Journal of
Marine Science
and Engineering

MDPI

Article

Strengthening Angel Shark Conservation in the Northeastern Mediterranean Sea

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Citation: Giovos, I.; Katsada, D.; Spyridopoulou, R.N.A.; Poursanidis, D.; Doxa, A.; Katsanevakis, S.; Kleitou, P.; Oikonomou, V.; Minasidis, V.; Ozturk, A.A.; et al. Strengthening Angel Shark Conservation in the Northeastern Mediterranean Sea. *J. Mar. Sci. Eng.* **2022**, *10*, 269. https://doi.org/10.3390/jmse10020269

Academic Editor: Dariusz Kucharczyk

Received: 11 January 2022
Accepted: 8 February 2022
Published: 15 February 2022

Abstract: Angel sharks are among the most threatened species of sharks globally. Twenty-two species have been identified globally so far, with three species being present in the Mediterranean Sea: *Squatina aculeata*, *Squatina oculata*, and *Squatina squatina*. The Mediterranean populations of all three species have been assessed as Critically Endangered by the IUCN Red List of Threatened Species due to the steep decline of their populations as a result of their historical and current overexploitation by demersal fisheries. Therefore, currently there is an ongoing increasing effort for advancing the conservation of the species in the basin. Recently, in the context of the Regional Action Plan for Mediterranean Angel Sharks, the Aegean Sea and Crete have been identified as critical areas for all three species. This study provides the first predictive distribution map of the three angel shark species in the basin, while critical areas for the conservation of the species were identified through a systematic spatial conservation planning analysis. Our analysis revealed low overlapping between the existing MPA network and critical areas for the distribution of the species primarily in Greece and then Turkey, while 20% of the critical areas for the distribution of the species overlaps with Fisheries Restricted Areas of the region. This highlights the need for creating MPAs focusing on shark conservation within the Mediterranean that are currently completely absent. In addition, we provide policy recommendations that can secure better protection of angel sharks through the enforcement of the current legislations and the engagement of all relevant stakeholders.

Keywords: Squatinidae; elasmobranchs; chondrichthyans; Mediterranean; species distribution modeling; Spatial Prioritization Modeling

1. Introduction

Angel sharks are flat-bodied, bottom-dwelling sharks with broad pectoral fins, and dorsally located eyes and spiracles. Twenty-three species of angel sharks have been identified globally [1–3]. Their distribution ranges from temperate to tropical marine waters, while most species inhabit areas on the continental shelf and upper slopes down to 500 m [4]. Their life-cycle characteristics (i.e., slow growth and low reproductive rate) and demersal nature make them susceptible to large-mesh nets and trawl fisheries [5]. In part due to the intensification of fisheries and habitat loss, angel sharks have become one of the most threatened families of elasmobranchs in the world, with many species in urgent need of protection [5].

Direct fishing as target species, incidental capture, and illegal fisheries have caused severe population declines in many elasmobranch species [6,7]. The Mediterranean Sea is a hotspot of extinction risk for sharks and rays [5] and hosts three angel shark species, the sawback angel shark (*Squatina aculeata*), the smoothback angel shark (*Squatina oculata*), and the angel shark (*Squatina squatina*). The populations of all three species have been assessed as Critically Endangered by the IUCN Red List of Threatened Species [8–10], due to the steep decline of their populations throughout their range. This was the result of their historical and current overexploitation by demersal fisheries, especially trawl fishing, and habitat loss [11–14]. Regarding the northeastern part of the Mediterranean, all three species inhabiting the Mediterranean Sea are under protection by the Turkish Fisheries Law (https://www.resmigazete.gov.tr/eskiler/2018/04/20180419-7.htm, accessed on 1 September 2021) since 2018, while for Greece the species are listed as protected under the Council Regulation (EU) 2018/120.

All three species of angel sharks exist in the Aegean Sea [14–17]. These species used to be a popular and highly prized food source, sold under the common name of "Rina" (in Greece). Nowadays, fishmongers, retailers, and restaurant owners commonly sell products from *Dasyatis* spp., *Raja* spp., and other batoids, which are purposely mislabeled as "Rina" in order to increase their profits [14,16]. Currently, the angel shark populations in the Aegean are suspected to be extremely small because: (a) recent observations and reports have been scarce, (b) the species have almost no landings records in the Data Collection Framework reports 2005–2019, with only few exceptions, and (c) there are no reported angel shark landings in Greece in the official fisheries data by HELSTAT (1967–2017) [18]. The latter might be a result of the low resolution of landings, the absence of landing records from all fishing ports, as such data are collected only in a subset of landing sites, and the aggregation of many species of chondrichthyans in a few broad groups for reporting [19–21], given that angel sharks have been detected in the Greek fish markets [22]. Regarding the legal framework for the protection of the species from fishing activities in Greece, no provisions are foreseen on a national level, while on a European Union level it is prohibited for fishing vessels to fish for, to retain on board, to transship, or to land angel shark (*Squatina squatina*) in EU waters (Council Regulations (EU) 2019/124 and 2019/1241). In Turkey, a major threat identified for angel sharks is the bycatch of the species by commercial small scale fishers using gill nets, bottom-set long lines, handlines, and fixed bottom nets [23–25]. Therefore, the systematic use of such sporadic reports on the occurrences of these species are important since they provide critical information on their distribution, habitat, and reproductive biology, and may improve monitoring and conservation efforts [23]. All three species are under protection by the Turkish Fisheries Law since 2018.

Citizen science, social media reports, and local ecological knowledge have played a major role in collecting records of the three angel shark species [16,26]. Between 2013 and

2021, 16 individuals were recorded in the Aegean Greek national waters by such sources [27]. Of those, 15 were caught by fishers, out of which two were released alive, nine were landed, four were sold at fish market, while one record was of a stranded individual that washed up dead on a beach. This evidence triggered the investigation of the FAO Geographical SubAreas (GSAs) for the Mediterranean 22 (Aegean) and 23 (Crete), as potentially priority regions for the conservation of angel sharks in the basin [14] and prompted the development of the SubRegional Action Plan (SubRAP) for Geographical subareas (GSAs) 22/23 (Aegean Sea and Crete) [27]. The SubRAPs are a central part of the effective delivery of the Regional Action Plan for Mediterranean Angel Sharks [14], with the aim to facilitate further coordinated action specific to each region. Based on the SubRAP, the priority threats for angel sharks in this region includes the absence of species-specific landings, the misidentification of landings, Illegal, Unreported, and Unregulated (IUU) fishing, the negative effects from fishing gears, as well as the lack of knowledge regarding their habitat preference and the impacts of anthropogenic disturbances [14].

This work aims to contribute to the implementation of the SubRAP (Aegean Sea and Crete) through a systematic spatial conservation planning analysis which identifies critical areas for angel sharks in the Northeastern Mediterranean with an emphasis on GSAs 22 and 23. Based on the results of the analysis and the conservation and management measures currently being applied in the area, policy recommendations are suggested to secure better protection of angel sharks.

2. Materials and Methods

2.1. Study Area

The study area is located at the northeastern part of the Mediterranean basin, focused primarily on GSAs 22 and 23 (Figure 1), but records from GSAs 24 (Northern Levant Sea) and 28 (Marmara Sea) were also considered. The Aegean Sea is situated between the Greek peninsula and Turkey. With an approximate size of 215,000 km^2, it has an insular character with more than 1400 islands and islets, and a complex geomorphology, with a mixture of shallow shelves, deep basins, and troughs [28]. The Cretan Sea belongs to the southernmost part of the Aegean Sea; it has a size of 8300 km^2, and its depth reaches 2500 m [29]. These Mediterranean subregions presented high concentrations of endangered, threatened, or vulnerable species, as well as high habitat diversity [30]. However, the Aegean and Cretan Seas are heavily impacted by human activities and global stressors, among which historical and current overfishing is a major threat for biodiversity and ecosystem health [31,32].

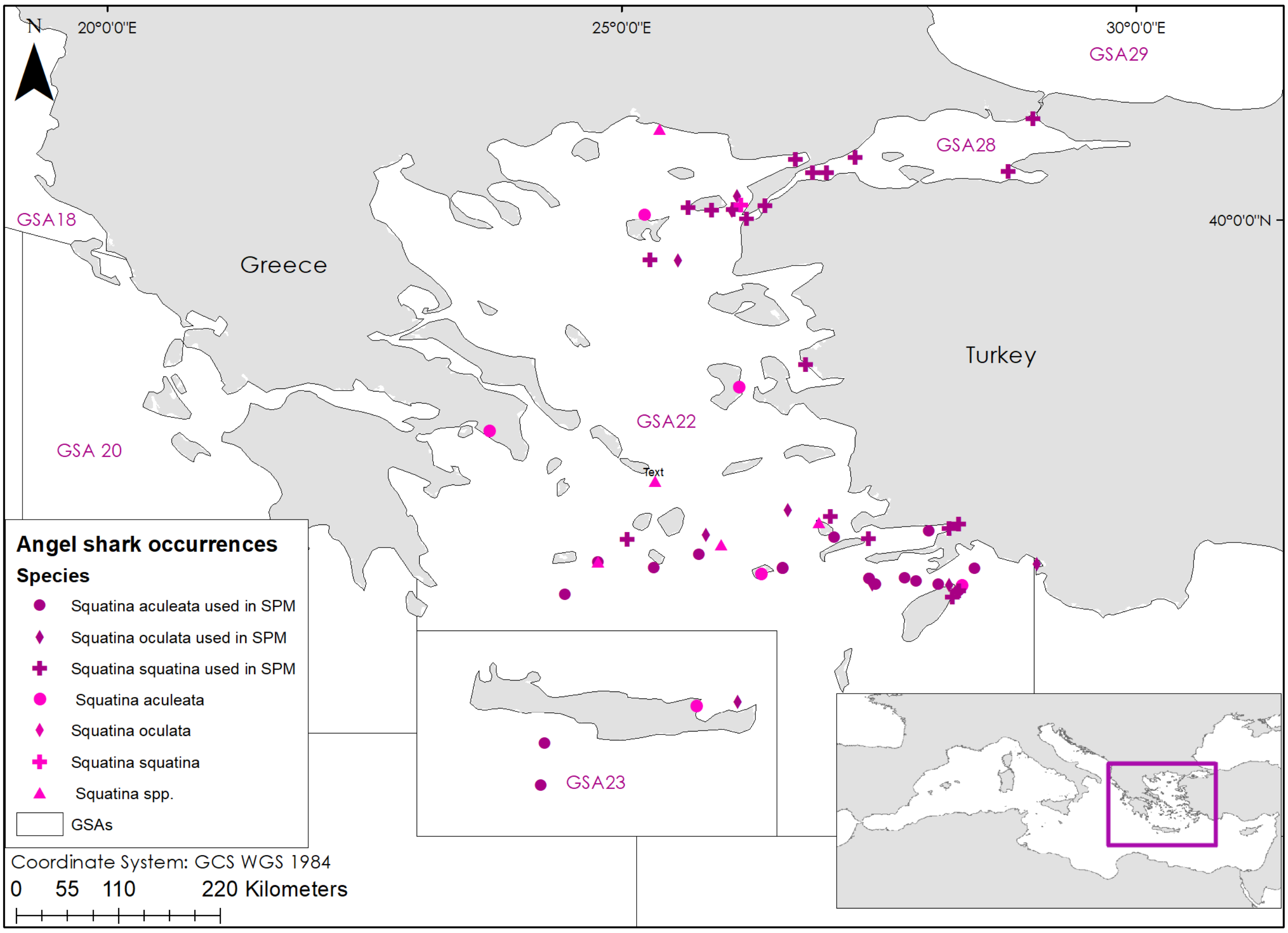

Figure 1. Observations of *Squatina* spp. in GSAs 22, 23, and 28 collected and used in the current study. In lighter blue are the records that were not used in the Spatial Prioritization Modeling (SPM) and dark blue the records of occurrences that were used in the SPM.

2.2. Data Sources

Information regarding observations of angel sharks in Greece are scarce. For this analysis, all available angel shark data were retrieved from the following sources: (i) the Angel Shark Sightings Map (ASSM) hosted by the Angel Shark Conservation Network (including all published literature therein), (ii) the M.E.C.O. (Mediterranean Elasmobranchs Citizen Observations) project, (iii) the MED.L.E.M. (Mediterranean Large Elasmobranchs Monitoring Program), (iv) the SharkPulse, a smartphone application developed to involve citizen scientists in monitoring global wild shark populations, (v) the iNaturalist, a social network of naturalists, citizen scientists, and biologists built on the concept of mapping and sharing observations of biodiversity across the globe, (vi) the ByElasmoCatch, monitoring elasmobranch fisheries in the North Aegean, (vii) the Global Biodiversity Information Facility (GBIF), and (viii) the Ocean Biodiversity Information System (OBIS). The ASSM was enriched with additional data identified in the scientific literature concerning records of the species. The EU Data Collection Framework (DCF) reports for the years 2005–2019 [33] were also reviewed to assess the possibility to detect angel shark hot-spot areas through fisheries. However, the data were aggregated for all three Greek GSAs (GSA 20-Eastern Ionian, 22-Aegean Sea, 23-Crete), and the effort was inconsistent between the years, with several years having no data due to the lack of the project implementation.

These sources were complemented by (i) a questionnaire survey exclusively targeting professional fishers from the southern Aegean and (ii) a call for angel shark observations in the social media channels of the Environmental Organisation iSea. The questionnaire used was based on Giovos et al. (2019) [16] (Appendix A, Table A1).

2.3. Species Distribution Modeling

Several approaches for species distribution modeling (SDM) are available, with varying data demands [34]. For the current study, MaxEnt was selected, since it is adequate for datasets with low species records, and spatial jackknife validation (n − 1) is possible [35,36]. The environmental data used were retrieved from the Bio-Oracle database v.2 [37] at 8 km pixel size. From the available dataset, the benthic dataset was used since angel sharks are benthic species; thus, variables describing surface conditions would be less relevant. The Bio-Oracle database is the only spatial dataset suitable for species distribution modeling that simultaneously includes surface and bottom (benthic) layers. No depth masking was applied to the data. The spThin R package [38] and an occurrence thinner radius of 8 km were used for the minimization of any effect of sampling bias [39]. The use of the USDM R package [40] was selected for the calculation of the variance inflation factor (VIF) for the set of selected predictors, based on their ecological relevance and in order to exclude the highly correlated variables from the set through a stepwise procedure (VIF values < 10) [41].

The Wallace R package [42] was used for modeling, allowing a fine-tuned MaxEnt algorithm [43] by using the ENMeval R package [36]. The "jackknife" non-spatial partition scheme of ENMeval was selected, since it uses all but one (n − 1) data points for training/validation until all data points have been used in validation [37]; this approach is the most suitable for small size samples [35,44]. ENMeval was used to evaluate models through the above partitioning scheme and to "fine-tune" two parameters of MaxEnt that affect model complexity and predictive power. These parameters are the regularization multiplier (RM) or beta values and the feature classes (FCs). The RM penalizes overly complex models, whereas the FCs are functions of the raw environmental data [45]. All FCs (L = Linear, Q = Quadratic, H = Hinge, P = Product) were selected and the RM was set between 1 and 5 with steps of 0.5, allowing for model complexity and model tuning. In summary, all predictor variable coefficients were shrunk progressively until some reached 0, and they were dropped out of the model. Only those variables with the greatest predictive contribution were kept in the final model. The model selection was based on the avg.test.AUC along with the lowest AICc, which was calculated for each model following the method by Warren and Seifert (2011) [46].

Spatial Prioritization Modeling

The prioritization modeling aimed to produce a spatial hierarchy of areas according to their conservation value. The conservation value of planning units (here grid cells—8 km pixel size) was estimated by evaluating the uniqueness of a cell in terms of angel shark species composition compared to the other cells. High valued cells should be considered first for conservation actions, since their degradation may lead to greatest biodiversity losses [47]. The priority index varies from 0 to 1, indicating the least and most important areas for conservation, respectively. The Zonation algorithm [48–50] was used to identify conservation priorities. The ranking was conducted based on the potential distribution of the three angel shark species (see previous section on SDMs). The top 10% (representing a surface area of 25,000 km^2) of conservation priorities were identified. The full priority ranking of the entire study area was also provided. The additive benefit function (ABF) algorithm was used, with equal weights to all species, according to which greater importance is assigned to cells that have high occurrence levels of all three considered species [51].

To investigate to which extent priority areas for angel sharks can be benefited by existing management measures applied in the area, the spatial distribution of officially designated marine protected areas (MPAs) and fisheries restricted areas (FRAs) within the study area [52] were also considered. With regards to the FRAs, only the areas where restrictions are imposed to fishing activities with gears able to catch angel sharks (i.e., otter bottom trawls (OTB), set gillnets (GNS), trammel nets (GTR), and combined gillnets and trammel nets (GTN)) on a permanent basis were taken into account. Possible priority areas for angel sharks that are located within MPAs and/or FRAs were identified for future conservation consideration. Finally, the corresponding overlap between the priority areas and the MPAs, as well as the overlap between the priority areas and the FRAs, were estimated to evaluate which part of the priority areas is already included in these existing area-based measures within the study area. All analyses and maps were conducted based on the World Geodetic System WGS84 as a reference coordinate system.

3. Results

3.1. Data Collection

The data collation from various sources resulted in 64 occurrence records of *Squatina* spp. from GSAs 22, 23, 24, and 28 (Table 1, Figure 1). From those, 26 were of *S. aculeata*, 10 of *S. oculata* and 23 of *S. squatina*, while for 5 records, identification was feasible only at a genus level. Overall, 71.88% (n = 46) of the records were obtained from published bibliography, 4.69% (n = 3) from ASSM, 14.06% (n = 9) from the M.E.C.O. database, 3.13% (n = 2) from the SharkPulse, and 6.25% (n = 4) from the call through social media (Table 1). No records were detected in the databases of the ByElasmoCatch Project, MEDLEM, iNaturalist, GBIF, and OBIS. Moreover, nine professional fishers completed the questionnaire by Giovos et al. (2019) [16], four of whom stated that they had seen an angel shark in the past but did not have photos or videos to prove it. Most of the fishers indicated that the species have almost disappeared from their fishing grounds. Finally, historical records and records with vague information (lack of coordinates) or absence of pictures, along with five angel shark records identified up to the genus level, were removed from the database as insufficient data, resulting in the final dataset (Table 1) consisting of a total of 49 occurrences: 20 of *S. aculeata*, 9 of *S. oculate*, and 20 of *S. squatina.*

Table 1. The total dataset of *Squatina* spp. occurrences records with the source and the year of sighting. Asterisk (*) indicates the records included in the Species Distribution Modeling (SDM).

N	Species	Year of Sighting	Type of Report
1	*Squatina aculeata*	2020	The M.E.C.O. Project
2 *	*Squatina aculeata*	2018	[16]
3 *	*Squatina aculeata*	2018	[16]
4	*Squatina aculeata*	2020	The M.E.C.O. Project
5 *	*Squatina aculeata*	2013	The M.E.C.O. Project
6 *	*Squatina aculeata*	2004	[53]
7 *	*Squatina aculeata*	2006	[53]
8 *	*Squatina aculeata*	2018	[16]
9 *	*Squatina aculeata*	2015–2016	[30]
10 *	*Squatina aculeata*	2015–2016	[30]
11 *	*Squatina aculeata*	2015–2016	[30]
12 *	*Squatina aculeata*	2015–2016	[30]
13 *	*Squatina aculeata*	2015–2016	[30]
14 *	*Squatina aculeata*	2015–2016	[30]
15 *	*Squatina aculeata*	2015–2016	[30]
16 *	*Squatina aculeata*	2015–2016	[30]
17 *	*Squatina aculeata*	2015–2016	[30]
18 *	*Squatina aculeata*	2005	[54]
19 *	*Squatina aculeata*	2015	[32]

20 *	*Squatina aculeata*	2015	[32]
21 *	*Squatina aculeata*	2016	[32]
22 *	*Squatina aculeata*	2020	[32]
23	*Squatina aculeata*	1979	The M.E.C.O. Project
24	*Squatina aculeata*	2020	Current project
25	*Squatina aculeata*	2020	Current project
26	*Squatina aculeata*	2019	The M.E.C.O. Project
27 *	*Squatina oculata*	1999	[55]
28 *	*Squatina oculata*	2015	The M.E.C.O. Project
29 *	*Squatina oculata*	2004	[53]
30 *	*Squatina oculata*	2020	ASSM
31 *	*Squatina oculata*	2015–2016	[30]
32 *	*Squatina oculata*	2015–2016	[30]
33 *	*Squatina oculata*	2015–2016	[30]
34 *	*Squatina oculata*	2015–2016	[30]
35 *	*Squatina oculata*	1997	[55]
36	*Squatina oculata*	2018	[23]
37	*Squatina* spp.	2018	[16]
38	*Squatina* spp.	2018	[16]
39	*Squatina* spp.	1983	The M.E.C.O. Project
40	*Squatina* spp.	2020	Current project
41	*Squatina* spp.	2019	Current project
42 *	*Squatina squatina*	2018	The M.E.C.O. Project
43 *	*Squatina squatina*	2020	Angel Shark Conservation Network
44 *	*Squatina squatina*	2017	SharkPulse
45 *	*Squatina squatina*	2015–2016	[30]
46 *	*Squatina squatina*	1997	[55]
47 *	*Squatina squatina*	2004–2005	[56]
48 *	*Squatina squatina*	1996	[55]
49 *	*Squatina squatina*	2020	ASSM
50 *	*Squatina squatina*	2013	[25]
51 *	*Squatina squatina*	2005–2008	[57]
52 *	*Squatina squatina*	2010–2014	[58]
53 *	*Squatina squatina*	2015	[25]
54 *	*Squatina squatina*	2018	[25]
55 *	*Squatina squatina*	2015	[25]
56 *	*Squatina squatina*	2018	[25]
57 *	*Squatina squatina*	2015	[25]
58 *	*Squatina squatina*	2000–2001	[59]
59 *	*Squatina squatina*	2015	[60]
60 *	*Squatina squatina*	2014	[25]
61 *	*Squatina squatina*	2012	[25]
62	*Squatina squatina*	2014	SharkPulse
63	*Squatina squatina*	2018	[23]
64	*Squatina squatina*	2020	The M.E.C.O Project

3.2. Species Distribution Modeling

From the initial set of 72 predictors [37] after the preselection based on ecological relevance [26,61] and the further analysis with the VIF test, we ended up with five predictors: (Supplementary 1 (S1) file). Table 2 summarizes the accuracy metrics of the model of each species based on the lowest delta. AICc along with the final number of occurrence points were used in the models. The tables with the models and the corresponding AIC values are provided in the Supplementary file 2 (S2). Response curves for each species for the selected predictors and variable importance metrics are provided in Supplementary file 3 (S3).

From the predictors used, primary productivity (min and range), minimum temperature, and depth had the most significant contribution to the models. However, the predictive power of each variable was different for each species: primary productivity and depth drove *S. squatina* predicted presence, minimum temperature and depth drove *S. aculeata* predicted presence, and primary productivity, depth, and minimum temperature drove *S. oculata* predicted presence. *Squatina squatina* and *S. oculata* have shown a widespread probability of occurrence in the coastal zone of the Aegean Sea, showing that they may reach depths of down to 700 m in the Cretan Sea (Figure 2). On the other hand, *S. aculeata* had higher probability of occurrence in the South Aegean Sea, with high values in the plateau of Cyclades and Dodecanese, along with the continental shelf of the Cretan Sea (Figure 2).

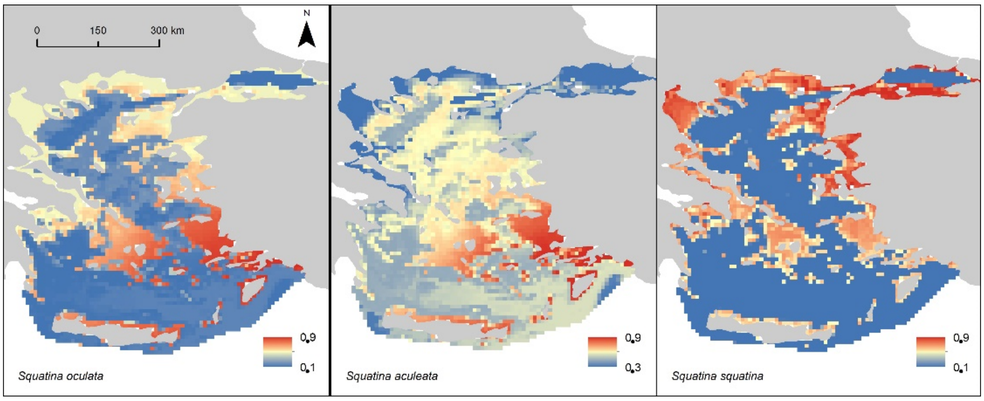

Figure 2. Habitat suitability maps for the three angel shark species in GSAs 22, 23, and 28, with red being areas that are highly suitable and blue unsuitable.

Table 2. Settings and accuracy metrics of the final models of the Species Distribution Modeling (SDM) in Wallace R package.

Species	Settings	Features	rm	Train.AUC	Avg.Test.AUC	Occurrence Points Used in the Model
Squatina aculeata	H_3.5	H	3.5	0.72	0.71	14
Squatina squatina	H_3.5	H	3.5	0.84	0.83	19
Squatina oculata	H_3.5	H	3.5	0.90	0.83	9

3.3. Spatial Prioritization Modeling

As shown by the performance curves of the prioritization, the proportion of angel shark species distributions within priority areas were increased according to the proportion of the total area that may be set under protection (Figure 3a). The top 10% priority areas ranged from 14% (for *S. aculeata*) to 21% of species distributions (for *S. squatina*) (Figure 3a,b) and top 30% priority areas could reach up to 50% of species distributions (Figure 3a).

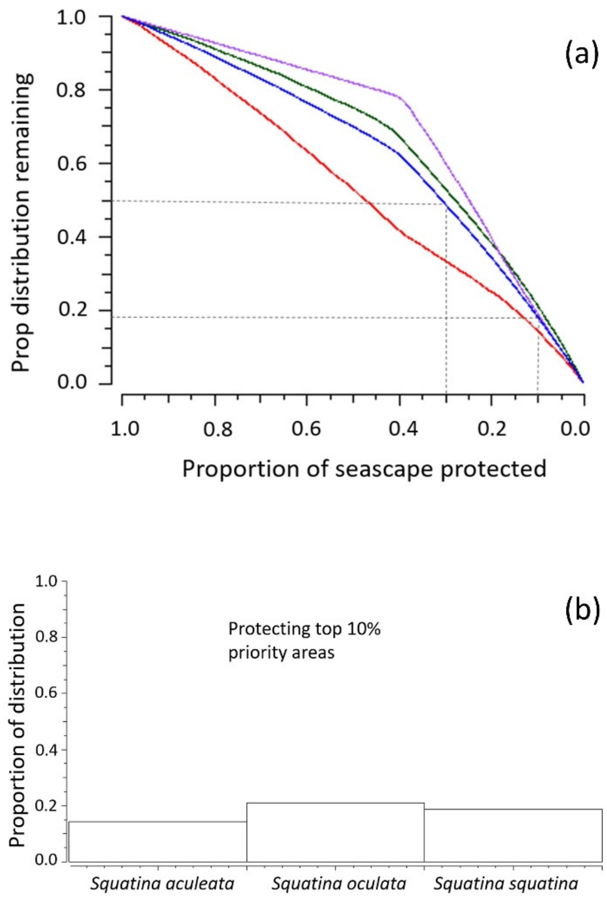

Figure 3. (**a**) The average proportion of species distributions remaining over the proportion of seascape under protection. In the red line, the lowest fraction among species and in the blue line, the average across all species. (**b**) The proportion of distribution (per species) included within the top 10% priority areas.

According to the spatial pattern of the *Squatina* species prioritization analysis (Figure 4a,b) and considering a conservative scenario, if measures were focused on the 10% of the study area, three priority areas seem to play a highly critical role for the three angel shark species monitoring and protection: (i) the Cyclades islands, (ii) the South Aegean coast of Turkey and the Dodecanese islands, and (iii) the northern part of Crete (Figure 4b).

If additional conservation efforts might be implemented (thus, considering 20% or 30% priority areas), other complementary important areas might be considered all along the Aegean coast of Turkey, the east of Samothraki Island, and around the coasts of Rhodes Island (Figure 4a).

Considering possible high priority areas that are located within existing MPAs, five MPAs that included the top 10% priority areas for *Squatina* species in the Aegean were identified (Figure 4b). Three MPAs were located in the south Aegean coast of Turkey (Datca-Bozburun, Fethiye-Gocek, and Gokova) and two along the west coast of Turkey (Foca and Dilek Peninsula). No overlap was observed with MPAs in Greece. The priority areas that overlap with MPAs covered a total surface area of 2516 km^2, representing ~10% of the identified priority areas. Some of the top 10 priority areas were also included inside FRAs of the Aegean Sea (Figure 4b). These areas were mainly located along the northern coasts of Crete, around the Cyclades islands, around the Dodecanese islands, and the west coasts of Chios. Overall, the priority areas that overlap with FRAs in the Aegean Sea covered 5176 km^2, corresponding to 20% of the identified priority areas.

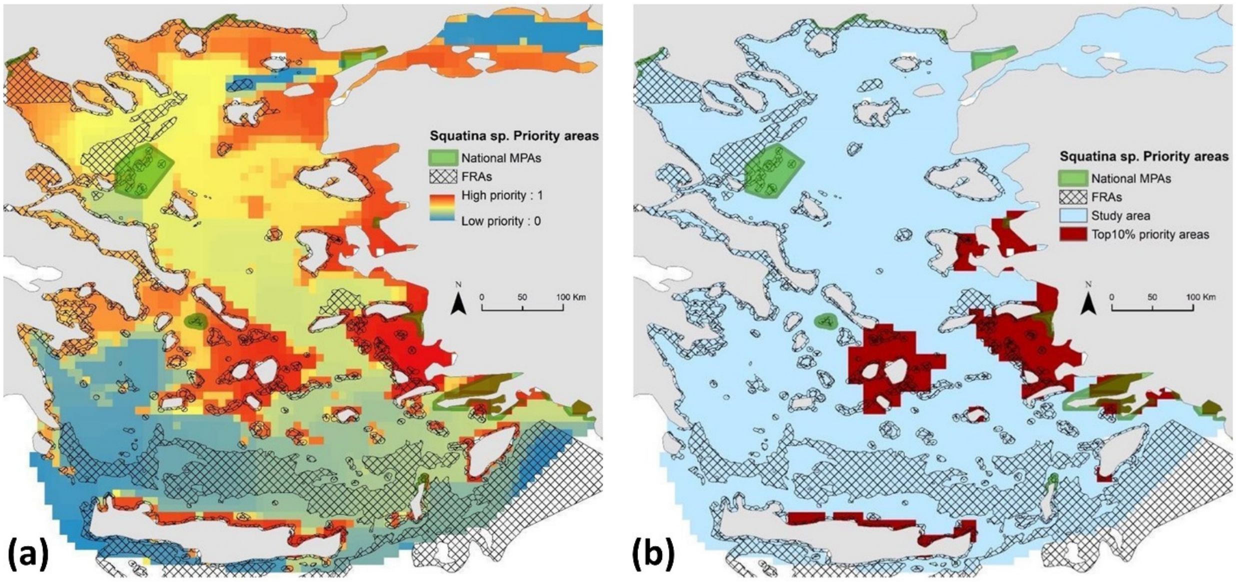

Figure 4. The prioritization scheme based on the three Squatina species. (**a**) Priority Ranking varies from 0 to 1, with high priority areas indicated in red and low priority areas in blue. (**b**) The top 10% priority areas (i.e., having ≥0.9 priority ranking value) are indicated in red and correspond to high priority areas for species monitoring and protection. All analyses and maps were conducted based on the World Geodetic System WGS84 as a reference coordinate system.

4. Discussion

Species Distributions

The recent increase of research effort in the Mediterranean basin revealed several new records of all three Mediterranean angel shark species to help identify critical areas for their population e.g., Aegean Sea [14,16,17,27], Corsica [62], Croatia [63,64], Libya [14,65], and Sicily [16,66]. However, angel sharks are most commonly observed dead in markets, and these animals were released [16] or observed alive only on a few occasions. Angel sharks are currently protected in the Mediterranean both through the GFCM (Recommendation GFCM 42/2018/2)) and the EU Regulation (EU) 2015/2102 due to their inclusion in Annex II to the Protocol concerning Specially Protected Areas and biological diversity in the Mediterranean ("Protocol to the Barcelona Convention"). Moreover, *S. squatina* was listed on Appendices I and II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS) in 2017 and included in Annex 1 of the CMS Memorandum of Understanding on the Conservation of Migratory Sharks (CMS Sharks MOU) in 2018. In addition to the legislation mentioned above, the Action Plan for the Conservation of Cartilaginous Fishes (Chondrichthyans) in the Mediterranean Sea [67] provide a framework for species conservation and habitat protection. Despite the existence of legislation and action plans, the Mediterranean has been identified as a hotspot of elasmobranch mortality globally [5], while the compliance with relevant regulations is low throughout the basin [68,69], including within Greece [20,21].

In this work, we focused on the Northeastern Mediterranean, following the recommendation of the SubRAP and especially of the Goal 2 "Angel shark habitat is identified and protected", Objective 2.1 and 2.3 ("Angel shark distribution is better understood" and "Angel shark habitat is identified, specifically Critical Angel Shark Areas (CASAs)". This study provides the first predictive distribution map of the three angel shark species in the region and critical areas for the conservation of the species were identified. It is important to mention that due to the low number of observations, it is possible that other CASAs might exist in the study area, and for this reason, more effort should be put into monitoring angel sharks in the region. Since this is the first attempt to model the probability of occurrence of the angel shark species in the Aegean Sea and the near areas, some issues have been identified during the modeling process. For example, the number of occurrence points from the field surveys and the literature were too small to allow a robust modeling approach to be conducted. However, those identified by the current work could be used as a baseline understanding to inform future conservation and guide targeted research, aiming to protect the three angel shark species in the Aegean Sea. The 8 km pixel size of the predictors used in the current study provided the first view of the probability of occurrence of the three angel shark species. This information will enable focused research on priority areas and a better insight into the habitat of angel sharks. The main drivers of distribution for angel sharks in the southern Aegean are primary productivity (min and range) and minimum temperature and depth. These variables have also been confirmed to influence the distribution of angel sharks in other areas, such as the Canary Islands [26,70]. However, there seems to be a difference between the occurrence and the drivers of distribution of the three species in the area. *S. squatina* seems to have a higher probability of occurrence in the northern part of the area, while the other two species (*S. aculeata* and *S. oculata*) show a preference towards the southern areas. The limited dataset does not allow to draw mature conclusions on these differences; however, considerations should be taken for any species-specific conservation actions as well as species identification.

These results can also be used to foster synergies and collaborations within the fisheries sector on a broad scale. In the future it will be critical to establish a systematic collection of occurrence data by Citizen Science initiatives targeting an enriched dataset that will allow the improvement of any modeling work, and therefore, improve the robustness of data to inform the conservation of the three species.

5. Conclusions

It was not feasible to fully map the nature of interactions between fisheries and angel shark (bycatch and trade), but it was evident that fishers were, to a large extent, aware that these species are protected. This is of high importance for prioritizing conservation actions that will improve the management of the species. From these qualitative results, it is clear that work needs to be done with the local communities for minimizing the impact of fisheries in the angel shark populations of the Aegean Sea and the near GSAs (i.e., capacity building workshops for identifying, reporting, establishing good practices, ensuring safe handling and release techniques of angel sharks, etc.).

A low-level overlap between the existing MPAs and the indicated CASAs was identified. Area-based approaches, such as MPAs, can advance the conservation of biodiversity [71]. Oftentimes, meso predators, such as angel sharks, have been used as indicators for defining new MPAs (e.g., [72,73]). However, MPAs designated for elasmobranchs are largely absent from the Mediterranean and other European seas, despite the existence of relevant tools, such as the Action Plan for the conservation and management of elasmobranchs and the Specially Protected Areas of Mediterranean Importance (SPAMIs) [74]. This should be taken into consideration from policy makers and conservationists who could add pressure to Mediterranean states in order to use such tools that can substantially improve the conservation of elasmobranchs in the Basin.

The new EU Biodiversity Strategy for 2030 has set ambitious goals for expanding the European network of MPAs to 30% of the seas (with at least one third of protected areas being strictly protected). This will offer an outstanding chance for the effective conservation of the Critically Endangered angel sharks and many other threatened marine species, provided they will be included among the target species for conservation. To achieve this, a systematic conservation planning approach for the enlargement of the network of MPAs in the region is of utmost importance [75], as it provides a transparent and comprehensive framework for prioritization of biodiversity conservation areas [76], properly accounting for trade-offs between biodiversity conservation and economically important sectors [77].

A very limited number of marine species have been prioritized in the Habitats Directive, which (together with the Birds Directive) drives the selection of Natura 2000 sites (the European network of protected areas). Hence, there is a need to streamline the Habitats Directive with the IUCN Red List and other international and regional conventions, such as the Barcelona Convention in the Mediterranean Sea [75], and thus, include angel sharks and other threatened elasmobranchs as target species for conservation. The IUCN Red List provides the most comprehensive global assessments of species extinction risk [78] and should be central to setting conservation priorities [75].

Finally, based on the findings and insights from the current study, recommendations are provided in Table 3 for Greece and Turkey to improve angel shark conservation in the Aegean Sea.

Table 3. Recommended actions for the protection and conservation of angel sharks in the Aegean Sea, adjusted to the context of each country.

	Actions to Secure the Conservation of Angel Sharks in the Aegean Sea
Greece	• Strengthen the enforcement of Regulation (EU) 2015/2102 and Recommendation GFCM/42/2018/2. • Engage the national data collection framework (DCF) to improve angel shark data availability and quality. • Strengthen citizen science networks, to provide more angel shark records and confidently identify between the three species, to complement the national monitoring systems. • Communicate the conclusions of the "Strengthening Angel Shark Conservation in the Southern Aegean Sea" Project to competent authorities and policy makers to inform them of angel shark conservation status, research, and proposed recommendations. • Improve species identification through dedicated training of the monitoring, control, and enforcement authorities. • Minimize illegal fishing and selling of angel sharks through awareness raising and collaboration with the fishing communities. • Raise public and consumer awareness of angel shark conservation status.
Turkey	• Strengthen the enforcement of Fisheries Law (No: 1380) prohibiting targeting and retention of all three angel shark species. • Strengthen the enforcement of Recommendation GFCM/42/2018/2. • Elaborate and implement a national action plan for angel sharks following the SubRegional Action Plan (SubRAP) GSAs 22/23 and National Action Plan for the conservation of cartilaginous fishes (Öztürk 2018) • Establishment of the national data collection framework to improve angel shark data availability and quality. • Strengthen citizen science networks, for providing more angel shark records and confidently identify between the three species, to complement the national monitoring systems. • Raise public awareness of angel shark conservation status.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/article/10.3390/jmse10020269/s1, S1: VIFanalysis; S2: Squatina_Evaluation_Table; S3: Response curves and Var Importance.

Author Contributions: Conceptualization, I.G.; methodology, I.G., R.N.A.S., D.K., D.P. (Dimitrios Poursanidis) and A.D.; software, D.P. (Dimitrios Poursanidis) and A.D.; validation, I.G., R.N.A.S., D.K. and S.K., formal analysis, I.G., R.N.A.S., D.K., D.P. (Dimitrios Poursanidis), A.D. and D.P. (Dimitra Petza); investigation I.G., R.N.A.S., D.K. and V.M.; resources, I.G.; data curation, R.N.A.S. and D.K.; writing—original draft preparation, I.G. and D.K.; writing—review and editing, all authors; visualization, I.G., R.N.A.S., D.P. (Dimitra Petza) and A.D.; supervision, A.R.H., E.K.M.M., J.B. and D.J.-A. project administration, I.G. and D.K. funding acquisition, I.G. All authors have read and agreed to the published version of the manuscript.

Funding: The research was funded by the Shark Conservation Fund; data collection was additionally funded by the Save Our Seas Foundation. The publication of the research is part of the project "Know-Participate-Protect the Environment", which is being implemented under the Active citizens fund in Greece by iSea and its partner Green Tank. The Fund Operator for the Active citizens fund in Greece is the Bodossaki Foundation in consortium with SolidarityNow.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data can be found upon request in info@isea.com.gr.

Acknowledgments: We would like to thank all fishers for reporting their findings to the project.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Questionnaire used in the context of the study.

Title: Survey on the Presence of Angel Sharks in Greece
1. Have you ever noticed any angel sharks in your area? • Yes • No
2. Observation area (e.g., Trani Ammouda, Sithonia, Halkidiki) • Open answer
3. Coordinates (optional) • Open answer
4. Observation depth (in meters) • Open answer
5. Distance from the shore (in meters) • Open answer
6. Number of individuals • 1 • 2 • 3 • 4 • 5<
7. Estimate size in centimeters (for more than one individual, please separate sizes with a comma) • Open answer
8. Substrate type • Sandy bottom • Muddy bottom • Seagrass meadows • Underwater caves and rocky bottoms • Other
9. How was the observation made? (coastal fishing, scuba diving, swimming, etc.) • Open answer
10. Do you have a photo or video from your observation? • Yes • No

11. If yes, indicate the link from the available media (YouTube video, uploaded image, etc.)
    - Open answer
12. Do you often see angel sharks in your area?
    - Yes
    - No
13. Area of residence
    - Open answer
14. Do you know anyone in your area who has seen angel sharks?
    - Yes
    - No
15. Could you bring us in touch with them?
    - Yes
    - No
16. Do you know if there used to be angelic sharks in your area? If so, in which areas?
    - Open answer

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