



Occurrence and impact of interactions between small-scale fisheries and predators, with focus on Mediterranean monk seals (*Monachus monachus* Hermann 1779), around Lipsi Island complex, Aegean Sea, Greece



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ARTICLE INFO

Article history:

Received 20 February 2016

Received in revised form 18 October 2016

Accepted 22 October 2016

Handled by Dr. B Arara

Available online 9 November 2016

Keywords:

Small-scale fisheries

Marine mammals

Mediterranean monk seal

Fisheries management

Greece

ABSTRACT

Antagonistic interaction between Mediterranean marine mammals, including the endangered monk seal (*Monachus monachus*), and small-scale fisheries is a growing problem in the Aegean Sea. Effective management measures are needed to ensure both the survival of the monk seal population, and its coexistence with the small-scale fisheries. In this study, data from 371 fishing journeys by 8 different boats was collected between March and November 2014. Evidence of depredation by monk seals was recorded in 19.1% of fishing journeys, by cetaceans in 5%, and by other predators in 16.5%. Analysis of landings data showed that gear and depth were the variables most likely to influence the occurrence of depredation. There was a significant decrease in the catch per unit effort (CPUE) of four of the nine targeted fish species when depredation by monk seals occurred. The total cost of monk seal depredation was estimated to be 21.33% of the mean annual income of fishermen in the Aegean Sea. We discuss how the implementation of marine protected areas and the use of specific fishing gear could reduce the frequency of interactions, and thus mitigate the loss experienced by the fisheries as well as contribute to the conservation of an endangered species.

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1. Introduction

The interaction between marine animals (e.g. marine mammals, sharks, turtles) and fisheries is a common occurrence in many parts of the world. It can often be antagonistic in nature (Read, 2008) and it has intensified as commercial fishing activities have increased (Northridge and Hofman, 1999; Read, 2008). Multiple studies have demonstrated the impact of interactions between fisheries and marine mammals, for example bottlenose dolphins (*Tursiops truncatus*) in Italy and Spain (e.g. Díaz López, 2006; Lauriano et al., 2004; Pennino et al., 2015; Rendell et al., 2008), grey seals in Ireland (Cosgrove et al., 2013) and monk seals in Turkey and Maderia (Güçlüsoy, 2008; Hale et al., 2011). Interactions are a problem for fisheries because they result in loss of catch and damage to fishing gear (Moore, 2003; Lauriano et al., 2004). The marine mammals can

experience injury or mortality as a result of being tangled in fishing gear and also suffer from competition for resources with the fisheries. Indeed, one of the principal reasons that interactions occur is the decrease in food availability as a result of localized overfishing pressures (Moore, 2003). The interactions therefore represent a serious conservation issue for marine species and for the sustainability of artisanal fisheries.

Artisanal fisheries play a significant role in providing a source of food for hundreds of millions of people worldwide, thus contributing to poverty reduction and to the sustainable development of many areas of the world, including Europe, Asia and Central America (FAO, 2011; Chuenpagdee and Pauly, 2008). Given the importance of such fisheries, their sustainability is a high priority (Johnson et al., 2013) especially since the growth in fisheries in the developing world now outpaces growth in agriculture (Garcia and Rosenberg, 2010). In the European Union, Greek fisheries have the highest number of professional licenses (European Commission, 2001). Greek small-scale fisheries are of strong cultural and socio-economic importance to local communities (Fabio and Hazin, 2005). Preservation of artisanal fisheries is also impor-

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tant because, compared to the industrial fisheries, they tend to be more selective in the species that are caught, use less destructive fishing gear, take less by-catch, and use less fuel (Fabio and Hazin, 2005). Losses in artisanal fisheries as a result of interactions with marine mammals could threaten the economic viability of the fisheries in the area.

As well as the detrimental impact on the fisheries, interactions are of conservation concern for marine mammal species in the region. The Aegean Sea is an important habitat for several dolphin species (Güçlüsoy et al., 2004b; Öztürk et al., 2008) and also supports the largest subpopulation (250–350 individuals that represents 35–50% of the total population) of Mediterranean monk seals (*Monachus monachus*), (Güçlüsoy et al., 2004a,b; Hellenic Society for the Study & Protection of the monk seal (Mom), 2007), the most endangered pinniped in the world (International Union for Conservation of Nature [IUCN], 2007). Monk seals are opportunistic predators (Jacobs and Panou, 1988; Boutiba and Abdelghani, 1997) and data from captive monk seals indicate that they consume 5 to 10% of their total body weight (240–400kg) per day (Jacobs and Panou, 1988; Scoullos et al., 1994; Caltagirone, 1995). They consume a wide variety of prey primarily from shallow water habitats (Sergeant et al. 1978), including fish such as red mullet (*Mullus sp.*), sea bream (Sparidae), bogue (*Boops boops*), mullets (*Mugilidae*), and octopus (Octopodidae) (Sergeant et al., 1978) all of which are important commercial species in the Aegean.

Monk seals can become entangled in a variety of fishing gear including set-nets, purse seiners (Kıraç and Savas, 1996) and they are most vulnerable to static gear and abandoned nets (Panou et al., 1993; Kıraç and Savas, 1996; Tudela 2004). They also suffer from the depletion of fish stocks as a result of overfishing, habitat degradation and the seal deterrent practices that are used to protect aquaculture facilities (Westerberg, 2010). The economic loss suffered by the fishermen as a result of the marine mammal interactions causes hostility against the seals and has led to deliberate killings by the fishermen (Johnson and Lavigne 1999; Güçlüsoy et al., 2004a; Johnson 2004).

In order to mitigate the existing problems, data is required about the factors that play an important role in the interaction between seals and fisheries and the impact on the fishery. This data can then be used to develop effective management plans such as the plan of action for marine mammals in UNEP/MAP (Anonymous, 1998). The objectives of this study were: i) to assess the influence of fishing practices on the occurrence of interactions with monk seals, ii) to evaluate how catch per unit effort (CPUE) of importance fish species is impacted by interactions, iii) to calculate the economic loss to the fishery as a result of interactions and, iv) to map the location of the monk seal-fishery interactions in order to determine the areas with the most interactions.

2. Methods

2.1. Study area

The study took place between 1st of March and 30th of November 2014 on the Dodecanese island of Lipsi (Fig. 1) and their islets (37°18'N 26°45'E). These are situated in the Southeast region of the Aegean Sea, 40 km off the coast of Turkey, between the islands of Leros, Patmos and Arki. The region around Lipsi island was divided into sections arbitrarily (N, S, E, W, SW, NW, SE, NE) (Fig. 1).

During the time of the study the Lipsi fishing fleet comprised of 29 boats bearing professional fishing licenses, out of which 15 operated full time, and the remaining 14 operated seasonally or were inactive. We categorized the level of dependence on small scale fisheries by the fishermen by following Tzanatos et al. (2006). Thus

the full time fishermen were classed as “high dependence”, spending an average of 229 days fishing. The seasonal/inactive fishermen spent in the range of 145–195 days fishing and were therefore categorized as “partially dependent” or “non-dependent”. All fishermen involved in this study were in the ‘high dependence’ category. The fishermen fished in depths between 2–100 m, with a preferred depth of 10–20 m. Boat size varied between 5.80 m–12.80 m with engine power of 15–70 hp. The characteristics of the gear used by the fishermen are summarized in Table S1.

2.2. Data collection

Data was collected by Archipelagos Institute of Marine Conservation researchers on a daily basis throughout the fishing period between March and November 2014. A total of eight fishermen on eight separate boats took part in the study. Researchers recorded all data while speaking with the fishermen after the boats had landed in the harbour. Two different surveys were done depending on the collaboration level of the fishermen. In survey one; data was collected about gear characteristics, fishing location, depth, habitat, duration of activity, gear-fauna interaction from four fishermen. These fishermen also allowed the researchers to measure the individual fish in the catch. In survey two; the remaining four fishermen provided the same information, except they only provided total weight per species instead of size of landed species.

Information that we collected about gear-fauna interaction included the presence/absence of interaction, the animal involved in the interaction (monk seal, cetacean or other), type of damage (net damage, catch damage or both), gear, location (indicated by the fishermen on a map), depth (between 2–100m), habitat (sea-grass, rock, heterogeneous and sand) and time of the interaction. Previous research has illustrated the characteristic monk seal three-hole net damage pattern, with one large hole (20–30 cm diameter) caused by the mouth and two smaller holes caused by the fins holding the net (Karavellas 1994; Berkes et al., 1979). In contrast cetacean net damage pattern comprises of large irregular shaped tears (Öztürk and Dede, 1995) of approximately 1–2 m in diameter. We thus identified the animal involved in the interaction by inspecting the holes in the nets to look for the distinctive damage patterns and by asking for confirmation from the fishermen. Any damage to nets that did not result from monk seal or cetacean depredation was classified as ‘other’. Catch damage was recorded when there were obvious bite marks on fish in the net. The specific predator of the net damage was identified from the nature of the net damage. We only recorded presence or absence of catch damage, not the proportion of fish that were damaged or undamaged. This is because we did not have the permission of the fishermen to record more detail in the time available. Fishermen who took part in survey two in particular only allowed us to record the total weight of the catch per fish species. In addition, in many cases of monk seal depredation, catch was lost and only a small number of fish remained in the nets. In these cases a measure of proportion of damaged fish would not have been reliable. Any depredation that resulted in damage to catch, but not damage to nets was classified as depredation by ‘other’ predators, since the predator was small enough to enter the net without causing net damage. For clarity, we refer to any interaction with a predator as ‘depredation’ and we identify damage resulting from the depredation as ‘net damage’ or ‘catch damage’.

2.3. Data analysis

The occurrence of depredation was modeled using a binomial generalized linear model (GLM) with presence or absence of depredation by any species as the outcome. The predictors that were included were: geographic area (N, S, E, W, SW, NW, SE, NE) (Fig. 1), habitat type (Posidonia, rock, sand, heterogeneous), gear type (gill

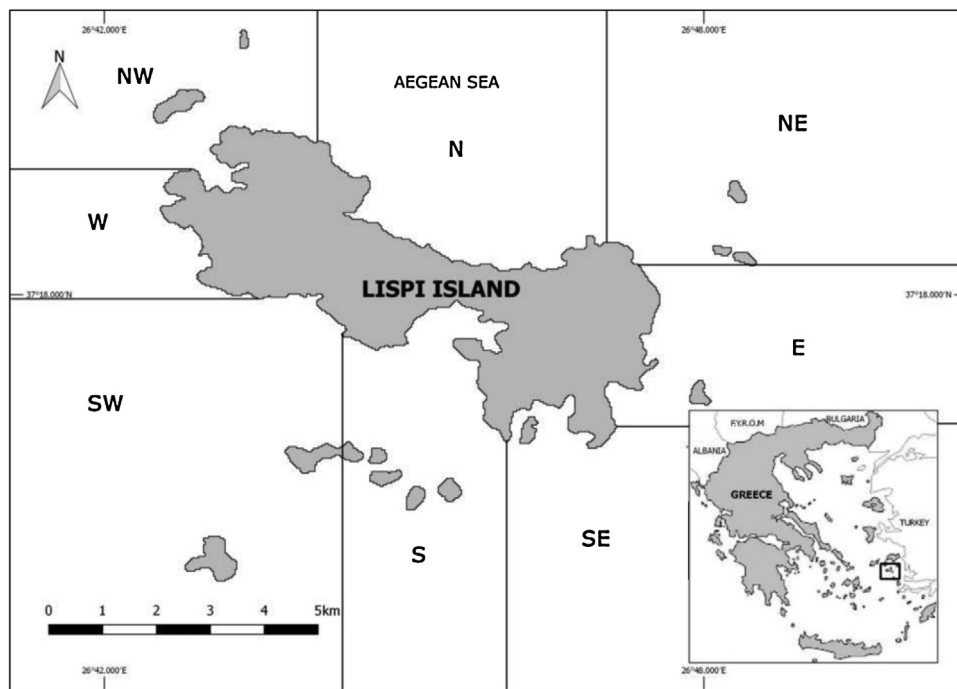


Fig. 1. Map of Lipsi Island, Greece showing how the study area was divided into geographic areas.

net, trammel net, gill-trammel net, longline), season (spring, summer, autumn) and depth a continuous predictor (average depth of every fishing operation). We also used a binomial GLM to specifically model depredation by monk seals. In this model the outcome was the presence of monk seal depredation compared to the presence of depredation by all other predators. The predictors that were included were: geographic area, habitat, gear, season, depth and type of damage (gear, catch, both) as predictors. All possible combinations of models were fitted using R (Fox, 2002; R Development Core Team, 2010) and the Akaike Information Criterion (AIC), (Akaike, 1974) scores were used to assess the relative quality of all the models.

In order to estimate the loss of catch after monk seal depredation we calculated CPUE as kilograms landed per day per boat from the four fishermen that took part in survey one. Fish standard length (cm) was converted into weight (kg) using the equation $W = aL^b$ where a and b are parameters based on length-weight ratio (LWR) estimations for every species (Froese et al., 2013). To examine the effect of catch composition, the CPUE of the nine most commonly caught species, that represent 67.7% of the total catch (*Sparisoma cretense*, *Siganus luridus*, *Oblada melanura*, *Scorpaena scrofa*, *Sepia officinalis*, *Dentex dentex*, *Pagellus erythrinus*, *Belone belone* and *Octopus vulgaris*), was calculated and a t -test used to compare CPUE when monk seal depredation occurred with CPUE when no depredation occurred. Using the Bonferroni correction to account for multiple tests we adjusted significance to $p < 0.006$ to indicate a difference between depredation or no depredation (Haccou and Meelis, 1995).

2.4. Economic impact

We used the economic data from survey one to estimate the economic loss resulting from damaged nets and catch loss. In addition, we recorded data in order to assess the economic loss caused by net damage and catch damage. The data collected included: the cost of the petrol per liter, petrol used per hour, distance travelled per hour, time taken to repair damaged nets, cost of repairing the nets, average number of holes per year caused by cetacean and

monk seal damage (based on the hole pattern and size), price of repair cord per kg, and the cost of purchasing new gear. The price of fish species (tourist price and local price) was also noted.

2.5. Geographic pressure

In order to determine the areas where fishing pressure and where interactions between fisheries and monk seals were greatest, we mapped the data provided by the 8 fishermen about fishing location and depth and we then added the locations in which the interactions with monk seals occurred. The map was created in ArcMap 10.1 (ESRI, Redlands, CA, USA) using the Kernel density estimation (Okabe et al., 2009) (output cell size $3e-005$). We defined fishing pressure as low when there was one trip to a location, 'medium' when there was between one and four trips to a location and 'high' when there was more than four trips to a location. We used the same classification (number of interactions) to map low, medium and high numbers of interactions with monk seals. In addition we created an overlapping map to show the locations where fishing pressure and monk seal interactions were greatest. To do this we created the following categories: no interaction: fishing without seal interaction; low: low medium or high fishing pressure and low seal interaction; low/medium: low fishing pressure and medium seal interaction; medium: medium fishing pressure and medium seal interaction; medium/high: medium fishing pressure and high seal interaction or high fishing pressure and medium seal interaction; low/high: low fishing pressure and high seal interaction; High: high fishing pressure and high seal interaction. We also calculated the total area in km^2 where fishing took place and where interactions occurred.

3. Results

Data was recorded from a total of 371 fishing journeys, by eight different fish vessels. The four fishing vessels involved in survey one provided detailed information about 170 journeys, while the four fishing vessels in survey two provided all information except catch measurements from a total of 201 journeys. Evidence of interac-

Table 1
GLM model of risk factors associated with presence or absence of damage to fishing gear caused by predators around Lipsi Island, Greece.

	Estimate	Std. Error	z value	Pr (> z)
(Intercept)	0.264	0.372	0.708	0.4792
Gear [T. Gill and Trammel]	0.882	0.414	2.130	0.0331 *
Gear [T. Trammel]	−0.204	0.357	−0.572	0.5672
Gear [T. Longline]	1.005	0.568	1.769	0.0770 .
Average Depth	−0.011	0.006	−1.750	0.0801 .
Season [T. Spring]	−0.044	0.359	−0.122	0.9025
Season [T. Summer]	−0.594	0.328	−1.812	0.0699 .

Signif. codes: ‘***’ 0.05 ‘.’ 0.1.

tion with predators occurred on 153 (41.2%) fishing journeys. Monk seal depredation was recorded on 71 occasions (19.1%) of all fishing journeys, cetacean depredation on 18 occasions (5.0%) and depredation by other species on 64 occasions (17.2%). On 14 occasions (3.7%) the depredation resulted from a combination of monks seal and other predators; monk seal and cetacean depredation never occurred at the same time. Of all depredation, damage to nets and damage to catch (obvious bite marks) occurred simultaneously on 67 occasions (44.0%), damage to nets only without obvious catch damage on 76 occasions (50.0%) and damage to catch only on 9 occasions (6.0%). Depredation by monk seals or cetaceans always resulted in net damage. Damage to catch, without damage to nets resulted from the impact of predators that were small enough to enter the nets.

3.1. GLM analysis – presence or absence of depredation by all predators per fishing journey

The model that best predicted the presence of depredation by all predators combined (monk seals, cetaceans or other predators) was the model containing gear, depth and season (AIC: 439) (Table 1). Biologically plausible interactions (gear type*depth, gear type*season) were tested and were found to be non-significant. There was an inverse relationship between depth and the probability of damage to gear or catch [estimate mean = −0.011]. The deeper the gear was deployed, the lower the probability of damage. Regarding the fishing gear, compared to the use of gill net alone (intercept), longline was more likely to be damaged [estimate mean effect = +1.005]. A combination of gill and trammel net in the same place also had a higher probability of damage [estimate mean = 0.882]. Trammel nets were less likely to be damaged [estimate mean = −0.204]; however, this estimate was not significantly different to that of gill nets (p > 0.05). Damage was most likely to occur in autumn (Intercept) and, in comparison, there was a decreased risk in summer and spring [estimate mean effect = −0.594, −0.044 respectively].

3.2. GLM analysis – occurrence of depredation by monk seals compared to depredation by cetaceans or other species

The optimum model describing the occurrence of monk seal depredation compared to depredation by cetacean or other species included average depth, gear, type of damage (gear, catch or both) and season (AIC 55.49; Table 2). All biologically plausible interactions were tested and were found to be non-significant. There was a negative relationship between depth and the probability of damage [estimate mean; −0.101], so the deeper the gear was deployed, the lower the probability of damage by monk seals (Fig. 2). The greatest probability of damage was observed on gill nets (intercept), while trammel net, longline, gill – trammel nets showed lower probabilities of damage caused by monk seals [estimate mean effect; −5.330, −4.932 and −4.794 respectively]. There was a greater probability of damage by monk seals in spring and summer [estimate mean 4.405,

Table 2
GLM model of risk factors associated with depredation by monk seals compared to depredation by cetacean or other species combined around Lipsi Island, Greece.

	Estimate	Std. Error	z value	Pr (> z)
Intercept	6.754	1.803	3.746	0.00018 ***
Damage[T.Catch]	−28.246	2733.881	−0.010	0.99176
Damage[T.Nets]	−3.341	1.195	−2.797	0.00516 **
Depth.Average	−0.101	0.030	−3.410	0.00065 ***
Gear[T.Gill and Trammel]	−5.330	2.357	−2.262	0.02372 *
Gear[T.Trammel]	−4.794	1.943	−2.467	0.01364 *
Gear[T.Longline]	−4.932	6.063	−0.813	0.41600
Season[T.Spring]	4.405	1.979	2.225	0.02608 *
Season[T.Summer]	2.929	1.642	1.784	0.07450.

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1.

2.929 respectively] compared to autumn (intercept). There was significantly more damage made by monk seals to both catch and nets (intercept) than only to nets [estimate mean effect; −3.341]. Note that all gear types were used in the summer, but that gill was not used in spring, while gill and trammel combined and longline were not used in the autumn

3.3. Catch per unit effort

We used a *t*-test to compare the CPUE of the 9 most targeted species with and without monk seal interaction from survey one (Fig. 3). It showed that the CPUE of four species (*S. officinalis*, *S. cretense*, *P. erythrinus*, *O. melanura*) was significantly lower when there was monk seal interaction than when there was not. There was no difference in CPUE with and without monk seal interaction for the remaining five species.

The majority of the targeted species were caught using trammel nets. The species caught using this method were: *S. officinalis*, *S. cretense*, *P. erythrinus*, *D.dentex*, *S.cretense* and *Scopaena sp.*, while *O. melanura*, *S.cretense* and *B.belone* were caught using both trammel and gill nets. The species *S.luridus* and *O.vulgaris* were also caught by trammel and gill nets even though they are not the target species for these gear types. A total of three species were caught using longlines (*erythrinus*, *P. bogoravero* and *Serranus cabrilla*), although only (*P. erythrinus*) was a target species. The other two were not target species because they only occur in small numbers.

It was not possible to compare the CPUE after monk seal depredation with CPUE after cetacean depredation because there were only 18 occurrences of cetacean depredation most of which (13 occurrences) occurred in survey two in which we were not able to collect accurate data about size of individual fish species.

3.4. Economic loss

Information from the 4 fishermen who took part in survey one allowed us to calculate the economic loss associated with predator interactions. The price for new nets was 572.5€/100 m for gill nets, 361.25€/100 m for trammel net and 50€/1000 m for longline. The cost of the fuel was 1.58€ per liter, which they spent at a mean rate of 3.26 liters/hour, with an average traveling speed of 8 (+/− 0.2) nm/h. The average number of holes caused by cetaceans was 9 (+/− 1.4) holes/year, with an estimated length of 1–2 m in diameter, whereas monk seal net damage was 60 holes (+/− 5.0) (3 hole pattern)/year with three partner holes of 20–30 cm. The range of time spent to repair the holes varied between 17 and 31 days. The amount of cord used to repair nets that were damaged by cetaceans was 5.6 (+/− 2.2) kg/year at a cost of 14€/kg, which yields a total cost of 78.4€ per year. The kg of cord used to repair damage by monk seals was 40 (+/− 30.0) kg/year which yields a total cost of 560€ per year.

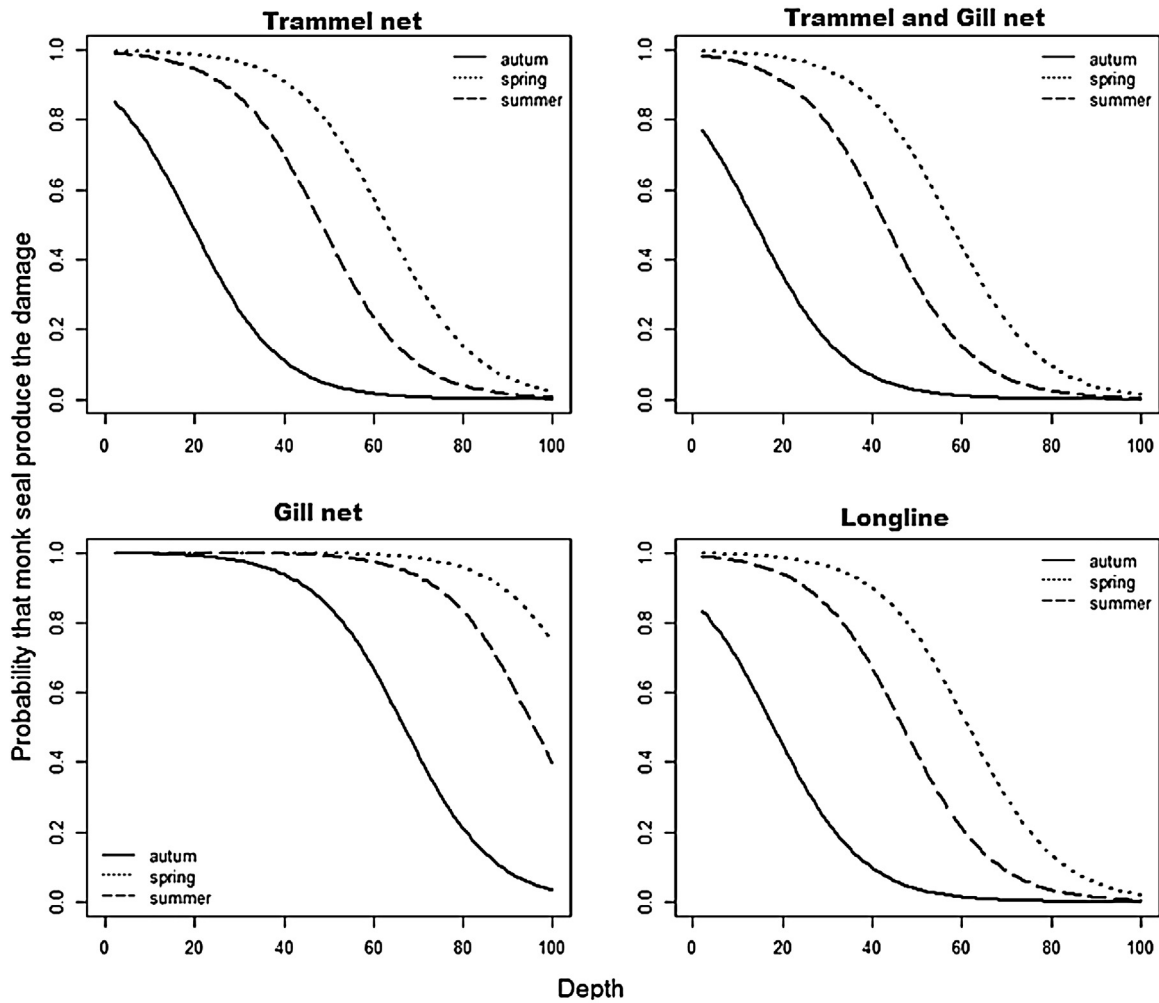


Fig. 2. Plots of adjusted values for gear, season, and depth in the model for the presence of depredation by monk seals compared to depredation by cetaceans or other species.

Table 3

Annual catch per unit effort (CPUE) of nine most targeted fish species on fishing trips when interaction with monk seal predators does and does not occur.

Species	CPUE Kg/day Depredation	CPUE Kg/day No depredation	CPUE Kg/Year Depredation	CPUE Kg/Year No depredation	CPUE loss Kg/year	Euros/kg Fish	Catch Loss Euro/Year
Sparisoma cretense	1,40	1,72	160,59	196,92	36,33	11	399,64
Siganus luridus	1,95	1,75	223,94	200,20	−23,74	10	−237,38
Oblada melanura	3,44	4,38	394,07	502,35	108,28	18	1949,02
Scorpaena scrofa	0,54	0,71	61,92	81,90	19,98	11	219,76
Sepia officinalis	1,10	1,20	125,91	137,17	11,26	9	101,34
Dentex dentex	1,71	2,17	196,61	248,34	51,74	25	1293,47
Pagellus erythrinus	0,54	2,55	61,51	292,40	230,89	12	2770,66
Belone belone	0,73	1,14	83,58	131,01	47,43	8	379,42
Octopus vulgaris	1,24	1,07	141,99	122,41	−19,58	10	−195,81
							6680

Information about the species price and the CPUE for every landing allowed us to estimate the difference between the catch with and without depredation, and therefore to calculate the economic loss related to the 9 most targeted species of the Lipsi fisheries (Table 3). These species represent 67.7% of the total catch of the fisheries. Catch damage as a result of depredation occurred on 50% of fishing trips. Since these fishermen are active on 229.4 days/year this proportion represents catch damage occurring on 114.7 days per year. The total annual cost of catch loss as a result of monk seal depredation was 6680.14€, which equates to

2230€/fishermen/year. This represents 21.33% of the mean annual income 10.451€ of fishermen in the Dodecanese (Tzanatos et al., 2006).

3.5. Mapping the location of fishing pressure and predator interactions

We mapped the locations where fishing occurred around Lipsi Island (Fig. 4a), which showed that the greatest fishing pressure tended to occur in the south and the east of the island. The total area

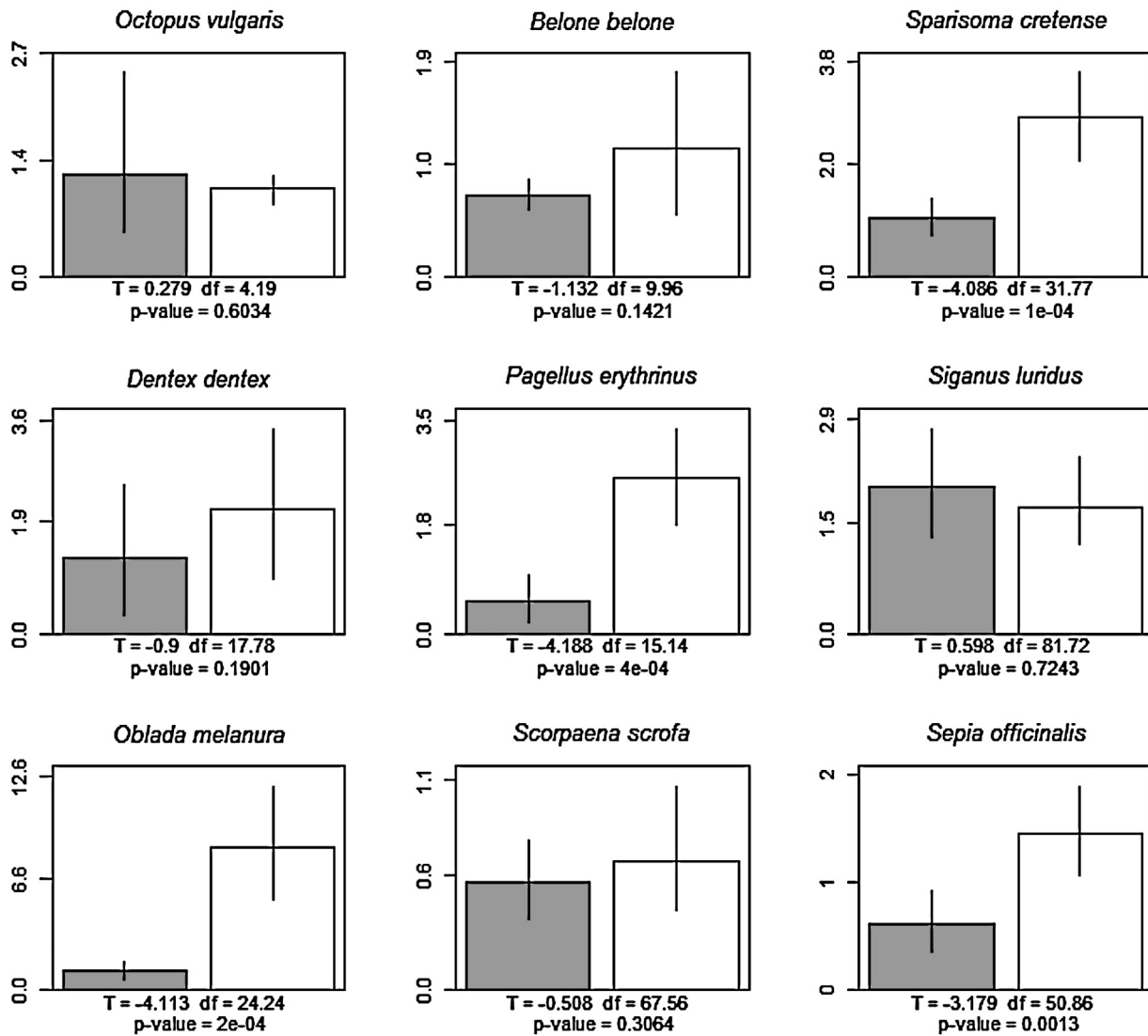


Fig. 3. Mean catch per unit effort (CPUE) (kg landed/day/boat) of the 9 most common commercial species in absence of any depredation (white) and in presence of monk seal depredation (grey). The number below each plot is a *t*-test P-value. Bars are means $\pm$ confidence intervals, which were calculated using standard bootstrap.

used for fishing was 25.7 km². The fishing pressure in most of the area was classified as low covering a total of (19.0 km²) the remainder was classified as medium (5.4 km²) or high pressure (1.3 km²). We also mapped the locations where interaction with monk seals occurred (Fig. 4b). The total area in which interactions with monk seals occurred was 19.7 km², the majority of this area (16.1 km²) was low pressure and the remainder was medium (2.8 km²) or high (0.8 km²) pressure. The areas of greatest interaction occurred in the south and the east of the island. The map that overlaps fishing pressure and predator interaction pressure (Fig. 4c), indicates that the locations where fishing pressure was greatest and where interactions also occurred most frequently were in the northeast, and around the islands to the south of Lipsi. Although Fig. 4b indicates that in the area to the north of Lipsi, fishing pressure was medium to high, the predator interaction pressure in that region tended to be low to medium, and thus the combined pressure in Fig. 4c was also classified as low. In Fig. 4c, the total area was 25.7 km². Within that area there were no interactions in 6.0 km², while low or medium categories covered 18.4 km² and the remaining 1.3 km² was categorized as low/high medium/high or high and were therefore where most interactions took place.

4. Discussion

Interactions between marine predators and small scale fisheries occurred frequently (on more than 40% of fishing trips) around Lipsi Island, Greece. Interactions occurred most often with monk seals (19.1% of trips). The interactions resulted in damage to fishing gear and damage or loss of catch. Interactions between pinnipeds and fisheries have been recorded in other regions of the Mediterranean (Güçlüsoy, 2008; Hale et al., 2011; Cosgrove et al., 2013) and can have a detrimental impact on the small scale fisheries as on the conservation of the predators concerned.

In this study, variables such as depth, gear and season were predictors of monk seal depredation, while habitat and geographic area were not relevant to the fit of the model. In both models most depredation occurred in shallow water. This may be related to the importance of the shallow waters for fish feeding, for shelter (Hindell et al., 2000; Hyndes et al., 2003;) and as nursery areas (Cocheret de la Morinière et al., 2002; Lloret et al., 2002). It also reflects that monk seals are described as shallow water divers, with an average dive time of between 6 and 18 min (Kirac et al., 2002).

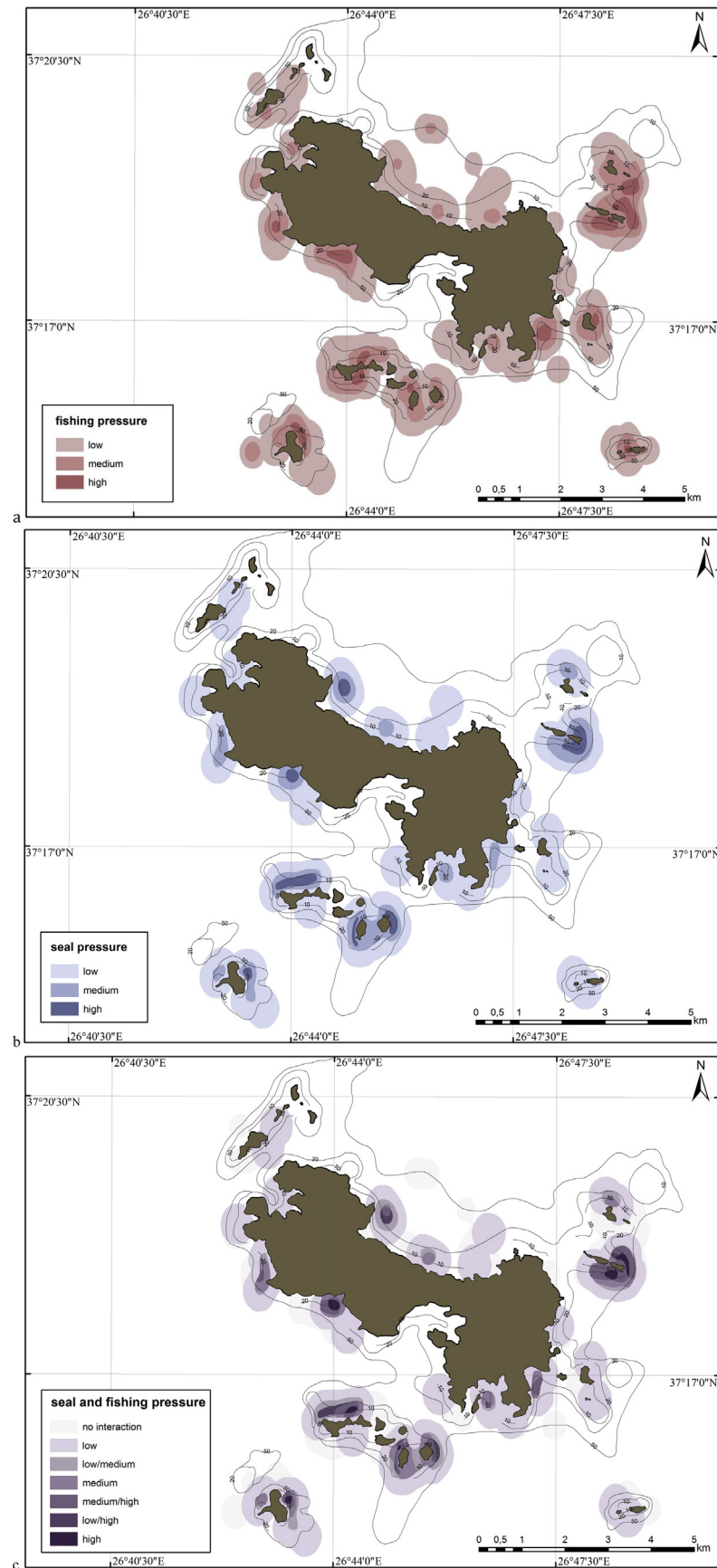


Fig. 4. Kernel density maps of Lipsi Island demonstrating a) fishing pressure b) seal pressure and c) Overlapping map of fishing pressure and predator interaction pressure. Area of each category in map c: 6.0 km² no interaction (fishing only); 16.1 km² low (low, medium or high fishing pressure and low seal interaction); 1.0 km² low/medium (low fishing and medium seal interaction); 1.3 km² medium (medium fishing and medium seal interaction); 0.9 km² medium/high (medium fishing and high seal interaction or high fishing and medium seal interaction); 0.2 km² low/high (low fishing and high seal interaction); 0.2 km² high (high fishing/high interaction).

Other studies in Greece have also demonstrated a higher rate of damage to nets inshore, than offshore (Panou et al., 1993).

Regarding damage to gear, the longline and gill net had the highest probability of damage as a result of depredation by all species (although these were not significant), while the gill net was the gear that was most often affected by monk seal depredation. It is possible that interactions occurred between longline and all recorded predators because they are thrown with bait which may act as an attractant. In comparison, monk seals may not interact with longline as frequently because they are only deployed for a short time and because they may be deterred by the presence of humans, presence of the boat and the sound of the engine. Interaction with gill nets may be more common because they are deployed on the surface of the water. For this reason the longline or trammel could be considered as a preferred type of gear to be used in the areas where there are higher numbers of monk seals and in marine protected areas (MPAs). This management strategy has also been proposed in Turkey (Güçlüsoy, 2008). In general, there does not appear to be a consensus about the type of gear that is most commonly predated by seal species. Some studies have shown that both gill and trammel nets experienced a high probability of monk seal damage (Güçlüsoy, 2008), others indicate that trammel nets were more likely to be damaged than gill nets although this was also dependent on the distance offshore (Panou et al., 1993). Studies on grey seals have indicated a higher rate of predation on gill nets (Cosgrove et al., 2013). Differences between these results may reflect differences in the method of deployment or in the number of nets being deployed.

With regard to the season, autumn was the season when depredation by all species was most likely. Conversely monk seal depredation occurred most often in the spring and summer months and less often during the autumn months. A possible explanation is that in autumn there is a change in the type of gear used, with an increase in the use of longline, trammel nets and octopus handline jigging. Another explanation is the timing of the breeding season. The breeding season of cephalopods extends through the year with a peak beginning in autumn (November to May) (Guerra et al., 1992), and the breeding season of the monk seal occurs principally in the months of September to November (Johnson et al., 2006; Shirihi and Jarrett, 2006). At these times the frequency of foraging tends to decrease and occurs in close proximity to the breeding grounds (Dendrinos et al., 1999; Pastor and Aguilar, 2003; Gazo and Aguilar, 2005).

For both models, habitat was not a predictor of depredation by all predators, nor specifically by monk seals. One explanation is that most of the predators are distributed around the entire island, or at least in all locations where fishing takes place. Nets were principally deployed over seagrass (32%), rock (33%) or heterogeneous habitat (24%), and appeared to be equally depredated. These habitats, in particular seagrass, are important fish habitat (Hindell et al., 2000; Hyndes et al., 2003) and nursery grounds for numerous species (Cocheret de la Morinière et al. 2002; Lloret et al., 2002).

Geographic area was also not relevant to the fit of the model. One reason maybe that there were eight categories and thus a low sample size for each category. We are also cautious about the reliability of the precise locations provided by fishermen. This is because most fishermen are protective of their fishing sites due to competition from other fishermen (Franquesa et al., 2001) and in some studies they have been shown to provide contradictory information (Pålsson, 1988; Thorlindsson, 1988).

The CPUE was significantly lower for four of the nine most economically important species (*S. cretense*, *P. erythrinus*, *O. melanura* and *S. officinalis*) when depredation by monk seals occurred. This information concurs with reports that monk seal have a preference for the Sparidae family e.g. *P. erythrinus*, *O. melanura* (Sergeant et al., 1978). This data also concurs with information that was pro-

vided by the fishermen, which indicates that the monk seals did not tend to predate poison spine fish such as the *Scorpaenidae* family and *S. luridus*. Unexpected results indicate an increase in CPUE of *O. vulgaris* (octopus) and *S. luridus*. One could speculate that the increase in octopus could be due to their attraction to damaged fish, which remain on the deployed nets after seal predation occurs. Such scavenging behavior has been recorded in the region (Bozzano and Sardà, 2002). The concentration of *S. luridus* species in deployed nets was greatest during monk seal depredation compared to no monk seal depredation. One hypothesis is that species of *S. luridus* become alarmed during seal hunting activities, causing them to collect in the nets.

We combined CPUE loss with estimated cost of damage to nets to provide a comprehensive estimate of the cost of depredation. The CPUE loss was 1670€ per fisherman per year for a total of 9 important species. The results of the economic analysis showed that fishermen lost an average of 2230€ (1670€ of catch+ 560€ to repair nets). This represents 21.33% of the mean annual income of the fishermen, which has been estimated to be 10.451€ in the Dodecanesos region (Tzanatos et al., 2006). Although many fisheries globally have experienced catch and net damage as a result of seal interactions (e.g. Bjorge et al., 2001), estimates of the economic loss are rare and comparison is not necessarily informative. A study of seal impact on salmon and sea trout fisheries in Scotland, for example, estimated that the cost of damage to catch and was £16500 per year per fisherman, however this study is relevant to the geographic location and costs are not directly comparable. As well as direct monetary losses, additional losses include the time spent repairing nets (17 days/year for monk seal depredation) and loss of earnings from inability to fish. In the future, a more detailed assessment could provide a better understanding of level of economic loss as a result of predator interaction. We recommend that such a study should also consider the impact of declining fish stocks, the costs of the petrol, boat maintenance and boat license.

We compared the CPUE on occasions when monk seal depredation occurred and did not occur as a simple comparison of 'implied loss'. The occasions when no interactions occurred thus act as a control since we assume that CPUE would be approximately equal to these if there was no damage. We were unable to control for other variables e.g. location, depth and season. A more detailed dataset would allow us to control for these factors, however this simple comparison provides an indication of loss as a result of depredation during this study, and a similar method has been used elsewhere (Brotos et al., 2008). Our comparison of CPUE per species gives an indication of the species that monk seals may be targeting. In the future we recommend a more detailed survey if fishermen allow, which should integrate information about gear type and information about the proportion of damaged and undamaged fish per species so that 'depredation per unit effort' could be calculated. One limitation to our data collection was the level of compliance of the fishermen. Some were apprehensive to provide detailed information in case of competition from other fishermen. Some were also unwilling to allow females onto their boat due to the cultural belief that it could bring bad luck.

The distribution of monk seals around the island is unknown, however data collected here about their interactions with fisheries has allowed us to map the areas where the most interactions between monk seals and fisheries occur. Although our GLM analysis showed that geographic region was not an indicator of the probability of depredation, our map helps to highlight regions where depredation has occurred. The data is an indicator of the presence of this endangered animal. The northeast, the north and the south were the regions where the interaction between fisheries and monk seal occurred the most. A full survey of the region would help to determine the species distribution and abundance, which

is at present unknown. In addition data collection about seal foraging, using tracking technologies for example, would help to identify critical foraging habitat and identify areas of overlap with fisheries (Bjorge et al., 2001). This would be beneficial to this species because this is the area where the largest monk seal population is thought to exist (Marchessaux and Duguay, 1977; Cebrian et al., 1998) and it would allow researchers to propose areas e.g. small islets as MPAs or areas for monk seal conservation. Such conservation areas could help to protect Aegean monk seals in a similar way that a conservation area has benefited the Foça monk seal in Turkey (Güçlüsoy 2008; Kırac and Güçlüsoy, 2008). Furthermore, establishment of MPA have proven beneficial to fisheries in other regions, for example in the Medes islands, where after 20 years of protection, the fisheries have increased by 6% (Merino et al., 2009) and some of the main fish species have recovered in numbers (García-Rubies et al., 2013).

During this study there were no cases of predator by-catch. There was one instance when a cetacean was caught in a net, which was released by the fishermen unharmed. Anecdotal evidence from the fishermen suggests that seal or other predator by catch is not common, most likely because the type of gear used is too weak to catch predators. Unfortunately there remains a risk to the conservation of predators as a result of interactions because fishermen have been known to deliberately caused mortality in an attempt to protect their gear and catch (Johnson and Lavigne 1999; Güçlüsoy et al., 2004a; Johnson 2004).

In conclusion, our work has shown that interactions between marine mammals and small scale fisheries around Lipsi Island have a detrimental economic impact on the fisheries in the area. We also showed which variables impact the interactions with different predators and which species of fish were most impacted. The occurrence of interactions and the amount of damage caused are dependent on the fishing gear, season and depth of fishing. In order to mitigate interactions we make two suggestions. First, we suggest limiting the type of fishing gear used in seasons of greatest depredation (spring) and testing the use of depredation mitigation devices (Rabearisoa et al., 2015). Clearly additional work would be needed to determine the feasibility of such management strategies to fisheries. Secondly we suggest designating an area of the islands as a MPA where fishing would not be allowed, or could be managed with a limited entry license system (Boncoeur et al., 2002). Further data needs to be collected however in order to identify areas suitable for MPA designation, ideally telemetry data to identify critical foraging habitat and areas of where there is most overlap with fisheries. These measures would have a positive impact on the conservation of the endangered monk seal population as well as the potential to promote the recovery of the fish stocks in the area. This would be a beneficial step towards reducing the interactions between marine mammals and fisheries in the region.

Acknowledgements

We thank all the Archipelagos researchers who assisted in the data collection. We are grateful to the fishermen who voluntarily allowed us to work with them and gather data from their landings and also to gain a greater understanding about the issue. We would like to extend many thanks to Losu Paradinas for his help with the statistics, to Victor Buchet for his comments and corrections. We thank to Justina Kliukaite for her GIS help. Moreover, thanks to the direction of Archipelagos Institute of Marine Conservation for enabling us to carry out this research. RC was in part funded by the Canada Excellence Research Chairs Program and by Operation Wallacea, UK.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.fishres.2016.10.013>.

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