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Conflict analysis between commercial fisheries and common bottlenose dolphin (*Tursiops truncatus*) in the Dodecanese region, Greece

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Abstract

Increasing depletion of fish stocks in the Mediterranean Sea intensifies conflicts between fisheries and marine mammals, such as the common bottlenose dolphin (*Tursiops truncatus*, Montagu, 1821). To increase the knowledge of such interactions in the eastern Mediterranean Sea, fishing activities of commercial fisheries and biomass of fish families targeted by fisheries and *T. truncatus* were analysed to identify areas that are more likely to be affected by these conflicts in the Dodecanese region of Greece. The area with the highest risk of conflict is located between Kos and Leros islands and the southwest coast of Turkey, which is mainly caused by trawl fishing activities. The presence of Sparidae, Merlucciidae, Mullidae and other unspecified fish families increased the likelihood of conflicts. Our applied method and results can be used to improve fishing regulations and management to diminish similar conflicts elsewhere in the world.

KEYWORDS

commercial fisheries, conflicts, Dodecanese, fish families, fishing activity, marine mammals

1 | INTRODUCTION

The growing human population and consumption rates of provisioning ecosystem services have many negative consequences on nature, including depletion of fish stocks in the ocean (Hilborn et al., 2020). The Mediterranean Sea has heavily exploited fishing grounds, which can be ascribed to poor legislation enforcement by responsible organisations and differences in multiple legislations implemented in the Mediterranean (Cacaud, 2005; Tsikliras et al., 2013; Vlachopoulou et al., 2013). Although the Aegean Sea particularly lacks fishery management plans, high fishing activity proliferates in the area due to a higher productivity than in the rest of the Eastern Mediterranean due to nutritional inflow from the Black Sea and rivers in the North of the Aegean (Briassoulis, 2004; Keramidas et al., 2018; Lykousis et al., 2002; Vlachopoulou et al., 2013). Consequently, fisheries and marine wildlife are highly abundant in this region, leading to frequent interactions (Papaconstantinou & Farrugio, 2000; Tsagarakis et al., 2010; Tsiaras et al., 2012). Cetaceans are one group most impacted by such interactions, with the common bottlenose dolphin (*Tursiops truncatus*, Montagu 1821) mainly being impacted due to its coastal distribution and high abundance (Bearzi et al., 2010; Frantzis et al., 2003; Milani et al., 2019; Pardalou & Tsikliras, 2018).

Fishing effort is also elevated in the Aegean Sea (Papaconstantinou & Farrugio, 2000; Tsikliras et al., 2013). High fishing boat density and high fishing effort, or amount of fishing, increase the frequency of interactions with marine mammals in the Aegean and makes the region particularly treacherous for *T. truncatus* (Bearzi et al., 2008; Papaconstantinou & Farrugio, 2000; Tsikliras et al., 2013). Interactions between fisheries and *T. truncatus* can have negative results such as conflicts and depredation events (Goetz et al., 2014; Pardalou & Tsikliras, 2018). Stealing or spoiling of fish from fishing nets by marine mammals can result in death of *T. truncatus* individuals by entanglement in fishing nets and culling by fishers (Bearzi et al., 2010; Goetz et al., 2014; Lauriano et al., 2009; Pardalou & Tsikliras, 2018; Tudela, 2004). Fishers cull cetaceans primarily because of economic losses caused by damaging and stealing fish from fishing nets (Goetz et al., 2014). Depredation behaviour increases when fish populations decline (Pardalou & Tsikliras, 2018). Additionally, conflict frequency increases when the same fish species are targeted (Bearzi et al., 2010; Fertl & Leatherwood, 1997). Therefore, due to their diet, marine mammals share the same interest with fisheries and most likely catch their prey in the same places at the same time, thereby causing conflicts (Goetz et al., 2014). Many fish families have been recognised as drivers of conflicts, which can be ascribed to uncertainty in the diet composition of *T. truncatus*, which is partially caused by differences in the diet in time and space (Bearzi et al., 2010; Blanco et al., 2001; Pardalou & Tsikliras, 2020). However, the families thought to be primarily involved in conflicts include Mullidae, Merlucciidae and Sparidae (Bearzi et al., 2010; Milani et al., 2019; Pardalou & Tsikliras, 2018). The catch rate of certain fish species by fisheries can be heightened with the use of specific gear at a specific depth. Therefore, the type of gear used by fisheries can be a proxy for the frequency of expected conflicts between fisheries and *T. truncatus* (Matthiopoulos et al., 2008; Milani et al., 2019; Pardalou & Tsikliras, 2018). Depredation by *T. truncatus* is enhanced when nets such as bottom trawls and static nets, specifically trammel and gillnets, were used in shallow waters (Bearzi et al., 2010; Milani et al., 2019; Pardalou & Tsikliras, 2020).

The variables "gear that is operated by fisheries" and "fish families of common interest between fisheries and *T. truncatus*" have been used as proxies before to determine the frequency of depredation (Bearzi et al., 2010; Milani et al., 2019; Pardalou & Tsikliras, 2020). However, geographical locations where conflicts occur more frequently have yet to be identified. Information on these areas might be used to mitigate and decrease the growing number of reported conflicts and ultimately avoid overexploitation of fish at certain places at certain times to maintain a sustainable environment for *T. truncatus* (Bearzi et al., 2008; Pardalou & Tsikliras, 2020; Taylor et al., 2016). Moreover, identifying potential conflict zones might help to visualise potential conflict zones for reducing the number of conflicts.

The primary aim of this study was to identify areas and fish species of high conflict risk between commercial fisheries and *T. truncatus* in the Dodecanese region. High-risk areas were hypothesised to be located in the regions with the highest fishing effort in the Dodecanese; the area around Rhodes and between the islands of Kalymnos, Agathonisi and the southeastern coast of Turkey (GFW, 2021a). According to previous research, Mullidae, Merlucciidae and Sparidae were hypothesised to be targeted fish families that lead to conflicts between fisheries and *T. truncatus* (Bearzi et al., 2010; Milani et al., 2019; Pardalou & Tsikliras, 2018). We developed a method to identify high-conflict areas with information available to the public by focusing on the Dodecanese region located in the Aegean Sea, a region with a lack of knowledge on the topic compared to mainland coastland waters while having the largest and most active fleet in the Mediterranean (Bonizzoni et al., 2014; Karachle et al., 2020; Pardalou & Tsikliras, 2020; Roditi & Vafidis, 2022). The method was developed by firstly gaining insight into activities of the Greek fishing fleet with global open-access data from Global Fishing Watch [dataset] (GFW, 2021b). Second, the public database of [dataset] Hellenic Statistical Authority (2021a) on the fish families landed by commercial fisheries was accessed to identify the targeted species. Third, data were complemented with the probability that a certain geartype caught a certain fish family and the probability of occurrence of fish families in the area as found in [dataset] Segschneider et al. (2019a). Finally, this information was correlated with fish families in the diet of *T. truncatus* based on a literature review.

2 | MATERIALS & METHODS

2.1 | Study region

We identified high-risk areas in the Dodecanese archipelago in the Aegean Sea, where conflicts between fisheries and *T. truncatus* were more likely. Boundaries of the study region were defined by specifying coordinates at the edge of islands nearest to borders of the Dodecanese region. Longitudinal boundaries were defined as the western point of the island Ofidoússa (26.1301°E) and the eastern point of Rhodes (28.2461°E). Latitudinal boundaries were defined as the southern point of Kasos (35.339 N) and the northern point of Agathonisi (37.488 N) (GFW, 2021a) (Figure 1). Surface area of the land was subtracted from the total surface area, as was calculated by distance between longitudinal and latitudinal coordinates, to define the surface area of the sea as approximately 33,267 km^2 (Figure 1) (GFW, 2021a. Panagiotidou et al., 2016).

2.2 | Data collection

2.2.1 | Commercial fisheries

Commercial fishing efforts of Greek fishing vessels in the waters between the Dodecanese islands during 2013–2019 were acquired from the Global Fishing Watch worldwide dataset [dataset] (GFW, 2021b). Fishing effort was defined by Global Fishing Watch as a calculation of the fishing activity by summarising the fishing hours of all fishing vessels in a certain area (GFW, 2022a). The 7-year

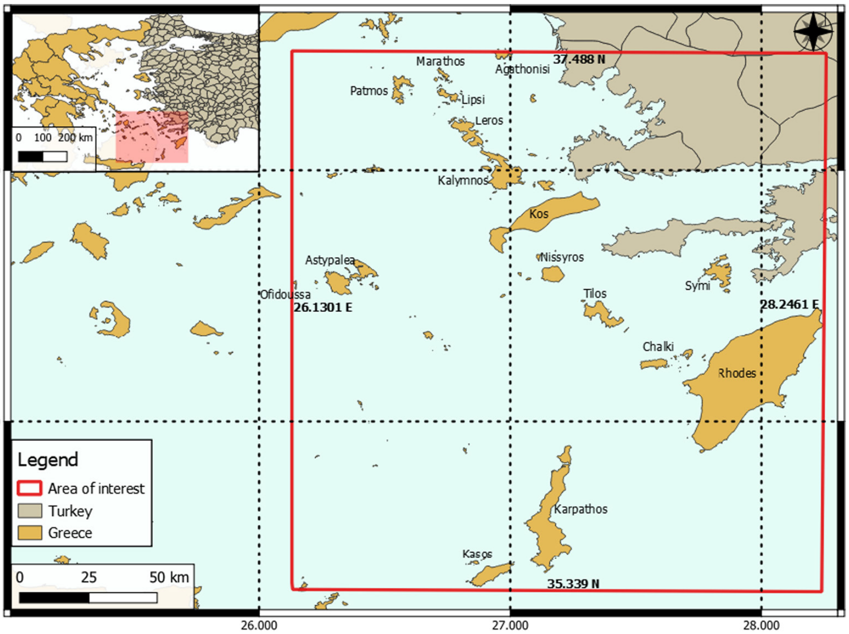


FIGURE 1 Study region of the conflict analysis between *Tursiops truncatus* and commercial fisheries in the Dodecanese, Greece during 2013–2019. The red outline indicates the study area; the Dodecanese region (Coordinate system: GGRS′87)

time range was selected because global information on the distribution of fisheries was available only during 2013–2019 at the time of the present study (carried out from April to July 2021). Datasets on sea fishing effort were filtered to include only vessels with "fishing hours" higher than zero to avoid including fishing vessels that passed through the corresponding coordinates (Appendix S2.1).

2.2.2 | Catch biomass

Biomass of fish, cephalopods, crustaceans and pelecypods caught by Greek vessels in Greek waters from 2013 to 2019 was published by the Hellenic Statistical Authority [dataset] (Hellenic Statistical Authority, 2021a). In the dataset, a collection of fish families labelled as "Others" was defined as a collection of fish species that were not included in other divisions but represented a significant portion of the catch by Greek vessels nonetheless (Hellenic Statistical Authority, 2020). In the present study, this group was defined as "Unspecified" to avoid confusion with "Others," which indicates a collection of multiple types of gear. The biomass caught in Greece was specified for each gear type as it was sampled during the annual survey of the Hellenic Statistical Authority (2020). Biomass of each fish family caught by each gear type (trawlers, beach seiners, purse seiners and others) in each year were originally reported as catch by the entire nation but were recalculated to estimate the biomass of each fish family caught by each gear type in each year in the Dodecanese region during 2013–2019 (Appendix S2.2). A unique conversion factor was used for the recalculation for each year from two variables from the dataset "Quantity of catch by fishing area" [dataset] (Hellenic Statistical Authority, 2021b):

$$\text{Conversion factor} = \text{Quantity of catches in the Dodecanese islands} / \text{Quantity of catches in total.}$$

After which, the conversion factor was used to recalculate the biomass caught for different gear types per year in the Dodecanese region:

$$\text{Biomass of a fish family caught in the Dodecanese region (tonnes)} = \text{Biomass of a fish family caught in Greece (tonnes)}^{*}\ \text{Conversion factor.}$$

The conversion factor assumed no variation in the ratio of fish families caught over different archipelagos present in Greece. Possible bias of results correlated with this assumption was reduced by including information on the distribution of fish families. Species that contributed the most to biomass caught of each family were selected according to the [dataset] Hellenic Statistical Authority (2021a), after which the probability of occurrence of each species in the study region was derived from [dataset] Segschneider et al. (2019a). The probability of occurrence ranged from zero to one to indicate the degree of habitat suitability [dataset] (Segschneider et al., 2019a; Appendix S2.3).

Data reported by Global Fishing Watch and the Hellenic Statistical Authority only included information from the part of the fishing fleet that operated with the Automatic Identification System (AIS) (GFW, 2021c; Hellenic Statistical Authority, 2020). Due to compulsory use of AIS in vessels exceeding a length of 15 metres, most vessels included in Global Fishing Watch and Hellenic Statistical Authority were part of the commercial fleet (GFW, 2021d; Hellenic Statistical Authority, 2020; Natale et al., 2015).

2.2.3 | Diet of *Tursiops truncatus*

The diet of *T. truncatus* was compiled from multiple studies in or near the Mediterranean basin (Bearzi et al., 2010; Blanco et al., 2001; Giménez et al., 2017; Gladilina & Gol'din, 2014; Milani et al., 2019;

Santos et al., 2007). However, biomass values of fish species caught by *T. truncatus* were not always comparable among studies. For example Mugilidae were included in the diet of *T. truncatus* in some studies (Bearzi et al., 2010; Milani et al., 2019; Santos et al., 2007) but excluded in other studies (Blanco et al., 2001; Gladilina & Gol'din, 2014). Furthermore, the percentage of some species in the diet of *T. truncatus* varied among studies, as was seen for the family Merlucciidae which contributed 11.67% (Bearzi et al., 2010), 43.90% (Blanco et al., 2001), 16.52% (Giménez et al., 2017), 8.20% (Milani et al., 2019) and 8.30% (Santos et al., 2007) to the diet of the common bottlenose dolphin. Next, the biomass of fish species in the diet of *T. truncatus* were reported as percentages of fish families or species found in stomach contents in some studies (Bearzi et al., 2010; Gladilina & Gol'din, 2014; Milani et al., 2019; Santos et al., 2007), and as estimated numbers of fish species based on fish otoliths found in stomach contents for other studies (Blanco et al., 2001; Giménez et al., 2017). Therefore, different species were ascribed to their corresponding families in this study.

Weights of fish families caught were obtained from biomasses reported by the previous studies. Studies reporting percentages of fish species present in the diet of *T. truncatus* also gave total biomass of fish families caught which enabled a calculation of the weight of each fish family in the diet of *T. truncatus* (Bearzi et al., 2010; Gladilina & Gol'din, 2014; Milani et al., 2019; Santos et al., 2007). For studies that reported on numbers of individual fish in the diet, the weight of individual fish species was calculated by multiplying the number of individuals in stomachs by the weight of individual fish species in the Aegean Sea and nearby seas (Blanco et al., 2001; Dulčic et al., 2002; Ferreira et al., 2008; Ilkyaz et al., 2008; Mustać & Sinovčic, 2010; Özaydin et al., 2007; Özaydin & Taskavak, 2006; Pombo et al., 2005; Yılmaz & Polat, 2011). This weight was then added to the biomass of other fish species belonging to the same family that were found in the diet of *T. truncatus*. Some studies on the diet of *T. truncatus* reported only the stomach contents of a few individuals, which was extrapolated in this study to the biomass consumed per year by multiplying the content by 12 h per day and 365 days per year. Multiplication by 12 h accounted for digestion time, which was considered appropriate to determine total biomass consumed per day (Hernandez-Milian et al., 2015).

We estimated biomass consumption of fish families by an individual *T. truncatus* in the Dodecanese region, but not yet the total biomass consumption of all *T. truncatus* individuals. The number of *T. truncatus* individuals in the Dodecanese was not estimated in the literature, so we used an estimation from a previous study of 2.5 *T. truncatus* individuals/100 km in the North Aegean Sea (Milani et al., 2017). Similar values were recorded in other areas in Greece and Turkey, excluding the South Aegean Sea (Baş et al., 2016; Bearzi et al., 2008). Due to the higher productivity of the North Aegean Sea compared to the Southern part, the encounter rate is thus likely to be lower (Segschneider et al., 2019b; Tsiaras et al., 2012). Nonetheless, the number of *T. truncatus* individuals in the study area was estimated using the encounter rate (2.5 *T. truncatus*), the surface area of the Dodecanese (33,267 km^2), the transect width (2 km) and the transect length (100 km):

$$\text{Local population size } T.\,truncatus = \text{Surface area}/(\text{Transect width} * \text{Transect length}) * 2.5.$$

Published encounter rates relied on visibility range, so we used two kilometres of transect width, which is acceptable for the area (Archipelagos Institute of Marine Conversation, personal communication, November, 2020). This led to an estimated number of 416 individuals of *T. truncatus* being present in the Dodecanese. This is a cautious estimation as comparisons of encounter rates can differ highly between sites and study designs. The number of individuals is compared to other studies earlier an underestimation, so potential conflicts of risk are maybe more significant than presented (Bonizzoni et al., 2014).

Data on biomass of fish families consumed were combined with data on retention time of fish in stomachs of *T. truncatus* and with the estimate of the number of *T. truncatus* individuals in the South Aegean Sea to obtain the total weight of fish families consumed in the area by *T. truncatus*. The data were represented as "weight of the prey family caught (tonnes) every year at 1 km by an individual dolphin" (Appendix S2.4).

2.3 | Data analysis

2.3.1 | Spatial distribution of fisheries

For statistical analysis and data representation, R version 3.5.0 (RStudio, RRID:SCR_000432, http://www.rstudio.com/) and QGIS 3.16 Hannover (QGIS, RRID:SCR_018507, https://qgis.org/en/site/) were used (QGIS Development Team, 2020; R Core Team, 2018). As a consequence of the non-normal distribution and heterogeneity of data, statistical comparisons of differences in location between gear types were tested using the nonparametric Kruskall–Wallis test, followed by Dunn's Test of Multiple Comparisons (Ogle et al., 2021). Heat maps of locations of gear types depicting the amount of fishing activity in the area were made with the heatmap plugin in QGIS in the layer properties of the vector data.

2.3.2 | Overlap between fisheries and *T. truncatus*

Mean biomass of fish families caught by each gear type from the [dataset] Hellenic Statistical Authority (2021a) during 2013–2019 by Greek vessels was combined with the diet of *T. truncatus* to identify resource overlap. Resource overlap was indexed using the Pianka niche overlap index to indicate the amount of niche or resource overlap ranging from zero (no niche overlap) to one (complete resource overlap) (Milani et al., 2019; Zhang, 2016). Overlapping fish families were visualised in a stacked barplot with the "ggplot2" package in R as percentages of the biomass of fish families caught per gear relative to the biomass of fish families caught by *T. truncatus*. Catch per gear was analysed with a Pearson's Chi-squared Test to determine if different gear types could be used as a predictor of fish families caught (Rao & Scott, 1981). The graph was designed through the "corrplot" R package that visually explains the correlation matrix given by Pearson's Chi-squared Test.

2.3.3 | Areas of conflict

Risk areas were identified using longitudinal and latitudinal coordinates of Greek vessel fishing effort in the study area by focusing on the gear type of [dataset] Global Fishing Watch and running the data through a hierarchical cluster analysis with geographical constraints using the R package "ClustGeo" (Appendix S2.1; Chavent et al., 2017; GFW, 2021b). Of 93,325 data entries, most were trawling activities. As a consequence, 5000 data entries were selected randomly for the "trawler" gear type for use in the hierarchical cluster analysis. Thus, clusters were analysed on the whole dataset and on gear-specific datasets. The Ward-dendrogram was used to visualise the cluster analysis, using the "factoextra" package in R. In addition, statistical differences in cluster locations were tested using the Kruskal–Wallis test and Dunn's Test of Multiple Comparisons (Ogle et al., 2021). Additionally, clusters were implemented in QGIS, in which outlines of cluster areas were defined using either a concave or a convex hull. The convex hull was used whenever the outline of the concave hull displayed odd shapes as a consequence of fishing efforts distributed around an island.

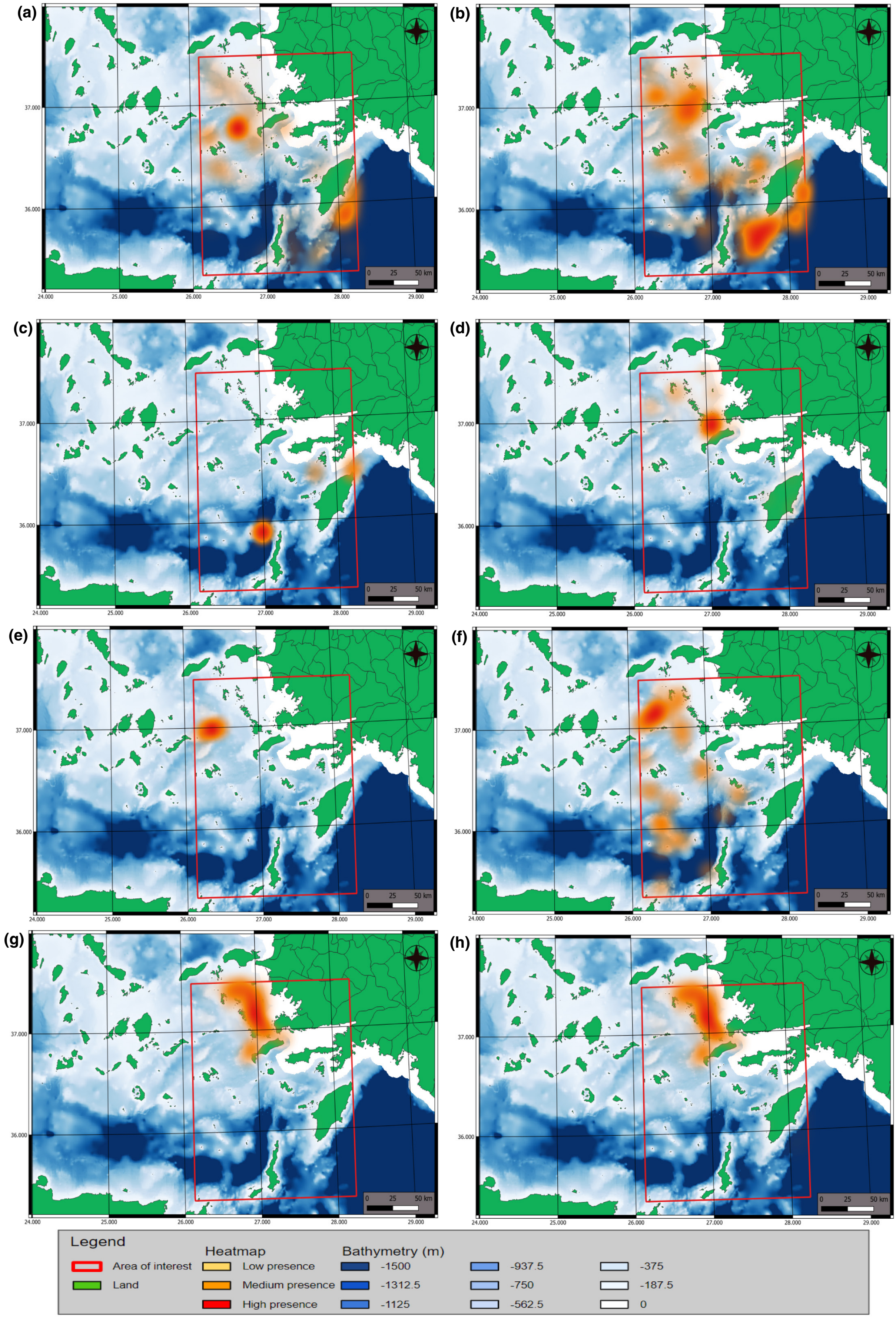
The probability of conflict in cluster areas was quantified by inversely ranking the results of variables. Variables related to biomass of fish caught, including the occurrence value of fish species in the area, the Pianka index, the predictive ability of the gear and the biomass of the fish families caught per gear relative to the biomass of fish families caught by *T. truncatus*. Other variables focused on commercial fisheries included the total amount of fishing effort in cluster areas and the amount of fishing effort by each gear in the cluster areas. For each variable, scores ranged from one to the number of data entries in which a higher score indicated a higher amount of possible contribution to the risk factor of a certain cluster. Some ranked variables had more data and therefore a higher maximum ranking number, so a weighted average of each variable was used to eliminate differences in the number of data entries used to calculate the risk factor (e.g. inverse rank scores were divided by the number of data entries for the variable; Appendix S2.5). This weighted average was multiplied by each variable scores, so all variables had scores from zero to one. Cluster scores were determined by addition of the scores of the different variables, where the predominant gear type in the area determined scores to be used in calculating cluster score for

TABLE 1 Differences in latitude and longitude of commercial fishing gears in the Dodecanese region of Greece during 2013–2019

	Latitude	Longitude
Geartype	Z statistic	Z statistic
Drifting longlines		
Purse seines	−22.463***	−5.114***
Fixed gear	1.272	−3.804**
Set gillnets	−15.279***	52.246***
Set longlines	−5.643***	20.246***
Fishing vessel	−1.272	−5.340***
Trawls	−97.201***	9.103***
Purse seines		
Fixed gear	−4.822***	2.961
Set gillnets	6.368***	43.589***
Set longlines	6.625***	20.967***
Fishing vessels	−19.183***	−0.876
Trawls	−19.527***	9.678***
Fixed gear		
Set gillnets	−3.561**	11.635***
Set longlines	−2.742	9.102***
Fishing vessels	1.419	−3.134**
Trawls	−7.749***	4.418***
Set gillnets		
Set longlines	2.493	−7.656***
Fishing vessels	−12.586***	49.895***
Trawls	−30.073***	−53.026***
Set longlines		
Fishing vessels	−4.889***	21.717***
Trawls	−18.175***	−18.544***
Fishing vessels		
Trawls	−60.137***	12.061***

Note: Z-statistics were generated using Dunn's Test of Multiple Comparisons following Kruskal–Wallis tests. (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$).

FIGURE 2 Heatmaps of commercial fishing efforts in the Dodecanese region of Greece during 2013–2019, divided by gear type: (a) Drifting longlines, (b) Fishing gear, (c) Fixed gear, (d) Purse seines, (e) Set gillnets, (f) Set longlines, (g) Trawls, (h) Total. Information on bathymetry was retrieved from EMODnet Bathymetry Consortium (2020), information on vessel distribution was retrieved from [dataset] GFW (2021b). Differences between latitude and longitude of fishing efforts were generated with Dunn's Test of Multiple Comparisons following Kruskal–Wallis test. Significant differences were found between every gear type ($p < 0.05$) except on the latitude for drifting longlines and either fishing gear or fixed gear, and between fixed gear and either fishing vessels and set longlines ($p > 0.05$). On the longitude, no differences were found between purse seiners and either unknown fishing vessels and vessels operating fixed gear ($p > 0.05$). (Coordinate system: GGRS'87)


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
37.000
36.000
24.000
25.000
26.000
27.000
28.000
29.000
0 25 50 km
Legend
Area of interest
Land
Heatmap
Low presence
Medium presence
High presence
Bathymetry (m)
-1500
-1312.5
-1125
-937.5
-750
-562.5
-375
-187.5
0

variables; the Pianka index, overlapping fish families, predictive ability of the gear and the probability of occurrence of fish families in the area. To combine data from fishing effort in the Dodecanese and resource overlap to calculate the risk factor, the gear was grouped into the following categories: trawls, purse seines and others (i.e. beach seines, fixed gear, fishing gear, set longlines, set gillnets and drifting longlines). This was justified since beach seiners contribute the least to the total biomass caught while drifting longlines and fixed gear, including gillnets and set longlines, were also reported as "others" type of vessels from Hellenic Statistical Authority (2021a, 2021b); Maynou et al. (2011); Stergiou and Erzini (2002). Furthermore, "fishing gear" was mentioned to consist of multiple types of gear due to the inability to distinguish between the type of gear operated by the vessel and can thus also be seen as "others" types of vessels [dataset] (GFW, 2021b). Scores were processed to visually represent risk areas defined in the low-to-high-risk range in QGIS.

3 | RESULTS

3.1 | Spatial distribution of fisheries

Of 93,325 total units of Greek fishing efforts in the Dodecanese during 2013–2019, 84,426 were trawlers, 4762 were drifting longlines, 20 were fixed gear, 932 were purse seiners, 1061 were set gillnets, 275 were set longlines and 1849 were unidentified gear (Global Fishing Watch, hereafter "fishing vessels"; Appendix S3.1).

Geographical locations of fishing effort by different gears differed significantly in both latitude (K-W test: μ = 37 0.09943, 95% CI [37.09724; 37.10162], $\chi^2 = 44{,}056$, $p < 0.05$) and longitude (K-W test: μ = 26.93766, 95% CI [26.93585; 26.93948], $\chi^2 = 38{,}326$, $p < 0.05$). Trawlers differed significantly in both latitude and longitude with all other gear types (Table 1). Most gears differed significantly in the geographical distributions (Table 1; Figure 2; Appendix S3.2). Latitudinal distribution did not differ significantly between drifting longlines and either fixed gear or unknown fishing vessels. Furthermore, latitudinal distribution did not differ significantly between fixed gear and either set longlines, and unknown fishing vessels ($p > 0.05$). Lastly, latitudinal distribution did not differ significantly between set longlines and set gillnets ($p > 0.05$). Longitudinal distribution ($p > 0.05$) did not differ significantly between purse seiners and either unknown fishing vessels and vessels operating fixed gear ($p > 0.05$).

3.2 | Overlap between fisheries and *T. truncatus*

Resource overlap between *T. truncatus* and fishing effort was greatest for trawling and other gears, least for purse seines, and intermediate for beach seines (Table 2), with varying contributions of fish families to overlap (Figure 3).

The total annual biomass of fish caught by *T. truncatus* (276 tonnes/year) was much lower than the total annual biomass caught by commercial fisheries (3427 tonnes/year). Purse seiners caught 1360 tonnes/year, other fisheries caught 1268 tonnes/year, trawlers caught 758 tonnes/year and beach seiners caught 42 tonnes/year.

Species caught depended on gear type (μ = 0.099, 95% CI [−0.934; 1.133], $\chi^2 = 2420.8$, $p < 0.05$) with the family Engraulidae mostly caught by purse seiners. However, when "other" fishing gear was used, the catch of individuals belonging to the Engraulidae family could not be predicted (Figure 4; Appendix S3.3).

3.3 | Areas of conflict

Six clusters were identified with a weight separation between clusters of 0.276 (Figure 5; Appendix S3.4). The six clusters differed in both latitude (K-W test: μ = 37.099, 95% CI [37.097; 37.102], $\chi^2 = 3558.1$, $p < 0.05$) and longitude (K-W test: μ = 26.938, 95% CI [26.936; 26.939], $\chi^2 = 2513.6$, $p < 0.05$). Clusters 4 and 5 differed significantly in latitude and longitude from all other clusters (Table 3). Clusters 2 and 3 did not differ significantly in latitude, whereas clusters 3 and 6 and clusters 1 and 2, differed significantly in longitude (Table 3) All other clusters differed significantly in latitude or longitude (Table 3).

Predominant fishing gears were associated with different cluster areas (Appendix S3.5), which were identified by place names: cluster 1 = West Kalymnos, cluster 2 = Agathonisi, cluster 3 = Patmos, cluster 4 = East Kalymnos, cluster 5 = Rhodes and cluster 6 = Astypalea (Figure 6; Appendix S3.6). The four closely oriented areas in the North included East Kalymnos (1923 gear units) Agathonisi (1391 gear units), West Kalymnos (711 gear units) and Patmos (600 gear units), while Astypalea encompassed north and south of the study region (165 gear units) and Rhodes was in the south (210 gear units). Fishing activity consisted mostly by trawling in Agathonisi and East Kalymnos, drifting longlines in Astypalea and purse seining in West Kalymnos and Patmos. Unspecified fishing vessels predominated in Rhodes.

After adding the weighted averages together (Appendices 2.5; 3.7), the area with the highest risk score was East Kalymnos (23.70488722), followed by Agathonisi (22.59899749), Rhodes (19.01441103), Astypalea (18.18107769), West Kalymnos (15.99686717) and Patmos (15.79010025) (Table 4). Clusters rated as high risk (East Kalymnos) and medium-high risk (Agathonisi) were grouped together in the northeast of the Dodecanese with other clusters distributed over the Dodecanese rated as medium risk (Astypalea and Rhodes) and low risk (Patmos and West Kalymnos), depending on their scores (Figure 7).

4 | DISCUSSION

Conflict areas were characterised by a high presence of trawlers that mostly targeted fish families Merlucciidae, Sparidae, unspecified, Mullidae and Gadidae and overlapped with the diet of *T. truncatus*. While the involvement of these fish families was already hypothesised and confirmed by multiple studies, the method

TABLE 2 Pianka index of niche overlap between *Tursiops truncatus* and commercial fishing gears in the Dodecanese region of Greece during 2013–2019

	Trawlers	Purse seiners	Beach seiners	Others	Total
Tursiops truncatus	0.4062358	0.0937314	0.2087767	0.3937644	0.3096912

Note: Overlap values between *Tursiops truncatus* and different vessel types were calculated with Pianka's index of niche overlap. "Others" refers to all other inshore fisheries which include, but are not limited to, fixed gear, drifting longlines, set gillnets, set longlines and the "fishing" category that combines vessels of unknown fishing gear (Hellenic Statistical Authority, 2020).

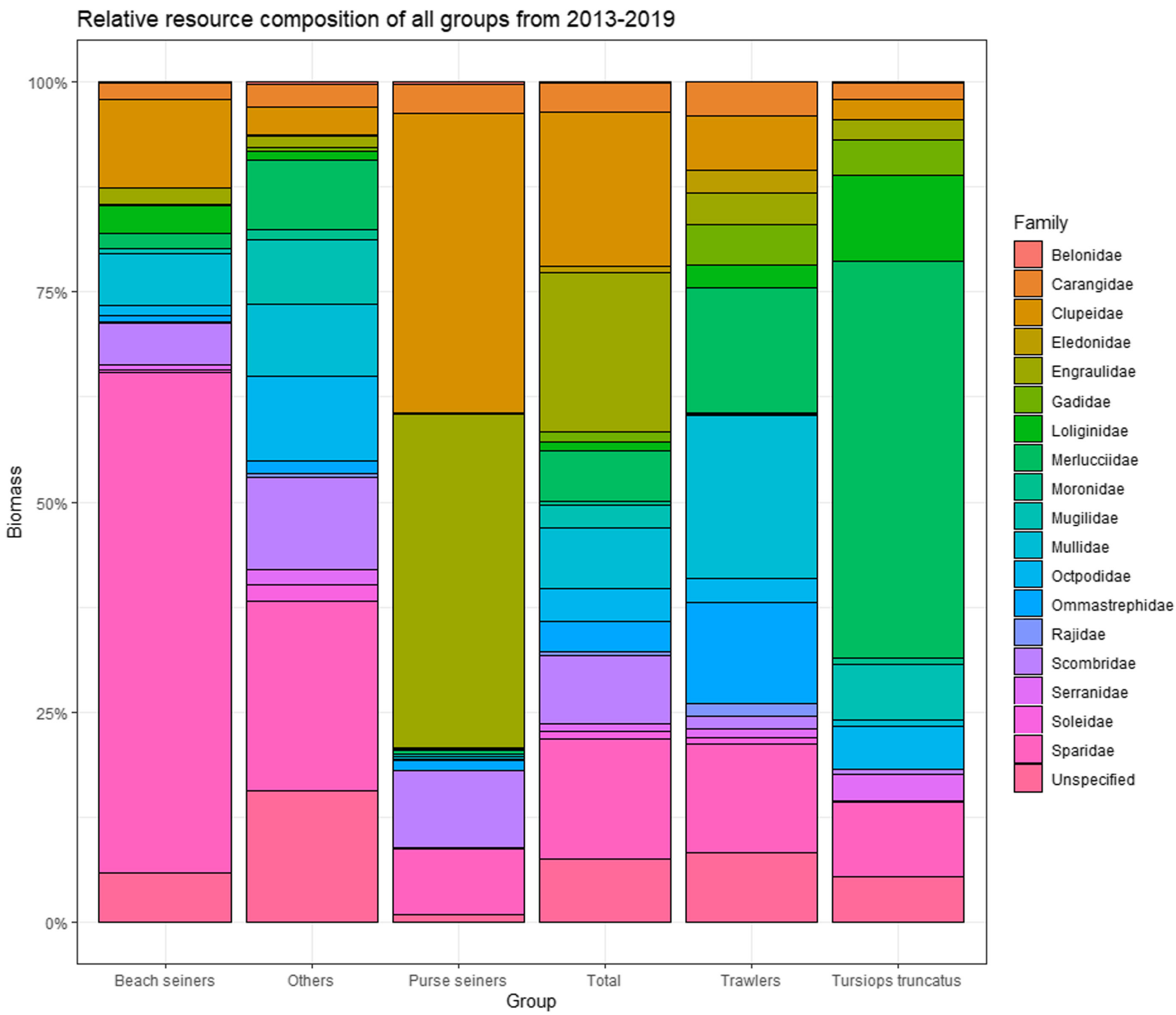


FIGURE 3 The relative catch composition of fish families by commercial fisheries and *Tursiops truncatus* in the Dodecanese region of Greece during 2013–2019. Percentages contributed by fish families to the composition are given. Others are specified as all other inshore which include, but are not limited to, fixed gear, drifting longlines, set gillnets, set longlines and the "fishing" category which combine vessels of unknown fishing gear (Hellenic Statistical Authority, 2020). Information on the resource composition of the fisheries was achieved from [dataset] Hellenic Statistical Authority (2021a), while information on the diet of *Tursiops truncatus* was achieved from Bearzi et al. (2010), Blanco et al. (2001), Gladilina and Gol'din (2014), Giménez et al. (2017); Milani et al. (2019); Santos et al. (2007)

used in this study confirms a degree of spatial overlap (Bearzi et al., 2010; Milani et al., 2019; Pardalou & Tsikliras, 2018). Further, risk of conflict decreased with the type of gear used. Therefore, riskiness decreased when a collection of gear defined as "others," including fishing gear, drifting longlines, set longlines, beach seines and set gillnets, is operated and then decreased further with the use of purse seines, because these fishing gears target different fish families.

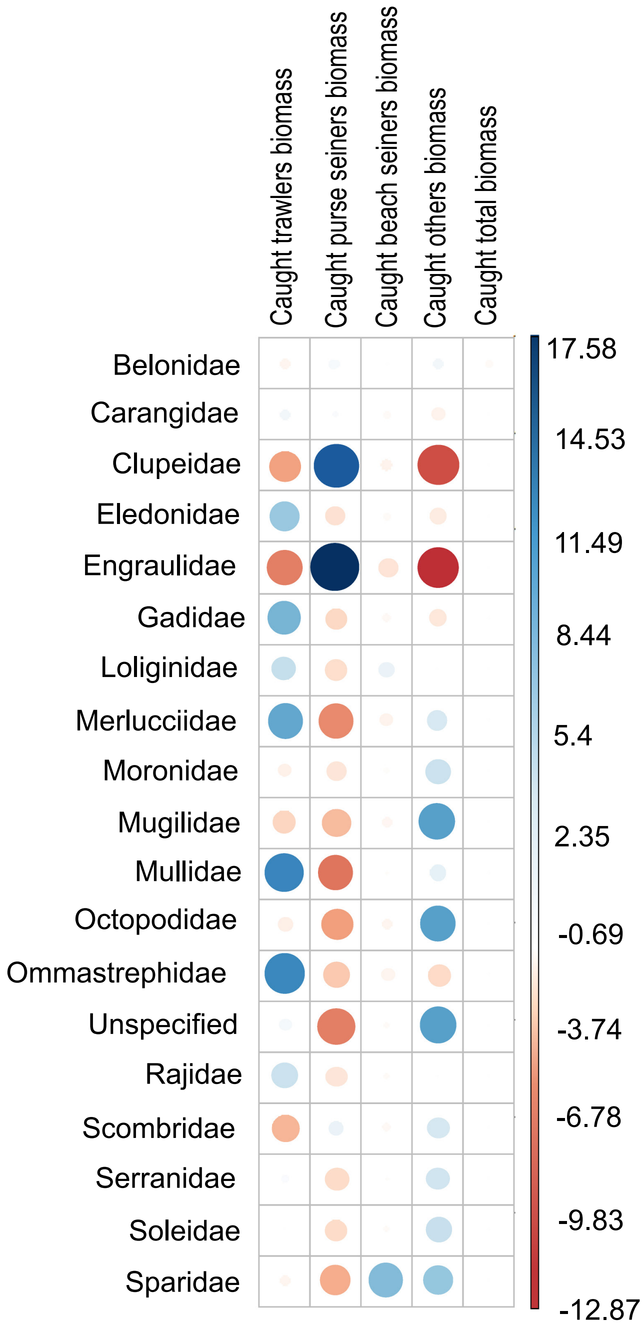


FIGURE 4 The dependence of fish families caught by commercial fisheries in the Dodecanese region, Greece during 2013–2019, divided by gear type. Residuals were calculated with Pearson's Chi-squared Test (μ = 0.099, 95% CI [−0.934; 1.133], $\chi^2 = 2420.8$, $p < 0.05$). A blue circle shows a positive association between the gear type and fish family, a red circle indicates a negative association. A large circle indicates a strong association between the two variables. Data were derived from [dataset] the Hellenic Statistical Authority (2021a)

4.1 | Spatial distribution of fisheries

Fishing effort was higher in the northern Dodecanese area than southern areas of the Dodecanese. Other research in the Aegean identified higher ecosystem productivity in areas with riverine inflow (Lykousis et al., 2002), which might explain high productivity in the northern Dodecanese from discharge of the Meander River in Turkey.

Intensity of trawler fishing effort was similar to the total amount of fisheries, which could be explained by a predominance of trawling effort (84, 426) in relation to the total number of effort entries (93,325). Fishing vessels with trawls, purse seines and fixed gear, including set gillnets and set longlines, were mostly fishing in shallow waters close to shore, which is consistent with previous studies (Boubekri et al., 2019; Cerdà et al., 2010; Stiles et al., 2010). The distribution of fisheries in shallow, coastal waters induced more interactions with *T. truncatus* in previous studies (Fertl & Leatherwood, 1997; Frantzis et al., 2003; Pardalou & Tsikliras, 2020).

4.2 | Overlap between fisheries and *T. truncatus*

The overlap between fisheries and *T. truncatus* was highest for trawlers and other gears, and lowest for purse seiners, similar to an earlier study by Milani et al. (2019), because target species of purse seiners in Greece are mostly pelagic while trawlers and *T. truncatus* focus on demersal species (Ei-Haweet, 2001; Stiles et al., 2010; Tsagarakis et al., 2012).

Sparidae were among the top five fish families with highest overlap between *T. truncatus* and fisheries because of a high probability of occurrence in the Dodecanese and the high catch numbers of Sparidae by *T. truncatus* and fisheries. In contrast, Merlucciidae were low in occurrence, but among the top five most caught families by trawls, purse seines, beach seines and "others." Overexploitation of Merlucciidae in the south of the Mediterranean Sea explains high catch rates despite low occurrence (El Bouzidi et al., 2022), and accounted for 47% of the diet of *T. truncatus*, so are likely highly involved in interactions between *T. truncatus* and fisheries. Furthermore, Mullidae was among the top five fish families, mainly caught by trawlers and was likely to be responsible for conflicts between *T. truncatus* and fisheries, was found in a previous study (Bearzi et al., 2010). Next, the group of "unspecified" fishes was unknown in distribution, but was caught by all types of gear, so was likely involved in conflicts between *T. truncatus* and fisheries. Therefore, Sparidae, Merlucciidae and Mullidae were families most likely to induce conflicts, confirming the hypothesis.

Last, some fish families affected the probability of conflicts between *T. truncatus* and fisheries but were caught by gear types less likely to be involved in conflicts with *T. truncatus*, thereby diminishing the influence of those fish families in the likelihood of conflicts. For example, when individuals belonging to the Engraulidae family are caught, they are most likely caught by purse seiners and dominate the scores of the predictive ability of gear. However, Engraulidae have little overlap between fisheries and *T. truncatus* and are therefore less responsible for conflicts and thus have less influence on the risk of conflict.

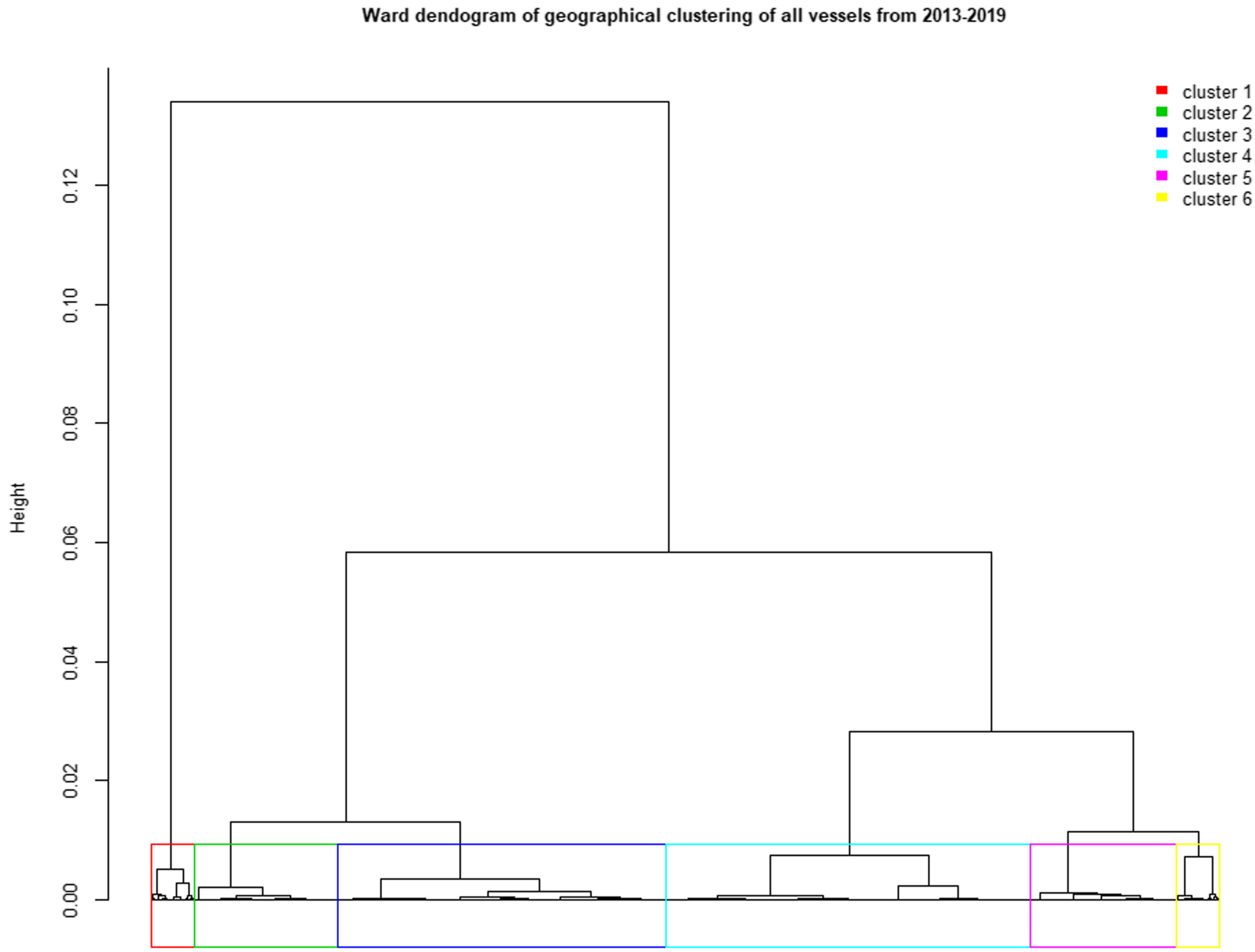


FIGURE 5 Differences in the cluster locations of commercial fishing effort in the Dodecanese region of Greece during 2013–2019. Cluster locations were generated with hierarchical cluster analysis with a Ward-Dendrogram. Pseudo inertia between clusters = 0.276. Data were derived from [dataset] GFW (2021b)

4.3 | Areas of conflict

A higher density of fishing vessels was concentrated in northern areas; East Kalymnos, Agathonisi, West Kalymnos and Patmos. In front of the Meander River, East Kalymnos was found the area at highest risk of conflict, likely because of high fishing effort and the predominance of trawlers, the gear with the highest overlap with *T. truncatus* (Table 2). Frequent interactions between trawlers and *T. truncatus* also occur in Australia (Jaiteh et al., 2013) and the coast of the United States (Greenman, 2012; Kovacs & Cox, 2014). East Kalymnos also has high purse seiner fishing effort, which should reduce the likelihood of conflict with *T. truncatus* (Marçalo et al., 2015; Wise et al., 2007), although not enough to mitigate risk induced by the large number of trawlers and high total fishing effort. Significant differences in locations of different gear types led to the possibility of assigning specific gear cluster areas to overall cluster areas to find the gear most present in risk areas while accounting for the exclusion of many data points of rare gear types when randomly choosing 5000 points.

As in East Kalymnos, trawlers dominated fishing effort in Agathonisi. However, less total fishing effort reduced classification of the area to medium-high risk. Medium risk areas were Rhodes and Astypalea, due to higher total fishing effort in Rhodes and higher presence of purse seiners in Astypalea, the latter of which overlapped less with *T. truncatus*. Drifting longlines also dominated in both areas, thereby explaining classifications of Rhodes and Astypalea as being only medium risk areas. Drifting longlines land their fish mostly from offshore in deep waters and catch mostly large pelagic fish, observations that are not commonly reported in the diet of *T. truncatus* (Báez et al., 2007; FAO, 2021a). Additionally, risk of conflict was higher in Rhodes and Astypalea than in West Kalymnos and Patmos because of higher presence of “other” types of fisheries, mainly fixed gear, such as set longlines, set gillnets and unknown fishing gear, that overlap with the diet of *T. truncatus* and thereby interact more with *T. truncatus* than purse seiners and drifting longlines (Table 2; Pardalou & Tsikliras, 2020). Overall, Patmos and West Kalymnos were of least conflict between fisheries and *T. truncatus* because fishing happened mostly with purse seiners and drifting longlines (FAO, 2021a; Báez et al., 2007; Wise et al., 2007).

In conclusion, we accept the hypothesis of a high-risk area between the islands of Kalymnos, Agathonisi and the south-eastern coast of Turkey, but reject the prediction of a second high-risk area around Rhodes. Rather, we identified another area of relatively high risk around the coast of Agathonisi, to 37.488 N 27.0725°E, crossing the eastern coast of Marathos and Lipsi, to the northern coast of Leros. The boundary of the risk zone at the edge of the study region suggests that the zone extends beyond the study area. In addition to these areas being fishing hotspots in the Mediterranean and being assigned as a high-risk area in this study, the areas around Kalymnos, Kos, Patmos, Leros and Symi are also heavily fished by small-scale fisheries using mostly gillnets, with which *T. truncatus* often interacts (Rechimont et al., 2018; Roditi & Vafidis, 2022).

TABLE 3 Differences in latitude and longitudes of clusters of commercial fishing effort in the Dodecanese region of Greece during 2013–2019

	Latitude	Longitude
Cluster	Z statistic	Z statistic
Cluster 1		
Cluster 2	−49.887***	−2.904
Cluster 3	−39.739***	18.148***
Cluster 4	−20.442***	−26.254***
Cluster 5	5.247***	−25.264***
Cluster 2		
Cluster 6	−3.436**	13.95***
Cluster 3	1.984	23.34***
Cluster 4	39.85***	−28.934***
Cluster 5	36.632***	−24.993***
Cluster 6	24.327***	16.266***
Cluster 3		
Cluster 4	27.924***	−46.156***
Cluster 5	32.616***	−37.295***
Cluster 6	21.684***	2.268
Cluster 4		
Cluster 5	18.015***	−11.446***
Cluster 6	7.401***	29.065***
Cluster 5		
Cluster 6	−6.814***	30.66***

Note: Z- statistics were generated using Dunn's Test of Multiple Comparisons following Kruskal–Wallis tests. (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$).

4.4 | Study limitations regards fishing efforts

A limitation of the study could be a lack of records of AIS systems in the open database that result from the shutdown of a vessels' AIS related to illegal unreported and unregulated fishing, which are commonly reported by NGOs. To address this problem, a system is being developed to use satellite imagery to detect such vessels and fishing activity (GFW, 2022b). Landed biomass from Illegal, Unreported and Unregulated (IUU) fishing practices was not taken into account when resource overlap was calculated and risk areas were identified in the Aegean Sea (Vlachopoulou et al., 2011). Maintenance of sustainable fishing is a topic of great interest in the Aegean Sea, and therefore should be added to future analyses of conflict areas (Göktürk & Deniz, 2017; Öztürk, 2015), although this remains impossible at present due to technical shortcomings. Potential underestimation of conflict areas, however, should not prevent development of management actions based on our findings.

Additionally, the presence and catch of artisanal fisheries, which make up around 50% of the catch nationwide, have not been included in this analysis because this information was not available (Keramidas et al., 2018). However, results of a recent study of the presence and catch of small-scale fisheries in the Dodecanese coincide with our findings of the presence and catch of commercial fisheries (Roditi & Vafidis, 2022). Furthermore, some purse seiner

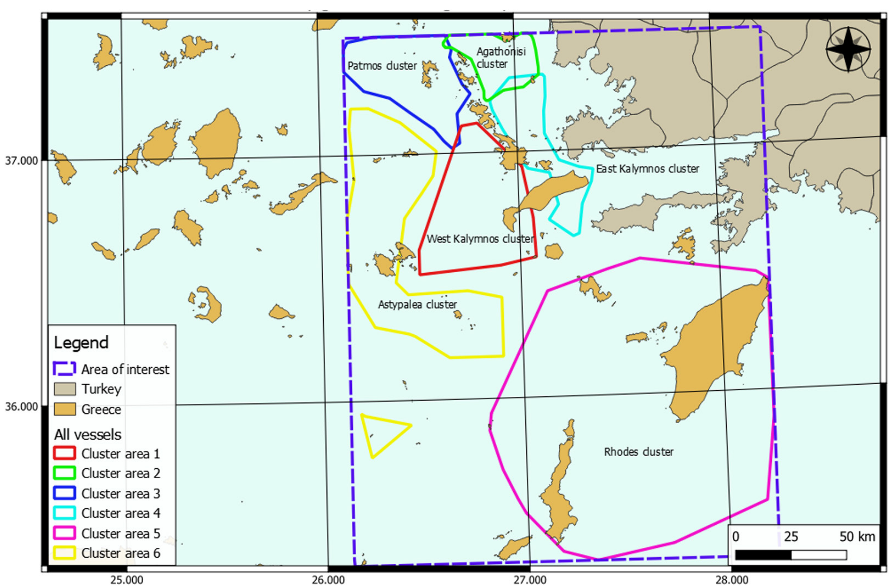


FIGURE 6 Clusters of commercial fishing effort after allocating 5000 randomly generated fishing efforts of all vessels in the Dodecanese region, Greece during 2013–2019. Trawlers were most present in Agathonisi and East Kalymnos. Drifting longlines were mostly found in Astypalea and purse seiners dominated the gear type of West Kalymnos and Patmos. Rhodes has mostly fishing vessels with unspecified gear. Most fishing efforts can be found in East Kalymnos and decrease, respectively, in Agathonisi, West Kalymnos, Patmos, Rhodes and Astypalea. (Coordinate system: GGRS'87)

TABLE 4 Characteristics and scores of the cluster areas of commercial fishing effort in the Dodecanese region of Greece during 2013–2019

Cluster area	Mostly operated gear	The five fish families with the highest resource overlap	Cluster area score
West Kalymnos	Purse seine gear	Sparidae, Merlucciidae, Clupeidae, Engraulidae, Unspecified	15.99686717
Agathonisi	Trawl gear	Merlucciidae, Sparidae, Unspecified, Mullidae, Gadidae	22.59899749
Patmos	Purse seine gear	Sparidae, Merlucciidae, Clupeidae, Engraulidae, Unspecified	15.79010025
East Kalymnos	Trawl gear	Merlucciidae, Sparidae, Unspecified, Mullidae, Gadidae	23.70488722
Rhodes	Fishing gear	Sparidae, Unspecified, Merlucciidae, Octopodidae, Mugilidae	19.01441103
Astypalea	Drifting longlines	Sparidae, Unspecified, Merlucciidae, Octopodidae, Mugilidae	18.18107769

Note: The five fish families that contribute most to the overlap between *Tursiops truncatus* and fisheries are listed from the highest contribution to the lowest. The corresponding gear mostly present in the cluster is given, in which "fishing" gear was operated by fishing vessels with an unknown gear type.

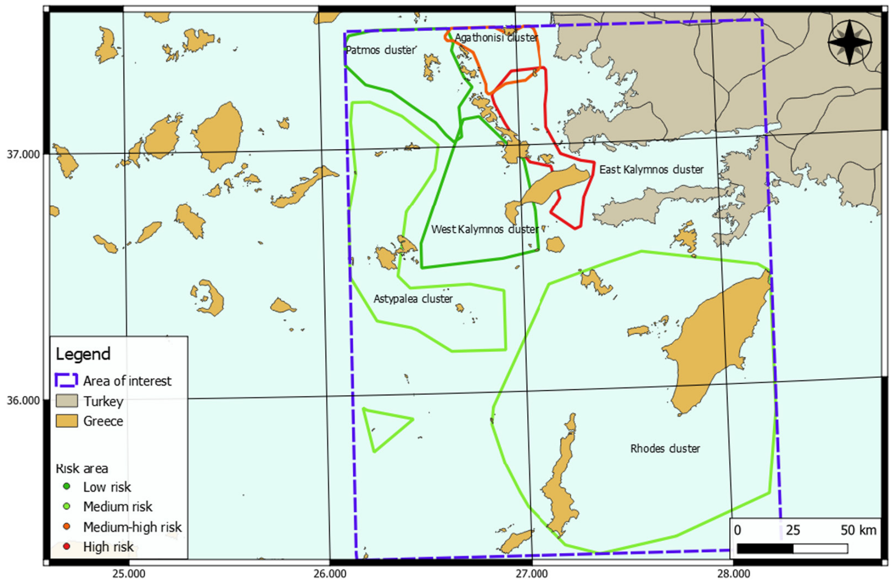


FIGURE 7 The risk of an arising conflict between fisheries and *Tursiops truncatus* in the different clusters in the Dodecanese region, Greece during 2013–2019. The high-risk area (East Kalymnos) has a score of 23.70488722, the medium high risk (Agathonisi) 22.59899749, the medium risk areas (Rhodes cluster and Asypalea cluster), respectively, 19.0144103 and 18.18107769 and the low-risk areas (clusters West Kalymnos and Patmos), respectively, 15.99686717 and 15.79010025. (Coordinate system: GGRS'87)

effort might have been filtered out in the analysis because the gear was operated static while the AIS only broadcasts changes in activity when vessels move (Min Mou et al., 2010; Tsagarakis et al., 2012). In contrast, other gears are operated or retrieved when the vessel moves (FAO, 2021a, 2021b, 2021c). However, few purse seiners are needed to catch a large amount of biomass caught by fisheries in total (Bearzi et al., 2010), so the number of purse seiners removed for lack of movement can be overlooked.

4.5 | Outlook

Despite study limitations, the method developed was able to identify areas where risk of conflict was highest in the Dodecanese in Greece, despite limited data on the exact abundance and distribution of *T. truncatus*, distributions of fish families and reported conflicts in the Aegean Sea or even the Eastern Mediterranean. A previous Aegean study suggested the need for studying risk areas based on the method presented herein (Giannoulaki et al., 2017). In the future, if more specific migratory behaviour and abiotic data are collected that could possibly influence the abundance of cetaceans and fish, identification of risk areas can be improved (Bearzi et al., 2008; Giannoulaki et al., 2017; Taylor et al., 2016). This method might also be useful for a conflict analysis between a lesser researched cetacean species and fisheries, such as the southern right whale (*Eubalaena australis*, Desmoulins, 1822) (Figueiredo et al., 2017; Zappes et al., 2013). Similarly, identification of risk areas for the endangered guitarfish with limited data enabled a valuable case study with wider management implementations and protection (Giovos et al., 2018). According to the precautionary principal Article 191(2) of the Treaty on the Functioning of the EU, the least scientific evidence should lead to full protection. If better information on migratory behaviour becomes available, our method can be modified to mitigate conflicts at certain times of year between fisheries and cetaceans (Goetz et al., 2014), which can lead to a partial economic loss or fisheries can target different species at that time of year (Zhou et al., 2015).

Additionally, information on the distribution and migratory behaviour of fish might have the beneficial side effect of discovering their spawning grounds, which can be incorporated into our method of addressing conflict areas, and thereby expanding the conflict analysis to a multi-dimensional analysis between fisheries-cetaceans-fish. Implementation of Marine Protected Areas (MPA's) in the area following results of our conflict analysis might reduce fisheries-cetacean conflicts because cetaceans mostly hunt in the MPA by following fish abundances, which will eventually spillover into areas not designed as no-take zones, therefore making them available for fisheries (Di Lorenzo et al., 2016).

Our method provides a valuable solution for collecting spatial data about high-risk areas, without the need for invasive methods of diet analysis of possibly endangered cetaceans and requires relatively few studies, thereby minimising time required for studies and the impact on the environment (Bearzi et al., 2010; Blanco et al., 2001; Giménez et al., 2017; Gladilina & Gol'din, 2014; Milani et al., 2019; Santos et al., 2007).

Our method can be applied elsewhere than only in the Aegean Sea. For example significant fishing occurs off the coast of Peru, but studies of conflicts with cetaceans are relatively recent and still restricted to the identification of conflicts, while offering possible solutions without a large ecosystem analysis (Campbell et al., 2020; García-Godos et al., 2013; GFW, 2021a; Mangel et al., 2013). Although community-based conservation efforts are made in Peru, government decisions are lacking (Alava et al., 2019). The use of an extended version of our conflict analysis method might be used to identify specific areas in need of protection for cetaceans.

5 | CONCLUSION

Risk areas identified in this study may be taken into consideration if new regulations are implemented to decrease conflicts and maintain a desired ecological condition of the sea. However, creation of new regulations could be difficult, risk areas change through time as a consequence of movement by both fisheries and *T. truncatus* (Appendix S4.1) For example some fisheries have already decreased the potential for arising conflicts by fishing in other areas to target different species (Pardalou & Tsikliras, 2018). The method used in our study can be used to explore conflict areas in special need of protection. Depending on the study area, the approach can be expanded to include more local information on fisheries, cetaceans and fish into a multidimensional conflict analysis that can be implemented regionally and globally. Information on these risk areas can also be used to educate fisheries. For example to validate riskiness of putative conflict areas, nature conservation institutes can evaluate assigned risk areas in practice.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the appendices of this article.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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