, during a precise period of the year and/or within the specific area (Deporte et al., 2012). The DCF defined *metiers* according to six nested levels: (i) activity, (ii) gear class, (iii) gear group, (iv) gear type, (v) target assemblage and (vi) mesh size and other selective devices. The European Union Common Fisheries Policy recognizes the importance of accounting for heterogeneity in fishing practices (European Commission, 2009), and a *métier*-based approach to fisheries management can be useful to reach this goal. In this context, if the impact on turtle species differs across *métiers* of the same fishing gear, the estimation of turtle bycatch at the *métier* level could help decision-makers improve management strategies and conservation outcomes, as well as predict the consequences of those strategies for target species.

This study aims to investigate possible differences of turtle bycatch among different *metiers* in the central Mediterranean by i) identifying the *métiers* from different demersal fisheries and ii) assessing if the different *métiers* have a different impact on sea turtles.To this end, we considered three case studies in the region: Calabria (Italy) Lampedusa (Italy) and Gulf of Gabes (Tunisia). These areas could be part of a single sea turtle management unit as they are relatively close to each other and are frequented by turtles originating from the same nesting sites, like Greece, Libya and Calabria, as indicated by genetic markers (Garofalo et al., 2013), tag returns (Casale et al., 2007b) and satellite tracking (Luschi and Casale, 2014; Mingozzi et al., 2016). Turtle bycatch in these areas has been widely studied (e.g., Cambiè et al., 2013; Casale et al., 2007a; Jribi et al., 2007) and Italy and Tunisia are among the countries with the highest bycatch levels in the Mediterranean (Casale, 2011).

2. Materials and methods

2.1. Data collection

Fishers were directly approached at their base port/mooring area between May and October 2013 in each of three study areas: Calabria (Italy, Ionian side, ports of Brancaleone, Palizzi, Condofuri, Bova and Melito), Lampedusa island (Italy, port of Lampedusa) and Gulf of Gabes (Tunisia, ports of Chebba and Sfax) (Fig. 1). Data collection was performed through face-to-face structured interviews with fishers, following a standardized questionnaire with close-ended questions. The interviews included information on: i) fishing gear (bottom longline, BL; bottom trawl, BT; gill nets, GN; trammel nets, TN), ii) catch composition (each target species expressed as % in weight of the total catch), iii) turtle bycatch per fishing gear per month and year, iv) fishing effort (fishing days per month) by gear and v) fishing operational parameters (gear's depth and soak time). However, these core data were also contextualized through a less structured conversation with open-ended questions. Although interviews are inherently less reliable than direct observation by researchers during fishing operations, it is the only feasible approach in contexts with low turtle catch rates, and we are confident that the data collected were suitable for the objectives of this study, for two main reasons: (i) we conducted other studies in the past, in collaboration with the same fisheries and fishers (e.g., Cambiè et al., 2013; Casale et al., 2007a; Jribi et al., 2007), (ii) even if the fishers – for any reasons – declared less turtle bycatch than the real one, this would be a general bias, not associated to a specific *métier* of the same gear, and would not affect the comparative approach of the study, aimed to identify *métiers* through differences of catches of target species within the same gear (see below). Although a different attitude to report turtle bycatch among the different study areas due to local context cannot be excluded, this would not have any effects on the comparisons of turtle bycatch among métiers, because they were performed at area scale only (see below).

2.2. Identification of fishing métiers

Fishing *métiers* are here defined as sub-sets of one fishing gear (BL, BT, GN, or TN), which we identified on the basis of the target species and their relative occurrence in the catch. We aggregated the catch of each target species by boat on a monthly basis, according to Pelletier and Ferraris (2000), and calculated the proportion (in weight) of each species on the total catch (all species caught in a month-vessel unit). Then we populated a two-dimension matrix (month-vessel by species) with these proportions.

Analyses were performed at two spatial scales: i) Area (i.e. each of the three study areas were analysed separately) and (ii) Region (i.e. the central Mediterranean, including all the three study areas). At the Area scale, in order to have a sufficient amount of data to obtain a robust catch profile, the analysis focused on the most used demersal fishing gears in each area (gears used by at least 5 vessels, which also reported information on turtle bycatch): TN and BL in Calabria, BT in Lampedusa and TN, GN and BT in the Gulf of Gabes (Table 1). Then, in order to assess a possible spatial effect on the characterization of the *meties* identified at the Area scale, analyses were performed at the Region scale, where only gears used in at least two studied areas were considered: BL (used in Calabria, Lampedusa and Gulf of Gabes), TN (Calabria and Gulf of Gabes) and BT (Lampedusa and Gulf of Gabes) (Table 1).

Only month × boat combinations with non-zero catches were included in the data matrix to produce the monthly catch profile. Different *metiers* were identified by means of a cluster analysis. An agglomerative hierarchical clustering (with Ward's method) was performed with the *cluster* package for R (R Development Core Team, 2018). The number of clusters (i.e. *metiers*) for each fishing gear was considered as the minimum number of clusters characterised by a reasonable structure (Average Silhouette Width, ASW > 0.5).

2.3. Modelling turtle bycatch

Turtle bycatch rate was calculated as turtles · month^{-1} standardized per unit of fishing effort. For BT the unit of effort was simply the fishing boat while for nets (GN and TN) and BL it was 1000 m of net and 1000 hooks respectively. In order to assess a potential effect of the month on turtle bycatch, only months with a similar fishing effort (number of fishing days) were included in the analysis (Calabria: May-September for BL, March-October for TN; Lampedusa: May-September for BT; Tunisia: September-June for BT and March-November for GN and TN). Information about fishing days per month was directly reported in Calabria and Lampedusa, while in Tunisia only the use of the gear by month (used/not used) was reported and then it was integrated with

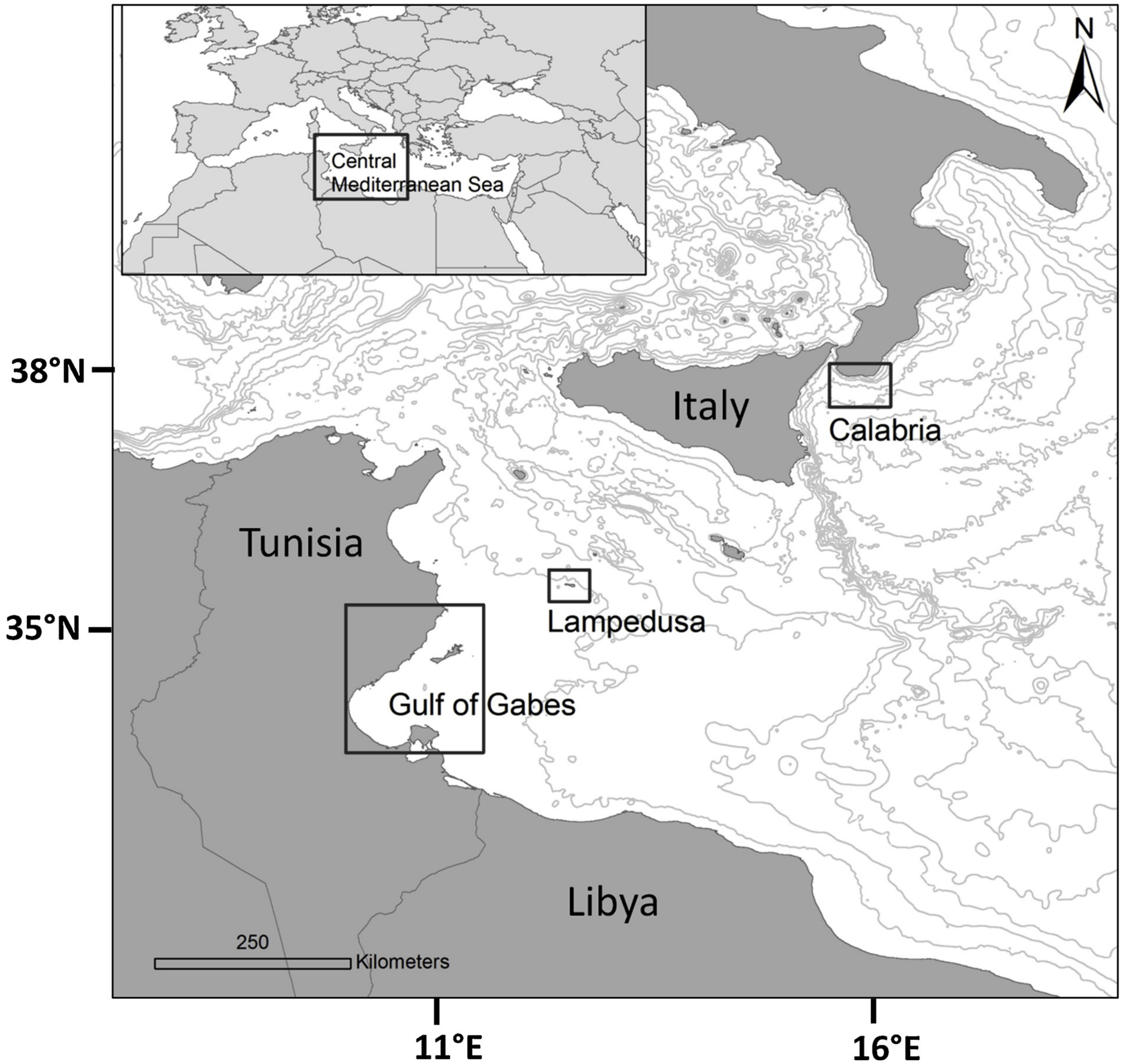

Fig. 1. Study area, the Central Mediterranean, with the location of the three case studies, Calabria (Italy), Lampedusa (Italy) and Gulf of Gabes (Tunisia).

Table 1
Number of interviews (total number of interviews and interviews with information on turtle bycatch) conducted between May and October 2013 by fishing gear and area. Interviews were conducted in 5 ports in Calabria, 2 ports in the Gulf of Gabes and 1 port in Lampedusa island.

Fishing gear	Area	Total interviews	Total fleet in the ports	% coverage	Interviews with data on turtle bycatch (%)
Bottom longline (BL)	Calabria	24	29	83%	24 (100%)
	Lampedusa	7	20	35%	3 (43%)
	Gulf of Gabes	4	25	16%	4 (100%)
Trammel nets (TN)	Calabria	16	22	73%	16 (100%)
	Gulf of Gabes	20	ca. 4500	ca. 1%	14 (70%)
Gill nets (GN)	Gulf of Gabes	10			10 (100%)
Bottom trawl (BT)	Lampedusa	10	25	40%	9 (90%)
	Gulf of Gabes	13	238	5%	13 (100%)
Total		104			93

published information on fishing days by gear (e.g., Gaamour et al., 2015).

The effect of two predictive variables (*métier* and fishing month) on the dependent variable (turtle bycatch) was investigated. The month is often associated with a variation in turtle bycatch (e.g., Cambiè, 2011; Casale et al., 2007a, 2012), possibly due to turtle behavioural patterns. In order to focus on the most representative *métiers* used by each fleet, only *métiers* used by more than two vessels were considered in the analysis. Potential correlation between months and *métiers* was assessed via Pearson’s chi square test of independence (or via Fisher’s exact test of independence, when the expected frequencies in the contingency tables were less than 5).

For each gear, the effect of the predictive variables on the dependent variable was assessed through a generalized linear mixed-effects

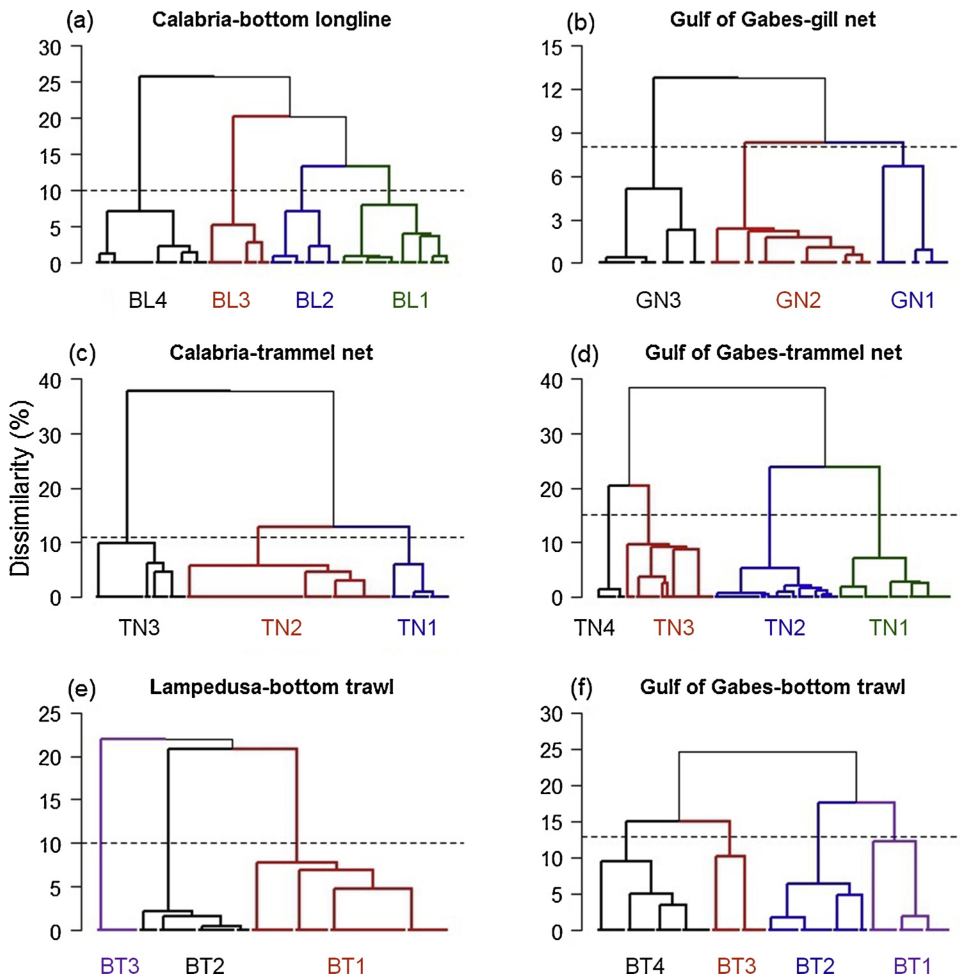

Fig. 2. Dendrograms from hierarchical clustering using catch data. For each fishing gear, the dashed lines, which represent the cut-off point identified by the silhouette average coefficient, determine the number of clusters. Each cluster identified a specific métier, indicated with acronyms. BL: bottom longline; BT: bottom trawl; GN: gill nets; TN: trammel nets.

Table 2
Catch profiles of the fishing *métiers* used by the studied fleets. Fishing gear is shaded grey and the corresponding *métiers* white. For each *métier*, target species (primary and secondary species) are indicated as % catch weight. (Note that each vessel can use multiple *métiers* and therefore, the sum of the number of interviews of the *métiers* can be higher than the numbers of interviews of the corresponding gear).

Area	Gear and *métiers*	No fishers	Primary species (%)	Secondary species (%)
Calabria	**Bottom longline (BL)**	**24**		
	BL_1	8	*P.phycis* (41.1)	*M. merluccius* (33.1), *H. dactylopterus* (20.3), other (5.4)
	BL_2	5	*M. merluccius* (62.6)	*H. dactylopterus* (18.9), *D. dentex* (17), other (1.5)
	BL_3	3	*D. dentex* (43.0)	*Epinephelus spp.* (31.1), *M. merluccius* (16.3), other (9.6)
	BL_4	8	*Scorpaenaspp* (50.4)	*M. merluccius* (40.8), *D. dentex* (8.8)
Calabria	**Trammel net (TN)**	**16**		
	TN_1	4	*Mullus spp.* (73.2)	*Diplodus spp.* (26.8)
	TN_2	7	*Mullus spp* (48.0)	*O. melanura* (28.4), *Diplodus spp.* (23.6)
	TN_3	5	*S. officinalis* (52.0)	*Mullus spp.* (30.4), *P.erythrinus* (4.1), other (13.5)
Lampedusa	**Bottom trawl (BT)**	**9**		
	BT_1	5	*Mullus spp.* (38.1)	*O. vulgaris* (32.7), *L. vulgaris* (23.8), other (5.4)
	BT_2	4	*O. vulgaris* (76.6)	*Mullus spp.* (10.0),*M. merluccius* (6.9), other (6.5)
	BT_3	1	*L. caudatus*(90)	*S. mantis* (5), other (5)
Gulf of Gabes	**Gill net (GN)**	**13**		
	GN_1	3	*P. erythrinus* (31.6)	*Diplodus spp.* (27.3), Mullusspp (24.1), other (17.0)
	GN_2	5	*Diplodus spp.* (72.2)	*S. aurata* (8.8), *P. erythrinus* (5.5), other (13.5)
	GN_3	4	*L. aurata* (54.4)	*Diplodus spp.* (23.2), *S. salpa* (7.9), other (14.4)
Gulf of Gabes	**Trammel net (TN)**	**20**		
	TN_1	5	*S. officinalis* (71.4)	*O. vulgaris* (18.2), *D. dentex* (5.1), other (5.3)
	TN_2	10	*O. vulgaris* (53.5)	*S. officinalis* (41.7), other (4.8)
	TN_3	6	*P. erythrinus* (40.9)	*O. vulgaris* (19.5), *Diplodus spp.* (9.1), other (31.5)
	TN_4	2	*M. kerathurus* (85.7)	*Mustelus spp.* (14.3)
Gulf of Gabes	**Bottom trawl (BT)**	**13**		
	BT_1	3	*S. officinalis* (37.3)	*M. kerathurus* (25.6), *C. rhonchus* (13.0), other (24.1)
	BT_2	4	*M. kerathurus* (54.2)	*D. sargus* (28.7), other (17.1)
	BT_3	2	*M. merlangus* (32.5)	*L. vulgaris* (21.2),*P. erythrinus* (16.2), other (30.1)
	BT_4	4	*Mullus spp.* (38.4)	*D. sargus* (29.3), *P. erythrinus* (17.0), other (15.3)

model (GLMM), in order to account for the correlation between observations from the same vessel (random factor). The GLMM was run by the *cplm* package for R, with the Tweedie distribution, since the dependent variable (turtle bycatch rate) was continuous and included a high number of true zeroes (i.e. fishing operations with no turtle bycatch and not missing data; Figure S1, Supplementary material) (e.g., Candy, 2004). If the predictive variables were not correlated (see above), we compared (ANOVA command in R, with a Chi distribution) the full model (bycatch rate ˜ *métier* + month) with models with a predictive variable removed (bycatch rate ˜ *métier* and bycatch rate ˜ month) and identified the predictive variables which significantly improved the model (Richards et al., 2011). If, on the contrary, the predictive variables were correlated, models with different predictive variables (e.g. bycatch rate ˜ *métier* and bycatch rate ˜ month) were compared and the predictive variable which mostly affected turtle bycatych was identified as the variable included in the model with the lowest AIC value.

3. Results

A total of 104 interviews were conducted with fishers from vessels representing a variable coverage of the total fleets in the study ports (Table 1). Of these, 93 had complete information on target species and turtle bycatch and were used in the analyses.

3.1. *Métiers*

BL, TN/GN and BT were the main gears used in Calabria, Gulf of Gabes and Lampedusa respectively (Table 1). At the Area scale, all fishing gears analysed were separated into different *metiers* (3 or 4 *métiers* per gear), with cut-off points ranging from 8 to 15%

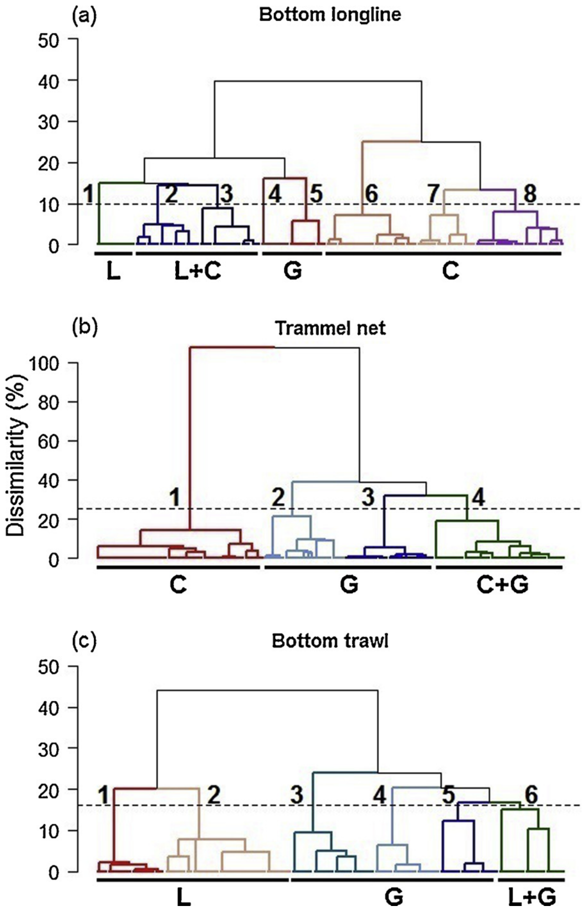

Fig. 3. Dendrograms from hierarchical clustering using catch data from the three case studies. For each fishing gear, the dashed lines, which represent the cut-off point identified by the silhouette average coefficient, determine the number of clusters. Each cluster identified a specific métier, indicated with a number. Bold continuous lines at the bottom group the clusters by area (C = Calabria, L = Lampedusa, G = Gulf of Gabes).

Table 3
Predictive variables (month, *métier*) for the dependent variable (turtle bycatch) assessed through GLMM at area scale (Calabria, Lampedusa, Gulf of Gabes) for those gears where predictive variables were not correlated (see text). P-values were generated for each variable via nested model comparisons to the full model (see text). Significant P-values mean that the model fit decreased when the focal variable was removed. (* P ≤ 0.05; ** P ≤ 0.01; *** P ≤ 0.001).

Area	Gear	Predictive Variable	p-value
Calabria	Bottom longline	month	< **0.001***
		métier	**0.049***
	Trammel net	month	0.127
		métier	0.685
Lampedusa	Bottom trawl	month	0.445
		métier	0.500
Gulf of Gabes	Trammel net	month	**0.050***
		métier	0.973
	Bottom trawl	month	**0.002****
		métier	0.366

dissimilarity (Fig. 2). The catch profile of each fishing *métier* was characterised by one primary species and one or more secondary species (Table 2). At the Region scale, there was a clear separation between areas, each characterised by its own typical *métiers* (Fig. 3). This and the high correlation between *métiers* and areas (Pearson's chi square test, P = 0.0005 for BL and P < 0.0001 for TN and BT), indicates that different areas are characterised by different *métiers*. For BL and TN only 25% of the *métiers* identified were shared by two areas (Calabria and Lampedusa for BL; Calabria and Gulf of Gabes for TN). For BT, 83% of the *métiers* were separated between the two areas where BT is used (2 *métiers* for Lampedusa, 3 for the Gulf of Gabes and 1 shared) (Fig. 3). For this high correlation between *métiers* and areas, the effect of the *métiers* on turtle bycatch was only investigated at the Area scale.

3.2. Turtle bycatch and fishing parameters

For all gear and areas except GN in in the Gulf of Gabes, the predictive variables (*metier* and month) were not correlated and results are shown in Table 3. The effect of *métiers* and month on turtle bycatch can vary between areas and gears. The variable "*métier*" had a significant effect on turtle bycatch for BL in Calabria (Table 3). In this case, BL3 was the *métier* characterised by the lowest bycatch rate (Fig. 4a). This *métier* primarily targeted common dentex (*Dentex dentex*) and was characterised by the shortest soak time (Fig. 4a). The four different *métiers* were also used at different fishing depths (BL1: 692 m ± 122 SE, BL2: 432 m ± 64 SE, BL3: 284 m ± 68 SE and BL4: 327 m ± 55 SE).

For GN in the Gulf of Gabes, the predictive variables (*metier* and month) were correlated (Fisher's test P = 0.04), therefore two separated models were compared (turtle bycatch rate ˜ *métier* vs. turtle bycatch rate ˜ month). The model "turtle bycatch rate ˜ *métier*" had a lower AIC value (AIC = 14) than the other (AIC = 27) and thus *métier* was considered to be the main factor affecting turtle bycatch. For this gear and area, GN1 was the *metier* characterised by the lowest bycatch rate, possibly due to the combination of two factors: that this *métier* was not employed in the months characterised by higher turtle abundance (June and July) and the higher fishing depth to target common pandora (*Pagellus erythrinus*) (Fig. 4b). Soak time data were not available for enough boats to be properly analysed.

The variable "month" had a significant effect on turtle bycatch for: i) BL in Calabria, with higher bycatch values in June and July (Fig. 4e), ii) TN in the Gulf of Gabes with higher bycatch in May and iii) BT in the Gulf of Gabes, with higher bycatch in June and September (Supplementary material, Figure S2). For TN in Calabria neither the factor "month" nor "*métier*" had a significant effect on turtle bycatch (Table 3).

4. Discussion

The present study provides evidence that different *métiers* of the same gear may have different impact on marine turtles. This is consistent with experimental studies on the effect of specific fishing parameters on turtle bycatch (e.g., Gilman et al., 2010; Gilman and Huang, 2017; Ortiz et al., 2016; Peckham et al., 2016).

The number of the *métiers* identified in each study area was comparable, indicating a similar level of complexity of demersal fisheries in different areas. The results show that, in the same fishing area, different *metiers* of the same gear can have different impact on turtles, as in the case of BL in Calabria and GN in the Gulf of Gabes. In Calabria, the BL *metier* with the lowest turtle bycatch rate was the one targeting common dentex (*Dentex dentex*). This *metier* was characterised by the shortest soak time, which may be the most likely factor for the low turtle bycatch. This *metier* was also characterised by the shallower depth and, although different among the BL *métiers,* depth was greater than the usual depth range frequented by sea turtles (0–50 m, e.g., Houghton et al., 2002) in all BL *métiers*. For these two reasons depth is unlikely an important factor. Differently, the greater fishing depth may be the main factor explaining the lower bycatch rate observed in the GN *metier* targeting common Pandora (*Pagellus erythrinus*) in the Gulf of Gabes.

These findings show that a *métier*-based approach can improve sampling design (e.g. data collection through on-board observations), as the implementation of a sampling scheme stratified by *metier* could

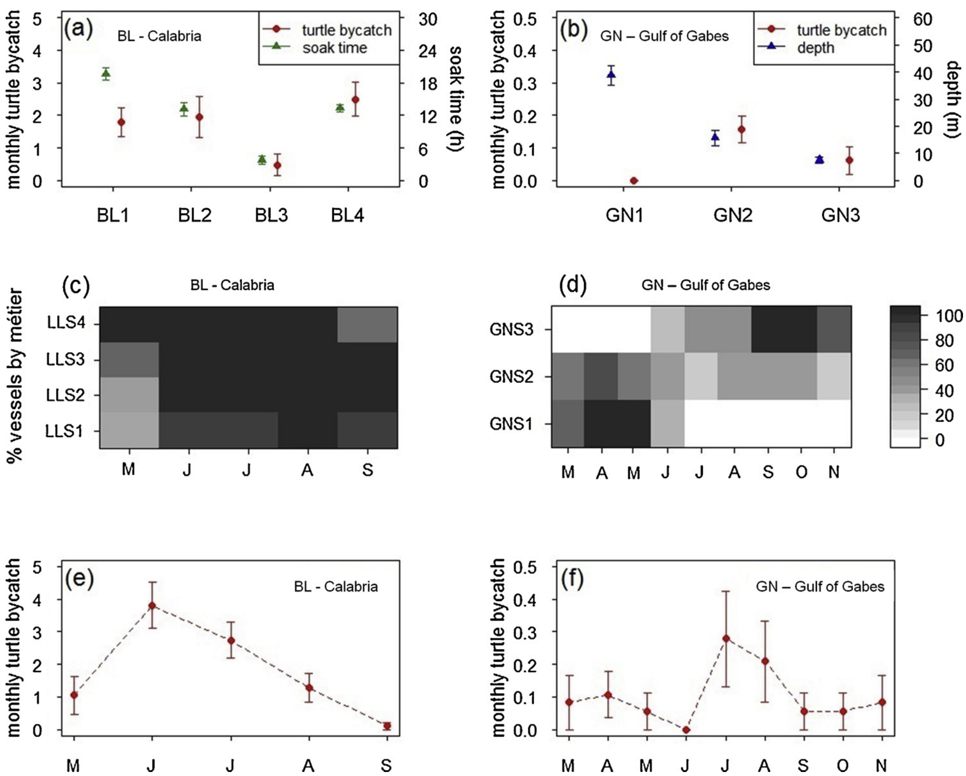

Fig. 4. Métiers with a significant effect on turtle bycatch (bottom longline, BL, in Calabria and gill nets, GN, in Gulf of Gabes). (a) Monthly turtle bycatch (turtles · month-1) and average soak time (hours) for the métiers identified in the bottom longline (BL) fishery in Calabria (Italy). (b) Monthly turtle bycatch (turtles · month-1) and average depth (m) for the métiers identified in the gill net (GN) fishery in the Gulf of Gabes (Tunisia). (c) Seasonal variation in the use of the métiers of the bottom longline (BL) in Calabria and the gill net (GN) in the Gulf of Gabes (d). The gradient colour shows the proportion of the vessels using a particular métier per month on the total vessels using that métier. (e) Monthly turtle bycatch (turtles · month-1) for the bottom longline (BL) in Calabria and for the gill net (GN) in the Gulf of Gabes (f). (Error bars = SE).

provide better and more representative estimates of bycatch rates for a specific fishing gear. Moreover, measures aimed to decrease turtle bycatch may be more effective for sea turtle conservation if targeting specific *meters,* instead of the gear as a whole. This would also reduce possible conflicts with the fisheries involved. However, small-scale fishing activity is highly dynamic, with fishers often switching among different *métiers* (e.g., Cambiè et al., 2017). Therefore, possible shifts from one *metier* to another due to conservation measures may be easier for fishers and more difficult to detect for managers than shifts among fishing gears. This is an important aspect because such shifts might impact other species. For example, a reduction of turtle bycatch through management measures encouraging fishers to deploy their GN at greeter depth (e.g. minimum gear depth) could lead to an increase of fishing pressure on common Pandora in the Gulf of Gabes. Similarly, a management measure implemented to reduce turtle bycatch and focused on decreasing the soak time in BL (e.g. setting a maximum soak time) in Calabria could cause a shift of target species, with a decrease of fishing pressure on hake (*Merluccius merluccius*) and a potential increase on common dentex, which is already overexploited in many areas (Carpenter and Russell, 2014). The information generated through a métier-based approach could help to better address management targets and ensure a sustainable fishing activity for all species involved. Fishers should be involved in these processes (bottom-up approach) also to promote compliance from the sector.

A *métier*-based approach can also improve detection of seasonal trends. Since different *metiers* may be characterised by different fishing seasons (e.g., Cambiè et al., 2017; Tzanatos et al., 2006), seasonal trends of turtle bycatch rate at gear level might theoretically reflect a switch among *métiers*, and only a stratification per *métier* can assess which is the case. Our results show that temporal variation in bycatch rate can occur in all areas analysed, with higher values in late-spring and summer. This could be due to an increase in turtle abundance, as individuals might move from off-shore to coastal waters for feeding reasons or to a more active feeding behaviour in the warm season, as high-water temperatures can increase sea turtle metabolic rates (Hochscheid et al., 2004). Improving monitoring and statistic techniques to discern the individual effect of both variables (months and *métiers*) on turtle bycatch could help to improve future management plans.

The results show a high diversity of *métiers* even within a relatively small geographic region like the central Mediterranean and highlight the importance of identifying management strategies appropriate to the spatial scale considered. In this respect, a management strategy aimed at promoting *métiers* which were proven to be less impactful at a small spatial scale, might not be the best approach on a regional scale, where an alternative approach may be the protection of hotspots where a high sea turtle bycatch rate occurs (e.g., Roe et al., 2014). Moreover, comparisons of turtle bycatch rates of the same gear in different areas may be biased if the gear is only apparently the same and in reality, different *métiers* of that gear are used in different areas.

Data provided by fishers on target species, fishing parameters and bycatch are essential to understand the dynamic of the fishing activity occurring in a specific area and fishers are often the only source of information on this topic (Bevilacqua et al., 2016). However, these data must be used with caution and the limitations of reports by fishers should be considered in the interpretation of the results. For instance, comparative approaches, like the one used in this study to compare between *métiers,* are inherently more robust than quantitative estimates, e.g. of catches.

Future research should integrate the information presented in this study with on-board observations, to test for the consistency with the several types of interviews data and to provide a more detailed picture of the fishing *métiers* identified, especially in terms of the technical aspects of the fishing operations, and of the turtle bycatch level. This information will be key to identify the most feasible and effective conservation measures, which may range from targeting a specific technical or operational parameter (e.g., Brčić et al., 2015; Lucchetti et al., 2019) to targeting a *métier* as a whole (e.g., through regulations on commercial species). However, given the low catch rate at vessel level typical of small-scale fisheries, this would require a significant allocation of resources and might be challenging.

CRediT authorship contribution statement

Giulia Cambiè: Conceptualization, Methodology, Formal analysis, Writing - original draft. **Imed Jribi:** Investigation. **Irene Cambera:** Investigation. **Giulia Vagnoli:** Investigation. **Daniela Freggi:** Investigation. **Paolo Casale:** Writing - original draft.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.fishres.2019.105405.

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