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Interaction of Loggerhead Turtles (*Caretta caretta*) with Traditional Fish Aggregating Devices (FADs) in the Mediterranean Sea

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Abstract*.—Traditional fish aggregating devices (FADs) have long been used throughout the Mediterranean Sea, but few data are available on their interactions with Loggerhead Turtles (*Caretta caretta*). In this study, we examined the influence of FADs on the spatial and seasonal distribution of Loggerhead Turtles in the Aeolian Archipelago (Italy) as well as the pattern of bycatch and other FAD-related impacts. We implemented an overlap analysis between FAD locations and the distribution of Loggerhead Turtles per season. We found that the geomorphology of the volcanic islands significantly influenced the selection of foraging hotspots. However, during the fishing season, the turtles strongly interacted with FADs, moving from neritic to oceanic habitats. Specifically, during the fishing season, we found 1) a higher number of turtles, 2) a clear overlap between Loggerhead Turtle and FAD locations and 3) shorter distances between turtles. Turtle-FAD interaction occurred in all life stages, although bycatch was more frequent for smaller turtles. FADs also affected the distribution of turtles across years by habituating them to temporary and unnaturally aggregated food sources. We found high levels of bycatch in FADs (19.4%), especially for turtles already entangled in longlines (33%). FADs were potentially dangerous because the turtles became entangled in the anchoring lines of nylon, which wrapped around their necks, flippers and posterior limbs. We suggest further investigations to assess the influence such illegal devices pose on the foraging ecology of Loggerhead Turtles and the levels of bycatch in other Mediterranean areas.

Key Words.—bycatch; curved carapace length; fishing devices; foraging hotspots; marine turtle; marine debris

Introduction

Fish aggregating devices (FADs) are permanent, semi-permanent, or temporary structures made from any material and used to attract fish. They have been used by fishermen worldwide throughout history to improve pelagic fish catches (Dempster and Taquet 2004; Sokimi 2006), especially in the central and western Mediterranean basin (Massutí and Morales-Nin 1991; Massutì et al. 1995; D'Anna et al. 1999; Andaloro 2003; Andaloro et al. 2007). Oceanic and coastal FADs provide an opportunity to decrease both the search time and operating costs for artisanal and commercial fishing vessels (Brock 1985; Raymond et al. 1989). Research on FADs in recent years has taken many directions, but little is known about the mechanisms driving the interactions of different species with FADs (Kingsford 1999; Dempster and Taquet 2004; Coelho et al. 2013). Different studies have focused on the ecology and composition of fish fauna related to FADs (Badalamenti et al. 1995; Deudero et al. 1999; Deudero and Morales-Nin 2000; Sinopoli et al. 2004; Andaloro et al. 2007). Moreover, a general risk of overfishing when using FAD and of significant levels of bycatch for different species has been demonstrated (Dempster and Taquet 2004; Delgado de Molina et al. 2005). However, no study has reported quantitative information on the levels of FAD interactions with Loggerhead Turtles (*Caretta caretta*), for example, whether FADs are responsible for Loggerhead Turtle spatial movements or their degree of mortality. The need for further scientific contributions on this topic has been recently reviewed by Coelho et al. 2013.

In recent years, habitat degradation and the progressive destruction of nesting sites have significantly affected the distribution patterns of Loggerhead Turtles in the Mediterranean (IUCN 2016, Appendix I CITES, Annex II Berne Convention) through changes in habitat structure and prey availability at different spatial and temporal scales (Lutcavage and Lutz 1997; Luschi and Casale 2014). Fishing activities, such as the use of longlines and active trawlers (Casale 2011), have been largely recognized as a major threat and cause of mortality of Loggerhead Turtles in several Mediterranean areas (Carreras et al. 2004; Orós et al. 2005; Casale et al. 2007; Casale and Margaritoulis 2010; Casale 2011). Entanglement in marine debris, such as items from land-

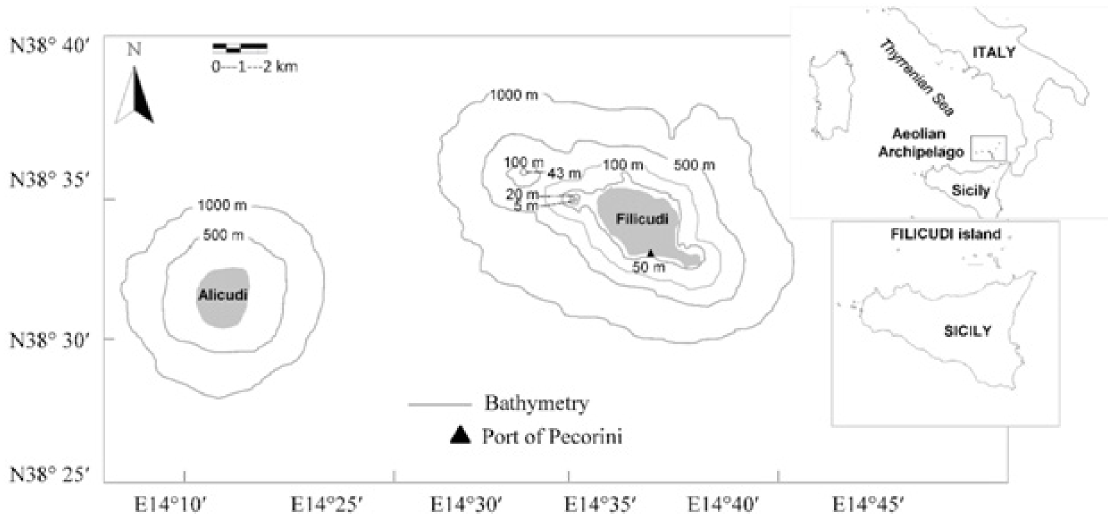

Figure 1. The study area located around the islands of Filicudi and Alicudi in the western Aeolian Archipelago (Southern Tyrrhenian Sea), Italy. The Pecorini port is also indicated. Bathymetry is expressed in metres (m).

based sources and ghost fishing gear, is responsible for high levels of bycatch to many marine species (Gregory 2009; Wilcox et al. 2013, 2014; Vegter et al. 2014). However, few publications directly refer to sea turtle entanglement in marine debris (Chatto 1995; Lopez-Jurado et al. 2003; Santos et al. 2012; Jensen et al. 2013; Camedda et al. 2014), and it is likely that many individual cases of bycatch have never been published (Nelms et al. 2015). Thus, quantitative research directly referring to the marine debris entanglement of turtles and to turtle mortality rates is lacking, and a large knowledge gap exists in terms of implications for global sea turtle populations (Nelms et al. 2015).

The Loggerhead Turtle has been documented in several Mediterranean areas (Margaritoulis et al. 2003; Casale et al. 2012; White et al. 2013; Schofield et al. 2013; Luschi and Casale 2014). Potential foraging grounds for Loggerhead Turtles have been found in the Adriatic Sea (Schofield 2010a, b; Casale et al. 2012; Schofield et al. 2013; Cardona et al. 2014) and along the Spanish coast (Hochscheid et al. 2005; Gómez de Segura et al. 2006; Hochscheid et al. 2013). Other important foraging areas are located in southeastern Turkey, the Egyptian coast (Gerosa and Casale 1999) and along the Tunisian and Libyan coasts (Casale et al. 2008). In the central Mediterranean, the Straits of Sicily and Messina are probably key routes for turtles migrating between the eastern and western Mediterranean basins (Casale et al. 2007), but little information is available on the presence of the Loggerhead Turtle in the Southern Thyrrenian Sea. To address this issue, we implemented a study on Loggerhead Turtles in the Aeolian Archipelago (Southern Thyrrenian Sea, Italy; Fig. 1). In this area from September to December, local fishermen arrange several illegal FADs in open waters (D'Anna et al. 1999; Andaloro, 2003; Andaloro et al. 2007). The use of FADs in the Aeolian Archipelago is related to the presence of economically important fish species, such as Dolphinfish (*Coryphaena hippurus*) and the Greater Amberjack (*Seriola dumerili*; Giovanardi et al. 1984; Porrello et al. 1993; Mazzola et al. 1996). FADs are constructed using palm leaves (Mazzola et al. 1993) anchored to the sea bottom with plastic bottles or other plastic debris, which in turn are secured to the sea floor by ropes and nylon lines (D'Anna et al. 1999; Andaloro 2003; Fig. 2). The target species in the proximity of FADs are then harvested using purse seines by commercial fishing vessels coming mostly from the coasts of Sicily and Calabria (Fig. 2). The fishing season starts when the juvenile Dolphinfish and Greater Amberjacks aggregate under the FADs along the coastal area (September) seeking refuge from predators (shade effect) or searching for food resources (D'Anna et al. 1999; Andaloro, 2003; Andaloro et al. 2007). At the end of the fishing season (December), not all of the FADs are removed by their location and some of them, breaking from their anchorages, arrive at the coasts in the form of common marine debris that pollute beaches and open seas.

Loggerhead Turtles are primarily generalist predators, exploiting prey item ranging from plankton to fish (Dodd 1988; Revelles et al. 2007a; Seney and Musick 2007), although they show a significant spatial variation in diet (Hatase et al. 2007; McClellan and Reed 2007; Casale et al. 2008; Mansfield et al. 2009; Zbinden et al. 2011). During the fishing season, FADs might provide a reliable food source for Loggerhead Turtles by offering a concentration of prey species with direct and indirect consequences on seasonal movements and on the selection of foraging hotspots. In addition, the Loggerhead-FAD interaction may be potentially dangerous because

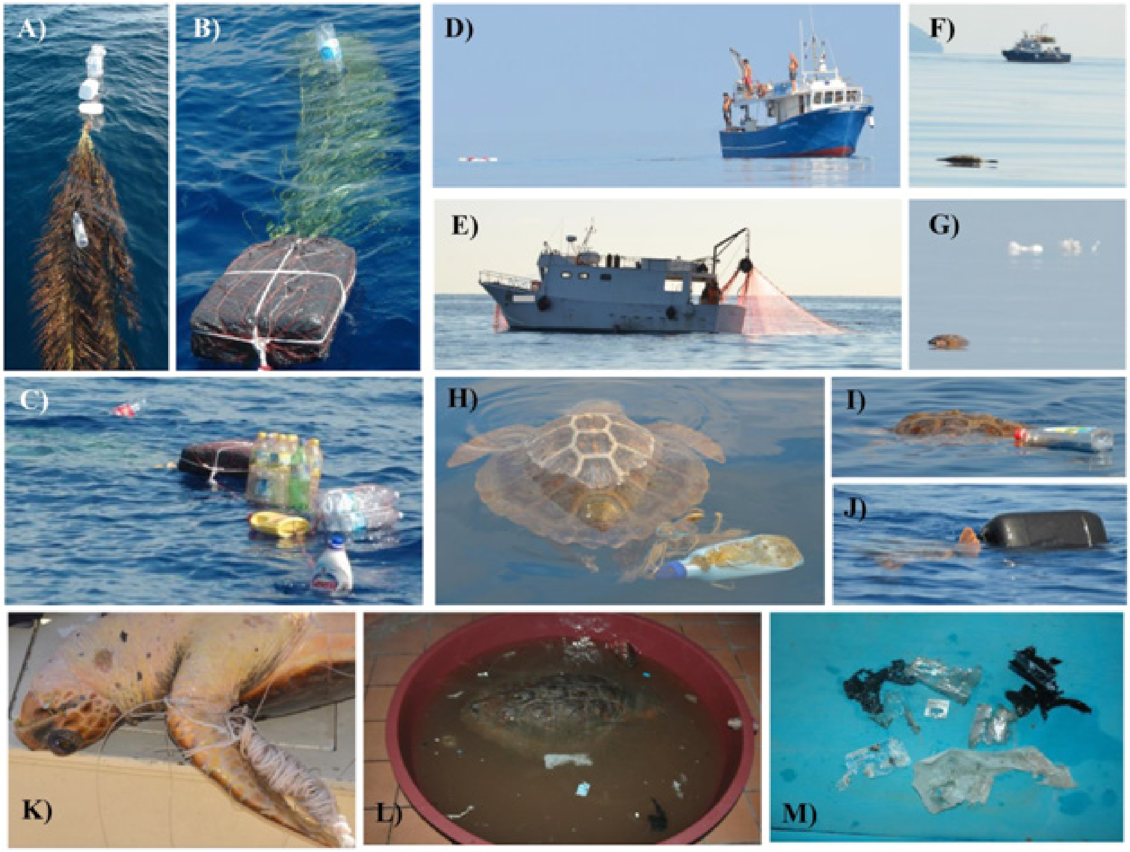

Figure 2. Frames (A), (B) and (C) show the traditional FADs constructed using palm leaves fixed to plastic bottles or other debris, which in turn are secured to the sea floor by ropes and lines; frames (D) and (E) show the fishing vessels coming from the coasts of Sicily and Calabria adopting purse seines to harvest the target species in the proximity of FADs; frame (F) shows the proximity of resting turtles to purse seines fishing vessels; frame (G) shows the proximity of resting turtles to FADs; frames (H), (I) and (J) show the bycatch of different Loggerhead individuals in floating debris of unknown origin (FADs or land-based sources); frame (K) shows a dead Loggerhead individual entangled in longlines and debris of probable FAD origin; and frames (L) and (M) show massive plastic in the feces of Loggerhead (*Caretta caretta*) individuals rescued in the proximity of FADs. (Photographed by Monica F. Blasi).

the turtles might become entangled or injured in the anchoring lines/debris around different parts of their body (Plotkin and Amos 1990; Campani et al. 2013; Casale et al. 2010; Nelms et al. 2015).

In this study, we investigated the influence of FADs on the spatial and seasonal distribution of the Loggerhead Turtle in the Aeolian Archipelago, as well as the pattern of bycatch in FADs and other potential FAD-related impacts. We expected that, during the fishing season, the Loggerhead distribution is likely to be influenced by the food resources found in FADs. We also expected that the turtle-FAD interaction may be potentially dangerous with significant levels of bycatch.

Materials and Methods

Study sites.—The Aeolian Archipelago is a geomorphologically varied area of volcanic origin located in Northern Sicily (Southern Thyrrenian, Italy; Fig. 1) with extensive neritic and oceanic habitats within short distances. The study area covered 400 km^2 around Filicudi, one of the seven Aeolian islands (Sicily, Italy - 38°35’ N, 14°34’ E; Fig. 1). We carried out dedicated boat surveys (n = 890) from March 2009 to November 2014 (excluding the month of February each year due to extreme weather conditions). The same expert observer performed the boat surveys throughout the 5-y period. We only surveyed in good light conditions (daily hours), in good visibility (> 300 m) and in sea states of Beaufort 3 or less. Daylight was divided into five intervals of 3 h each between 0600 and 0900. We performed the surveys by alternately starting in different daily intervals and starting and ending at the port of Pecorini (Filicudi, southwestern shore; Fig. 1). Although the routes varied depending on the weather conditions, we covered the entire area equally by alternately starting the surveys on the right/left side of the port (MacKenzie and Royle 2005) and by following a different path each day. During the surveys, we noted the following data at 10-min intervals (survey stations): time, GPS positions (Garmin GPS 12, Garmin Europe ltd, UK), boat speed, visibility, sea state (Beaufort scale) and presence of fishing gear. From 2011 to 2014, during the surveys, we also recorded FAD locations within the study area, noting the exact GPS position at the centre of the device.

Field data collection.—We sampled Loggerhead Turtles using a combination of visual observations (Altmann 1974) and capture methods. We slowly approached the turtles on the sea surface to record their exact positions using the GPS and their behavior using a 35 mm autofocus camera (D7000, Nikon Corporation, Shinjuku, Japan) with a 70–300 mm zoom lens and digital video cameras (Hero 4, GoPro, Inc., San Mateo, California). We recorded the Loggerhead surface behavior before the turtle dove or was captured. The Loggerhead behavior corresponded to either Feeding, if the turtle was directly observed to feed on different prey items on the sea surface or Resting, if the turtle was observed to emerge above sea level, usually to rewarm, with the typical basking position (Hochscheid 2013). At the time of sighting, we also reported the presence of FADs, fishing gear, other Loggerhead Turtles, sea birds and/or anthropogenic debris at an arbitrary distance from turtles of no more than 30 m. Only in a few cases did we observe direct interactions of turtles with FADs (for example, turtles feeding on prey on FADs or turtles directly entangled in FADs). Consequently, we selected < 30 m as an arbitrary distance to define proximity to FADs for resting turtles (according to Blasi and Boitani 2012). When possible, we captured individuals by hand to take body measurements (carapace length and width, and weight) and to evaluate the health status, and then we released the turtles at sea (if they were in good health) or brought them (if turtles were injured) to the Filicudi Wildlife Conservation Rescue Station (Filicudi Island, Aeolian Archipelago). We also documented stranded carcasses that had washed ashore by monitoring the coastal area one day per week and those that were floating on the sea water surface during the boat monitoring sessions. We measured the curved carapace length notch to tip (i.e., from the nuchal scute notch to the tip of the supracaudal scute [CCL]; Bolten 1999) for each captured loggerhead individual. We calculated the average CCL (± SD) for individuals that were captured in the proximity or not to FADs and according to geographic location (Latitude and Longitude). For not-captured individuals, we estimated turtle size from direct observations according to approximate sizes ordered in three classes: (1) small (CCL < 40 cm), (2) medium (CCL between 40–70 cm), and (3) large (CCL > 70 cm).

Loggerhead turtles with detectable injuries or that were dead were subjected to veterinary examination at the Filicudi Wildlife Conservation Rescue Station to determine the likely cause of rescue/death based on a complete external (for all turtles) and internal (for dead turtles) examination. We assigned a cause of rescue/death only if clear injuries were evident on the turtle body (e.g., bycatch in longlines or evidence of collision with boats). We assigned bycatch in longline fishery when the hook and/or the line were found in the tongue, oesophagus, stomach or intestinal tract upon the examination of the carcass. We used a metal detector to determine whether the hook was in the oesophagus, stomach or intestinal tract of living turtles if the fishing line did not come out of the turtle beak or cloaca. We assigned ingestion of debris when a large amount of plastic and/or anthropogenic debris was found in the faeces of rescued turtles (recovered at the Filicudi Wildlife Conservation Rescue Station) or in the stomach content of carcasses. We also recorded multiple injuries; in particular, we assigned the most severe and recent as the likely primary cause of rescue/death and the less severe as secondary causes.

Spatial analysis.—We created distribution maps of Loggerhead Turtles per season in order to point out likely differences related to different periods of the year and specifically in relation to fishing activity with FADs. We performed an overlap analysis overlaying FAD locations with the distribution of loggerheads obtained during the fishing season (autumn or winter) to estimate evidence of spatial interaction among turtles and FADs. For the overlap analysis, we included Loggerhead Turtle presence records during the fishing season from 2011–2014 corresponding to years we collected FAD records. Finally, we calculated distance matrices among turtles in the different seasons (spring: March-May; summer: June-August; autumn: September-November; winter: December-January) and between turtles and FADs to obtain information on the spatial use of the individuals in presence or in absence of FADs. Specifically, we calculated the distance between turtles in the different seasons (spring, summer, autumn and winter) in the proximity (< 30 m) or not (> 30 m) of FADs and the distance of turtles from FADs during the autumn and winter. In addition, the distance between FADs was also computed to better understand their spatial configuration in the study area. We performed these analyses in QGIS (QGIS Development Team 2013).

Statistical analysis.—We calculated the annual and seasonal encounter rates using the ratio n/L, where n is the total number of observations and L is the sighting effort, measured by computing the length of the track line surveyed under previously described favourable conditions (km; Blasi and Boitani 2012). We checked the normal distributions of the encounter rates, geographic locations and CCL measurements using Anderson-Darling tests and the homogeneity of variances using Levene's test. We used Welch's ANOVA to investigate the differences between groups of data were normally distributed and the Kruskal-Wallis test if the differences between groups of data were not normally distributed. We set the significance level at $\alpha = 0.05$. In particular, we compared Loggerhead locations in different years and seasons and in the proximity (< 30 m) or not (> 30 m) of FADs to determine the spatial differences related to fishing activities. We also compared the average CCL (± SD) in different years and seasons and in the proximity or not of FADs to determine spatial differences during life stages. We applied the SAS 8.1 software version 8.1 (Freund et al. 1986) for Windows to examine these relationships.

Results

Loggerhead Turtle observations.—We surveyed 1,268 h across 13,960 km. For each survey, we maintained an average speed of 10.4 ± (SD) 3.7 km h^{-1}. During the surveys, the sea state (Beaufort scale < 3) did not differ among years ($H = 2.71$, $P = 0.520$) or season ($H = 4.12$, $P = 0.310$). From January 2009 to November 2014, we recorded 488 observations of Loggerhead Turtles, with an average of 79.2 ± (SD) 83.5 observations per year and an average of 2.4 ± (SD) 10.1 observations per survey. We recorded 395 turtles in good health, 72 turtles rescued with problems and 21 dead turtles (carcasses). The CCL data were normally distributed ($AD = 0.52$, $P = 0.470$), while the turtle locations were not ($AD = 2.13$, $P < 0.001$). There was a homogeneity of variances in Loggerhead location ($L = 2.20$, $P = 0.210$) among the three size ranges. We collected observations of Loggerhead Turtles during daylight (mean = 2.5, SD = 1.3) and at a Beaufort sea state between 0 and 3 (mean = 1.0, SD = 0.89) with no difference among years (H = 14.20, $P = 0.320$) or seasons (autumn/winter: $n = 265$; spring: $n = 66$; summer: $n = 157$; $H = 11.10$, $P = 0.100$). We found that the encounter rate (n/km) of turtles in good health increased between 2009 and 2014 ($n = 395$; $H = 32.70$, $P = 0.001$; Fig. 3A) and it was higher in autumn (mean annual observations = 76.5, SD = 80.2) than in the other seasons ($H = 18.10$, $P < 0.001$; Fig. 3B).

Loggerhead Turtle behavior.—For all of the recorded behavior observations we made ($n = 430$), turtles were either resting ($n = 389$) or feeding ($n = 41$). We observed turtles feeding (on the sea surface) on planktonic prey, such as Mauve Stinger (*Pelagia noctiluca*), Velella (*Velella velella*), and ctenophores ($n = 18$), or on prey that had settled on FADs and floating debris (algae and

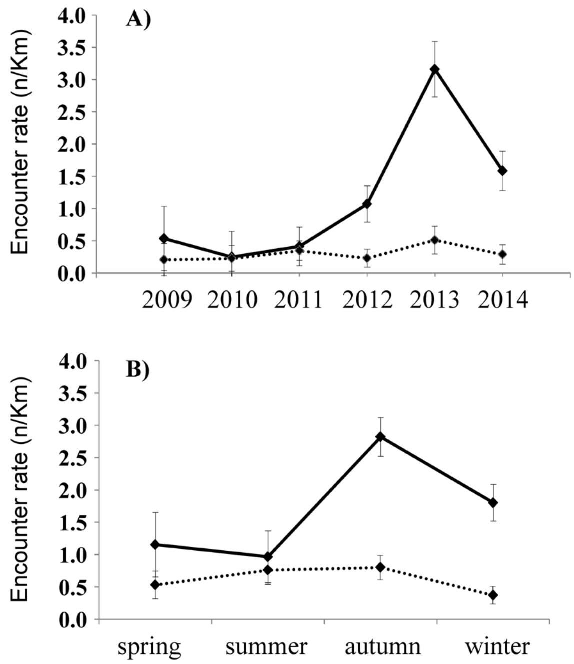

Figure 3. Mean encounter rates (n/km) (± SD) of Loggerhead Turtles (*Caretta caretta*) per year between 2009-2014 (A) and season (B). Spring: March-May; summer: June-August; autumn: September-November; winter: December-January. The encounter rates are reported for good health ($n = 395$) (continuous line) and rescued/dead turtles ($n = 83$; dotted line) found during the boat surveys (excluding stranded turtles).

pelagic gooseneck barnacles, *Lepas* spp.; $n = 23$). We also observed turtles close (< 30 m) to other turtles ($n = 24$), anthropogenic debris (plastic bags, marine debris; $n = 6$) or sea birds (i.e., Yellow Legged Gull, *Larus michahellis*, Schopoli's Shearwater, *Calonectris diomedea*, or Manx Shearwater, *Puffinus puffinus*; $n = 8$).

Proximity to FADs.—We recorded 35.5% of Loggerheads in the proximity (< 30 m) of FADs and fewer in the proximity of trammel nets (0.6%) and longlines (0.6%). In the proximity of FADs, we recorded 173 turtles in good health (mean CCL = 49.2 ± 6.1 cm) and we rescued 15 turtles with injuries (mean CCL = 52.8 ± 0.6 cm). The time of sighting turtles in proximity of FADs was between 1000–1400; however, the turtle time of sighting did not differ in the presence ($n = 157$, mean daily period = 2.5 ± 0.6; range 2–4) or absence ($n = 315$, mean daily period= 2.35 ± 0.92; range 1–5) of FADs ($H = 6.62$, $P = 0.060$). Of the 173 turtles recorded in the proximity of FADs, 85% ($n = 148$) were resting at an average distance of 19.9 ± 6.6 m from the FADs, with no difference among years ($H = 0.70$, P = 0.101) or season ($H = 0.90$, $P = 0.223$), while the other 15% ($n = 23$) were

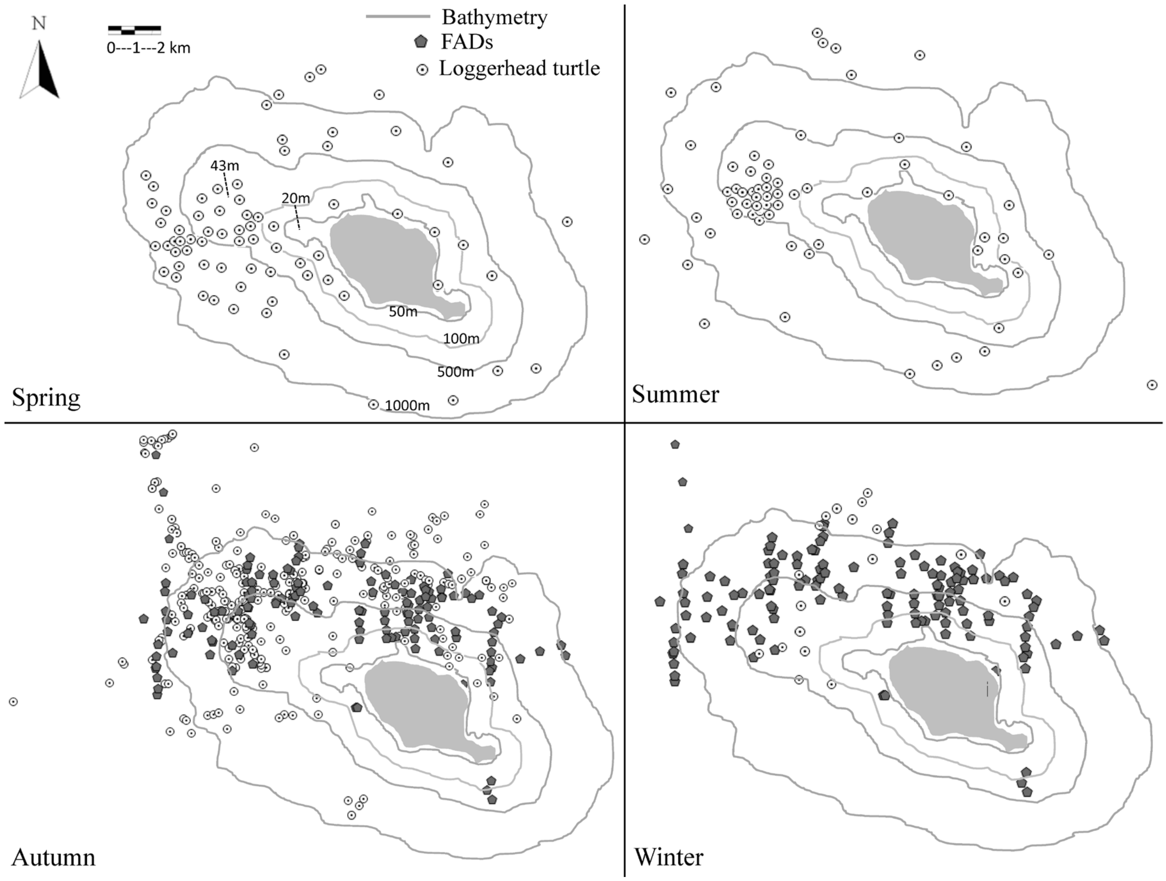

Figure 4. Distribution maps of Loggerhead Turtle (*Caretta caretta*) location around Filicudi island per season (for details of the study area see Fig.1). An overlap analysis of FAD location during the fishing season (autumn and winter) and the autumn and winter distribution of Loggerhead Turtles was performed to estimate the spatial overlap among turtles and FADs. Loggerhead records considered for the overlap analysis refer to the 2011-2014 survey period. Spring: March-May; summer: June-August; autumn: September-November; winter: December-January.

feeding on different prey that had settled on FADs (for two turtles the behavior was unknown).

FADs distribution.—We recorded 137 FADs from 2011 to 2014, 21 in 2011, 39 in 2012, 61 in 2013, and 16 in 2014. FADs were located around Filicudi Island, particularly in the northern area at a mean Latitude of 38°37'006''N ± 677'' (min. 38°29'895''N, max. 38°39'968''N) and a mean Longitude of 14°33'300''E ± 349'' (min. 14°25'534''E, max. 14°42'144''E; Fig. 4). The Latitude of the FADs significantly increased across years (H = 26.10, P < 0.001), while the Longitude did not vary (H = 5.10, P = 0.051). FADs were located at a mean distance of 43.7 ± 30.0 m from each other, and at a range of distances from the coast from 500 to 7,500 m. The fishing season lasted from September to December, and the target species in the proximity of FADs were harvested using purse seines of commercial fishing vessels with a frequency of three fishing sessions per week under good weather conditions (Beaufort < 3; Fig. 2).

Seasonal distribution of Loggerhead Turtles.—Using random paths during the surveys, we were able to uniformly cover the study area (data not shown; see Blasi and Boitani 2012). We created distribution maps of Loggerhead Turtle locations within the study area through all seasons (from 2009 to 2014; Fig. 4). We found that the geographic location of Loggerhead Turtles varied among years and seasons. In particular, the Latitude significantly increased among years (H = 34.80, P < 0.001) and varied significantly among seasons (H = 26.12, P < 0.001), with lower values (mean ± SD) recorded in spring (n = 65, 38°34'721''N ± 265'') than in summer (n = 87, 38°35'709''N ± 427'') or autumn/winter (n = 161, 38°37'910''N ± 687''). In contrast, the Longitude significantly increased among years (H = 15.90, P = 0.007) but did not differ among seasons (n = 361, 14°32'067''E ± 794''; H = 3.10, P = 0.403). We found that the mean distances between Loggerhead Turtles and FADs were lower in autumn than in winter (Table 1). In addition, we observed that during the fish-

Table 1. Distances (m) between Loggerhead Turtles (*Caretta caretta*) and FADs during the fishing seasons (autumn and winter). Autumn: September-November; winter: December-January. Each measurement is reported with the Mean (± SD), Minimum (MIN.) and Maximum (MAX.) distances.

Season	Mean Distance (m)	SD Distance (m)	MIN. Distance (m)	MAX. Distance (m)
Autumn	37.4	17.6	3.1	61.3
Winter	123.6	46.6	32.3	197.8

ing season, the distance between Loggerhead individuals was lower than in other seasons, with the lowest distances occurring in autumn and in the presence of FADs (Table 2).

We found that the geographic location of Loggerhead Turtles varied with turtle size (measured CCL; Table 3). In particular, the small turtles were found at lower Latitudes (*n* = 40, 38°34’084’’N ± 261’’) than the medium and large turtles (*n* = 64, 38°36’101’’N ± 396’’; Table 3), excluding during the summer, when the Loggerhead location did not differ (Table 3). However, during the fishing season (autumn and winter), small- and medium-sized turtles were located at higher Latitudes than in other seasons (Table 3). In contrast, the Longitude of the turtles did not significantly differ with turtle size for all observations ($H = 0.91$, $P = 0.603$) or among seasons (Table 3).

CCL measurements.—We found that the mean CCL of captured individuals (*n* = 361) was 48.7 ± 12.2 cm; 27.1% of turtles were considered small (*n* = 98), 66.0% were medium (*n* = 239) and 6.6% were large (*n* = 24). We found small turtles more frequently during spring (34.1%) than in other seasons. We found that the mean (± SD) CCL of individuals during the fishing season (*n* = 254, CCL = 50.8 ± 11.3 cm) was higher than that in the other seasons (*n* = 107, CCL = 48.6 ± 14.7 cm; $H = 5.80$, $P = 0.018$). In particular, the mean CCL was significantly smaller in spring (*n* = 62, CCL = 44.6 ± 13.2 cm) than in summer (*n* = 45, CCL = 50.7 ± 15.3 cm) or autumn/winter (*n* = 254, CCL = 50.8 ± 11.3 cm; $F_{2,357} = 4.01$, $P = 0.012$). However, during the fishing season, the mean CCL of turtles observed in the presence (CCL = 50.4 ± 9.6 cm) or absence (CCL = 48.3 ± 13.5 cm) of FADs did not significantly differ ($H = 0.13$, $P = 0.710$). In particular, turtles found in the proximity of FADs were mostly medium (66.5%), followed next by small (19.3%) and then large (11.2%). The mean CCL of individuals entangled in longlines was higher (*n* = 33, mean CCL = 56.4 ± 10.8 cm) than the mean CCL of individuals that ingested anthropogenic debris (*n* = 40, mean CCL = 48.1 ± 11.8 cm), displayed marks from boat collisions (*n* = 13, mean CCL = 45.3 ± 10.6 cm), or were entangled in FAD-related debris (*n* = 7, mean CCL = 38.2 ± 9.5 cm; $F_{3,88} = 3.25$, P = 0.006).

Causes of rescue/death.—We found that the main cause of rescue (*n* = 71) or probable cause of death (*n* = 22) in Loggerhead Turtles were (1) gastrointestinal occlusion due to massive debris ingestion (43.0%), (2) entanglement in longlines (35.5%), (3) boat collision (14.0%), and (4) entanglement in plastic debris (FADs or floating debris; 7.5%). In particular, the direct entanglement of turtles in FADs accounted for 2.2% (*n* = 2) of the turtles rescued, and in these cases, the anchoring line of FADs was wrapped around the flipper of a turtle. Bycatch in floating debris accounted for 5.3% (*n* = 5) of rescues, although it was unknown if this debris came from land-based sources or derived from the anchor breaking of FADs. In these cases, plastic bottles and trash (Fig. 2) secured to nylon lines were entangled around the neck (*n* = 2), flippers (*n* = 2), or posterior limbs (*n* = 1) of turtles (Fig. 2). However, we found entanglement in plastic debris (FADs or floating debris of probable FAD origin) in 19.4% (*n* = 18) of rescued/dead turtles (*n* = 93). In particular, we found that 33.3%

Table 2. Distances (m) between Loggerhead Turtles (*Caretta caretta*) in the different seasons. Spring: March-May; summer: June-August; autumn: September-November; winter: December-January. During the fishing season (autumn and winter), the distances were computed in the presence (e.g., within 30 m) (Autumn FADs; Winter FADs) and absence (e.g., > 30 m) (Autumn-NO FADs; Winter NO FADs) of FADs. Each measurement is reported with the Mean (± SD), Minimum (MIN.) and Maximum (MAX.) distances.

Season	Mean Distance (m)	SD Distance (m)	MIN. Distance (m)	MAX. Distance (m)
Spring	102.5	112.1	0.7	834.3
Summer	108.1	181.6	4.7	1387.4
Autumn - FADs	33.6	41.2	0.2	237.8
Autumn - NO FADs	72.3	129.4	3.7	1338.1
Winter - FADs	265.2	160.1	39.1	397.8
Winter - NO FADs	144.1	63.8	40.1	230.8

Table 3. The Latitudes (first line) and Longitudes (second line) of captured Loggerhead (*Caretta caretta*) individuals of different sizes (CCL, cm) per season and during the fishing season in the presence or absence of FADs are reported. Each latitude and longitude measurement is reported with the Mean (± SD) value and number of observations (n). Significant differences were tested by Kruskal-Wallis among turtles of different sizes (small, medium and large turtles) per season and among seasons with and without (NO FADs) FADs at each life stage.

CCL	Spring (n = 62)	Summer (n = 45)	Autumn/Winter NO FADs (n = 104)	*Statistical Test*	Autumn/Winter WITH FADs (n = 150)	*Statistical Test*
< 40 cm	38°34'165" ± 297"	38°36'676" ± 143"	38°34967 ± 628"	H = 1.32, P = 0.512	38°38'804" ± 342"	H = 19.01, P < 0.001
	14°31'664" ± 534"	14°29'820" ± 426"	14°30'825" ± 822"	H = 1.41, P = 0.532	14°30'953" ± 625"	H = 0.02, P = 0.902
40 - 70 cm	38°35'198" ± 385"	38°35'024" ± 809"	38°36'819" ± 474"	H = 8.90, P = 0.010	38°38'509" ± 164"	H = 9.10, P < 0.001
	14°30'633" ± 930"	14°33'240" ± 504"	14°30'553" ± 528"	H = 2.87, P = 0.201	14°30'217" ± 265"	H = 1.30, P = 0.324
> 70 cm	only one dead turtle	only two rescued turtles	38°37'848" ± 945"	—	38°40'264" ± 952"	H = 1.80, P = 0.201
	only one dead	only two rescued	14°30'269" ± 788"	—	14°28'778" ± 727"	H = 3.50, P = 0.060
Statistical Tests	H = 4.20, P = 0.040	H = 2.40, P = 0.123	H = 7.90, P = 0.020	—	H = 3.30, P = 0.232	—
	H = 3.50, P = 0.060	H = 0.70, P = 0.404	H = 0.10, P = 0.956	—	H = 4.60, P = 0.132	—

(four carcasses and seven rescues) of turtles entangled in longlines (11 carcasses and 22 rescues) were also entangled in floating debris of possible FAD origin. Most commonly, we observed the longline coming from the beak of the turtle, then wrapped around the neck (n = 4), flippers (n = 3) or posterior limbs (n = 1) and tied to additional floating debris (of probable FAD origin; Fig. 2). We also observed direct bycatch in plastic debris (of probable FAD origin) for turtles already entangled in longlines. In this case, the longline coming from the beak of the turtle was free, and nylon lines secured to marine debris (of probable FAD origin) were entangled around the neck (n = 2) or flippers (n = 1) of a turtle (Fig. 2). In particular, we found these turtles both near (four rescues) or distant (three rescues and four carcasses) to FADs. We found other secondary problems in turtles entangled in longlines: massive debris in the stomach or empty stomach; limb mutilations; marks of boat collision on carapace; head and limbs; thinness, bleeding, and haemorrhage. In addition, massive debris in faeces (n = 10) and marks of boat collision (n = 3) were found for all turtles rescued in the proximity of FADs (n = 15).

Discussion

FADs and Loggerhead Turtle distribution.—In this study, we clearly demonstrated that Loggerhead Turtles associate with FADs in this Mediterranean area. Specifically, during the fishing season, we found (1) a higher number of turtles, (2) a clear overlap between Loggerhead Turtle and FAD locations, and (3) a lower average distance between Loggerhead individuals, suggesting that fishing areas may be potential foraging hotspots for Mediterranean Loggerhead Turtles. In our study, we found that FADs are mainly located in the north at the boundary between the continental shelf and oceanic habitats, confirming that fishermen arrange their device in transitional habitats according to the highest productivity and diversity of target fish species (D'Anna et al. 1999; Andaloro 2003; Andaloro et al. 2007). FADs might provide a reliable food source for foraging turtles, offering a concentration of pelagic prey species. The ropes and lines that are used to secure the FADs to the sea bottom encourage the settlement of algae, small crustaceans, and barnacles, which may be easily accessible prey for Loggerhead Turtles and potential food for small fish (for example the Pilot Fish, *Naucrates doctor*) and other predators (e.g., Swordfish, *Xiphias gladius*, or Striped Dolphin, *Stenella coeruleoalba*). Different studies have highlighted the importance of pelagic foraging by Loggerhead Turtles through the identification of stomach contents and inferences via stable isotope analyses (Dodd 1988; Bjorndal 1997; Plotkin and Amos; Bjorndal et al. 2000; Revelles et al. 2007a, b). Moreover, it is well known that, in some Mediterranean areas, Loggerhead Turtles may exploit food resources in fishing zones, apparently attracted by bait or discarded materials, such as longline bait or prey that has settled on anthropogenic debris (Dodd 1988; Plotkin et al. 1993; Tomás et al. 2001, 2008; Revelles et al. 2007b).

We found that the spatial distribution of FADs may influence Loggerhead Turtle distribution with a significant effect on annual and seasonal movements. During the fishing season, Loggerhead Turtles showed a strong tendency to aggregate near FADs, shifting their distribution to higher Latitudes than in other seasons. It is possible that in these months, Loggerhead individuals might spend more time foraging in fishing areas, simply feeding in the proximity of FADs when the opportunity presents itself. In contrast, outside of the fishing season, the turtles might prefer habitats with a higher probability of locating and capturing desirable prey, such as benthic prey in neritic habitats (Musick and Limpus 1997; Bentivegna 2002; Bolten 2003; Luschi and Casale 2014) or epipelagic food transported by the local water circulation currents (Bentivegna et al. 2007).

In this study, we identified important foraging grounds for the Loggerhead Turtle, suggesting that the geomorphology of the volcanic islands may have a significant influence on the seasonal distribution of foraging individuals and on the availability of food resources along the coastal area (Bowen et al. 1995; Bolten 1999; Fauchald 1999; Bentivegna et al. 2007; Boyle et al. 2009). In particular, in summer, the individuals are mainly located in the north-western area, characterized by neritic habitats and a high variability of the sea bottom structure (Blasi and Boitani 2012). It is possible that turtles may prefer to exploit the neritic habitats of the Aeolian Archipelago for at least a part of their life (Laurent et al. 1998; Revelles et al. 2007b) following seasonal changes of prey availability (Musick and Limpus 1997; Bowen et al. 2004; Bentivegna et al. 2007; Boyle et al. 2009; Luschi and Casale 2014). Shallow waters provide a wide range of prey species that peak in diversity and abundance in different seasons (Gelwick et al. 1997). Water depth and different physiographic factors (e.g., underwater rocks) are known to correlate with the movement pattern dynamics influencing prey species distributions (Gelwick et al. 1997; Blasi and Boitani 2012). Consequently, we hypothesize that the Loggerhead distribution may seasonally change following the availability of this prey (Fauchald 1999). Fidelity to specific foraging habitats by Loggerhead Turtles has been reported in several Mediterranean areas (Limpus and Limpus 2003; Broderick et al. 2007; Schofield et al. 2010a, b; White et al. 2010; Rees et al. 2013), such as the Adriatic/northern Ionian Sea (Cardona et al. 2014) and along the Tunisian and Libyan coasts in the southern Mediterranean (Casale et al. 2008). However, in this study, we found that the Latitude of turtles increased across years, suggesting that the massive presence of FADs might have long-term biological consequences. FADs might provide a reliable food source for Loggerhead Turtles by offering a concentration of prey species during the fishing season. Thus, they also might potentially affect the foraging behavior of turtles by habituating them to temporary and unnaturally aggregated food sources (Parker et al. 2005), with direct and indirect consequences on seasonal movements and selection of foraging hotspots. It is well known that in this area, intensive fishing operations of coastal areas and a lack of protection of foraging habitats in neritic water have changed the distribution of food resources (Blasi and Boitani 2014; Blasi et al. 2015), which in turn may have affected the distribution of turtles and the costs of feeding competition. FADs have been already suggested to potentially act as ecological trap (Hallier and Gaertner 2008; Dagorn et al. 2010, 2013) by affecting migration routes, modifying the diet of pelagic species, and causing prey switching (Brock 1985) or poorer feeding conditions (Menard et al. 2000).

We found that the Aeolian Archipelago is frequented by Loggerhead Turtles of different sizes, from small juveniles to large adults. The size of turtles in the presence or absence of FADs during the fishing season seems to be quite similar. This suggests that turtle-FAD interaction occurs in all life stages, from juvenile to adult. However, we found larger turtles more frequently during the fishing season than in other seasons. The most recent results have revealed numerous exceptions to the typical distribution pattern proposed for this species (Hatase et al. 2002; Bolten 2003; Hawkes et al. 2006; Rees et al. 2010). For example, the prolonged residence of females in oceanic habitats (Hatase et al. 2002, 2007; Hawkes et al. 2006; Rees et al. 2010) suggests the possibility of pelagic feeding in adults (Tomás et al. 2001; Revelles et al. 2007a; Reich et al. 2010), and this might also explain why, in this study, we observed turtles with sizes typical of the adult stage in oceanic habitats. Because adult turtles have a varied diet (McClellan and Reed 2007; Revelles et al. 2007b; Casale et al. 2008; Mansfield et al. 2009; Zbinden et al. 2011) it is possible that these individuals prefer habitats associated with a higher probability of recruiting selected prey. Consequently, larger turtles might be more frequent during the fishing season as a result of an easier access to FAD-related food resources. Stable isotope analyses conducted in this area suggest that Aeolian turtles most likely feed in pelagic habitats, although some benthic species may be consumed (Tomassini L. et al., unpubl. data). Pelagic prey might be more common (Mills 2001; Richardson et al. 2009) and easily accessible than those in benthic habitats due to local tectonic structures involving the volcanic islands, which comprise extensive neritic and oceanic habitats within short distances (Blasi and Boitani 2012). We cannot exclude that the location of productive foraging patches recruited in different life stages (Bolten 2003; Bentivegna et al. 2007; Cardona et al. 2014) might potentially influence Loggerhead Turtle movements during pelagic feeding (Bentivegna et al. 2007; Revelles et al. 2007b; Cardona et al. 2014). In spring, the season of pelagic blooms along the coastal area (Siokou-Frangou et al. 2010), we observed Loggerhead Turtles feeding on Mauve Stingers and Velella. In addition, we found more small immature individuals than we did in other seasons.

Because we have no data on Loggerhead Turtle distribution prior to the implementation of fishing practices with traditional FADs (more than 10 y), we cannot unequivocally demonstrate that FADs have been the major cause of the distribution of Loggerheads in the Aeolian Archipelago, although the strong evidences we found cannot be neglected. Indeed, our study proved to be important for modelling the Loggerhead Turtle distribution in the Aeolian Archipelago with important findings that may influence future conservation strategies. Our results highlighted that the north-western part of the island is a foraging hotspot for Loggerhead Turtles that must be considered in the implementation of the future marine Protected Area and where FAD arrangements should be banned. We met our goal of investigating the influence of FADs on the seasonal distribution patterns of Loggerhead Turtles and the most affected foraging areas, a fundamental need for identifying appropriate conservation measures in the Mediterranean area (Casale et al. 2010).

FAD-related impact.—Our results provide strong evidence that bycatch in pelagic longlines is an important threat and cause of death for Loggerhead Turtles in the Aeolian Archipelago (35.5% of rescues; Margaritoulis et al. 2003; Carreras et al. 2004; Orós et al. 2005; Casale et al. 2007; Casale and Margaritoulis 2010). However, we found that bycatch in plastic debris was very common, accounting for 19.4% of the primary and secondary causes of rescue/death in the Aeolian area. In particular, bycatch in floating materials (nylon and debris from FADs or land-based sources) was very common in turtles entangled in pelagic longlines (33% of longlines cases). This suggests that FADs may represent a potential additional risk and source of mortality for these individuals attracted to FADs for easily accessible food resources. Consequently FADs may act as an ecological trap reducing the probability of survival of turtles (Hallier and Gaertner 2008; Dagorn et al. 2010, 2013). We found that FADs may be dangerous for Loggerhead Turtles because the turtles became entangled or injured in the anchoring lines and debris of FADs at different parts of the body, particularly the neck and flippers, as well as the posterior limbs. These entanglements produced injuries or loss of limbs or limited the ability to swim and dive, potentially drowning the turtle if held underwater (Nelms et al. 2015). These entanglements also lead to a general state of under-nutrition based on our observations of their poor body condition probably due to the inability of turtles to successfully capture selected prey (Nelms et al. 2015). It is well known that the effects of entanglement are injuries, such as abrasions or loss of limbs and a reduced ability to avoid predators or forage efficiently due to drag, leading to starvation or drowning (Gregory 2009; Barreiros and Raykov 2014; Vegter et al. 2014). In addition, entanglement may cause long-term suffering and a slow deterioration (Barreiros and Raykov 2014). Compromised turtles might also increase the ingestion of plastic from other marine debris more easily accessible on the water surface (Derraik 2002; Tomas et al. 2002; Lazar and Gračan 2011; Campani et al. 2013). We found that the most common cause of rescue/death for Loggerhead Turtles in the Aeolian Archipelago was gastrointestinal blockage due to the massive ingestion of plastic and debris (43% of causes of rescue). Especially, we found massive debris in the stomach of carcasses and in the faeces of turtles entangled in pelagic longlines or rescued in the proximity of FADs. As marine debris in the Mediterranean becomes more common, these items might be mistakenly consumed by these individuals (Tomás et al. 2002; Gregory 2009; Mrosovsky 2009; Hoarau et al. 2014) or accidentally ingested when mixed with normal dietary items (Di Beneditto and Awabdi 2014; Nelms et al. 2015). For example, one study found that juvenile Green Turtles (*Chelonia mydas*) consumed debris because it was attached to the macroalgae they target directly (Di Beneditto and Awabdi 2014). We cannot exclude that at least some of these plastic ingestions may derive from direct FAD interactions, but further investigations are needed to confirm this hypothesis (Nelms et al. 2015).

There are few investigations of the susceptibility to debris entanglements of the various sea turtle life stages, but one study found that for Olive Ridleys, the majority of trapped animals were large juveniles and adults (Santos et al. 2012). In this study, we found that the turtles that were entangled in debris were smaller (mean CCL = 38.2 ± 9.5 cm) than turtles with other problems. Although FADs mainly occur in oceanic habitat, we did not find that FADs are preferentially selected by juvenile Loggerhead Turtles based on spatial overlap between different size classes and FAD locations. Nevertheless it is possible that the smaller size of young juveniles enhances the possibility of bycatch in debris. However, the turtles that were entangled in longlines had large sizes (mean CCL = 56.4 ± 10.8 cm) than other captured turtles and several of these turtles (33.3%) also showed debris entanglement. Consequently we conclude that FAD bycatch has the potential to affect all life stages of the Loggerhead Turtle in the Mediterranean area.

This study on association of Loggerhead Turtles with FADs is a first step to understanding the impact of such illegal devices in the Mediterranean area. FADs have already been recognized as a major threat to many marine species in other areas (Hallier and Gaertner 2008; Dagorn et al. 2010, 2013). Although in our study only two turtles were found directly entangled in anchored FADs, additional turtles were found entangled in floating debris of probable FAD origin. It was difficult to establish how many of these debris entanglements derived from direct captures in FADs or from floating FADs that had broken from their anchorages because they were not removed by fishermen after the fishing season. The rates of entanglement in debris from FAD sources may be underestimated because of the difficulty in assessing the exact debris origin, e.g., from FADs or from land-based sources. We recommend the implementation of stricter regulations and controls that ban the use of illegal FADs in the Mediterranean basin. We also recommend that fishermen remove FADs at the end of the fishing season (December) to limit potential entanglement by Loggerhead Turtles. We suggest further studies to assess the potential risk that such illegal devices pose on Loggerhead Turtles, current bycatch levels and consequent mortality rates in other Mediterranean areas.

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