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The Gulf of Manfredonia: a new neritic foraging area for loggerhead sea turtles in the Adriatic Sea

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Abstract. The Adriatic Sea is an important foraging area for the loggerhead sea turtle, *Caretta caretta*, but neritic habitats for this species along the Italian coast were identified in the northern shallow area only. The Gulf of Manfredonia is a relatively wide shallow area in the south-west Adriatic and its features and preliminary information make it a potential foraging ground for turtles. In order to assess sea turtle occurrence in the area, we monitored seven bottom trawlers based in the port of Manfredonia during the period Oct 2010 – Jul 2011 through a voluntary logbook programme, resulting in a total of 62 turtle captures during 617 fishing days. Since a turtle capture represents a rare event during such sampling, data were analysed by a zero-inflated Poisson (ZIP) model. Results indicate that: (i) the Gulf is a neritic foraging ground for loggerhead turtles which occur there with a relatively high density comparable to other Mediterranean foraging grounds, (ii) it is frequented by a wide range of size classes, including small juveniles as well as adults, (iii) the highest occurrence is during the period Jun-Dec, (iv) over 1700 turtle captures occur in the Gulf annually. Preliminary findings about recaptured individuals suggest that part of the turtles are resident in the area. The peculiar features of the Gulf of Manfredonia and the collaboration of the fishing fleet, make it a valuable index site for studying current trends of sea turtle populations at sea as well as other aspects of sea turtle biology and conservation.

Keywords. Sea turtle, trawling, bycatch, neritic habitat, Mediterranean.

INTRODUCTION

The Adriatic Sea has been recently identified as one of the most important areas for sea turtles in the Mediterranean, notably loggerhead turtles, *Caretta caretta*, while the

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other two sea turtle species frequenting the Mediterranean, the leatherback, *Dermochelys coriacea*, and the green turtle, *Chelonia mydas*, occur in relatively low numbers in the Adriatic (Casale et al., 2003; Lazar et al., 2004a; Lazar et al., 2008). The Adriatic is clearly an important foraging ground for loggerhead turtles of all life stages, as indicated by several studies. First, high numbers of turtles are incidentally caught by fishing gears (Lazar and Tvrtković, 1995; Casale et al., 2004). Second, tag recoveries and satellite tracking of adults tagged while breeding in Greece showed that the Adriatic is one of the few foraging grounds for adult loggerheads from Greek rookeries (Margaritoulis et al., 2003a; Lazar et al., 2004b; Zbinden et al., 2008; Hays et al., 2010; Schofield et al., 2010; Zbinden et al., 2011) and a few turtles from Turkey and Cyprus were also found (Lazar et al., 2004b). Third, medium-long term permanence of juvenile loggerhead turtles in the area has been shown by tag returns (Casale et al., 2007b). Fourth, foraging in the Adriatic has been specifically assessed (Lazar et al., 2002; Lazar et al., 2011a). Fifth, the Adriatic and in particular the southern part, is an important developmental area for loggerhead turtles in the first years of life, probably hatched in Greece (Casale et al., 2010).

Loggerhead sea turtles are listed as endangered in the IUCN Red List of Threatened Species (IUCN, 2011). The main identified threats at sea in the Mediterranean are incidental catch in fishing gear, collision with boats, and intentional killing (Tomás et al., 2008; Casale et al., 2010; Casale, 2011) that appear to increase overall mortality (Casale et al., 2007c; Casale et al., 2010) and as a whole represent a high level of threat (Wallace et al., 2011). There is growing evidence of several anthropogenic threats in the Adriatic: the aforementioned incidental catch and also collision with boats, debris ingestion and pollutants (Affronte and Scaravelli, 2001; Franzellitti et al., 2004; Casale et al., 2010; Lazar and Gračan, 2011; Lazar et al., 2011b).

Given the scale of movements and the different habitats experienced during their lives, information about habitat use and most frequented areas is key for planning sea turtle conservation (Hamann et al., 2010). As a general tendency, small juveniles feed on preys in the epipelagic zone, usually in oceanic areas (i.e., out of the continental shelf) and as they grow they tend to frequent more neritic habitats (i.e., on the continental shelf), where they feed on benthic preys (Musick and Limpus, 1997; Bolten, 2003; Casale et al., 2008). So far, neritic habitats for loggerhead turtles in the Adriatic were identified in the northern wide shallow area while the southern Adriatic, with deeper waters, was thought to be frequented by smaller juveniles (Casale et al., 2004; Casale et al., 2010). However, recent anecdotal information suggested that the wide shallow area of the Gulf of Manfredonia, in the southern Adriatic, might host a neritic foraging area for high numbers of turtles.

This study aims to provide a preliminary assessment of the occurrence of loggerhead sea turtles in the Gulf of Manfredonia, in the context of the current knowledge about the distribution of the species in the Adriatic Sea.

MATERIALS AND METHODS

The incidental catch by fishing gear (or bycatch) is commonly used as an index of turtle abundance (e.g. Casale et al., 2004) and with appropriate units of fishing effort it allows comparison among

different areas. In neritic areas turtles are particularly subject to capture by bottom trawls, since this fishing gear captures all animals at sea bottom, including turtles when they feed on benthic preys.

In the 10-months period from 1 October 2010 to 31 July 2011 the turtle bycatch of seven bottom trawlers based in the port of Manfredonia (Italy) (Fig. 1) was monitored through a voluntary logbook programme similar to previous studies (e.g., Carreras et al., 2004; Casale et al., 2007a; Cambiè, 2011), i.e. fishermen periodically reported the number of fishing days and the number of turtles caught. This period represents a full fishing year because of the fishing closure in August-September, however in 2011 fishing effort was reduced in the period Jan-Mar due to strikes and this period was excluded from the following analysis. Vessel length ranged between 14.7 and 16.8 m (mean: 15.6 m; SD: 0.9 m; n = 7), headrope length (the upper of the two horizontal ropes of the trawl net's opening) was ≈ 40 m, the typical tow duration was 1-1.5 hrs, with 5-7 hauls per day, and speed ranged between 2.9 and 4 knots (data provided by the fishermen). Fishermen were also interviewed about the perceived trend of turtle catch categorized into three cases: increasing, stable, decreasing. A sam-

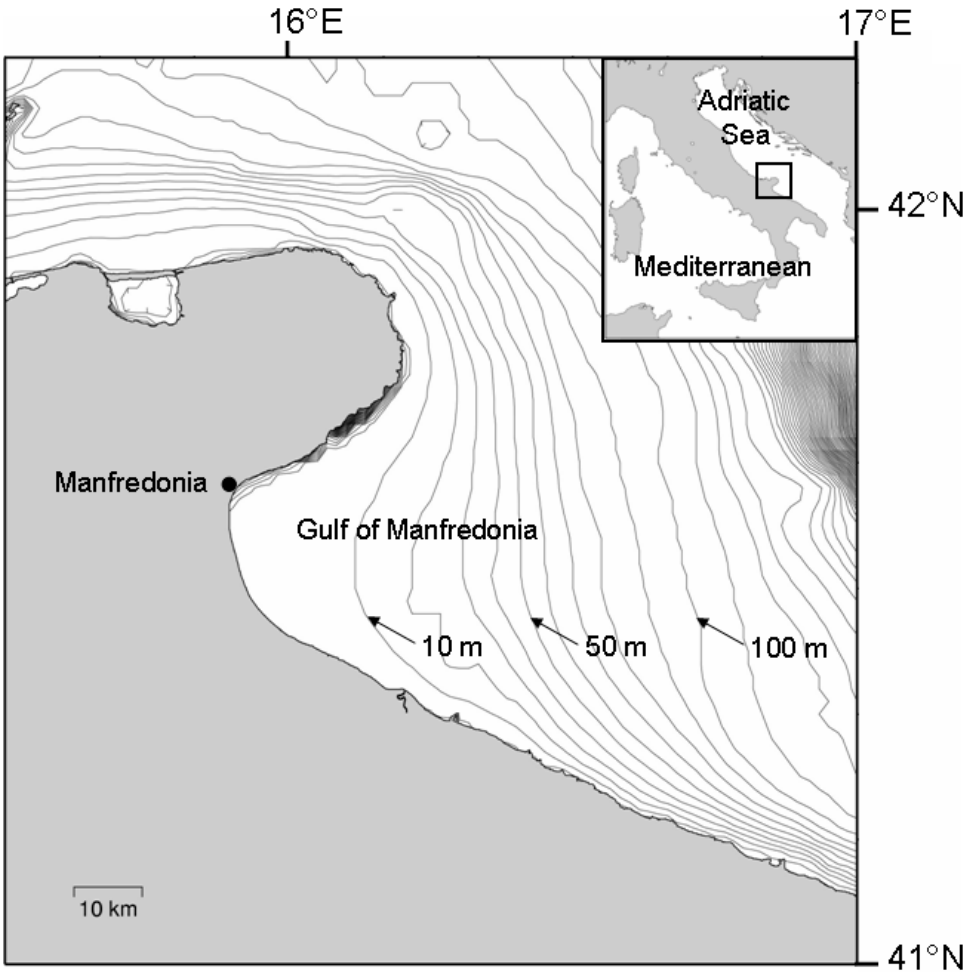

Fig. 1. Study area of the Gulf of the Manfredonia with 10 m isobaths.

ple of 121 turtles captured by the monitored or other bottom trawlers based at the Manfredonia port were landed and measured (curved carapace length notch to tip, CCLn-t) (Bolten, 1999) and the species determined. Before release turtles were tagged on both the front flippers with inconel tags style 681 (National Band and Tag, Newport, KY, USA), stamped with an alphanumeric code and a return address, in order to assess multiple captures.

Catch data were analysed with a zero-inflated Poisson (ZIP) model, an extension of generalized linear models (GLM) (Lambert, 1992) already used in a similar study (Cambiè, 2011). In sea turtle bycatch data, captures typically comprise a small part of the units of fishing effort (days, in the present study) and the majority of units have zero values (no turtle catch) while just a few have non-zero values (turtle catch). In such cases, the frequency of zeros is higher than that expected in a Poisson or a negative binomial distribution and zero-inflated models are preferred since they separately calculate the probability of being in a "perfect state" (zero catch) and in a "imperfect state" (including zero and non-zero values). The model was run with the pscl package for ZIP analysis (Zeileis et al., 2008; Jackman, 2011) in the R environment (R Development Core Team, 2009). The model provided catch rates (CRs) in the form of turtles per day per vessel. For comparison with other studies, other two CRs were calculated: turtles per month per vessel, and turtles per year per vessel.

The total number of turtles caught by the Manfredonia trawling fishery in the period monitored by this study was estimated from the total fleet of 204 trawlers (source: Coast Guard of Manfredonia) that are of similar size of monitored vessels.

Fishermen from 11 trawlers, including the monitored ones, were interviewed about turtle trends.

RESULTS

A total of 671 fishing days were monitored and 62 turtle captures recorded (Table 1). All the landed individuals in the framework of a wider project including more vessels than those monitored in this study, were loggerhead sea turtles, *Caretta caretta*, and ranged from 28.5 to 82 cm CCL (mean: 56.1 cm; SD: 11.4 cm; n = 121) (Fig. 2). Turtle size was not significantly different among months of capture (Kruskal-Wallis test; H = 12.1; P = 0.21; n = 121). Two turtles were re-captured (previously captured by trawlers in the study area and tagged) during the study period: turtle 1713A was captured the first time on 30 Sep 2010 and the second time on 15 Dec 2010, while turtle 1731A was captured on 4 Nov 2010 and 22 Apr 2011, respectively.

Table 1. Monitored fishing days of bottom trawlers in the Gulf of Manfredonia and by-caught turtles.

	Monitored days	N Turtles	Range turtles/vessel day
Oct	107	16	0-2
Nov	97	12	0-1
Dec	87	12	0-2
Apr	90	3	0-1
May	96	1	0-1
Jun	97	7	0-2
Jul	97	11	0-2
Total	671	62	

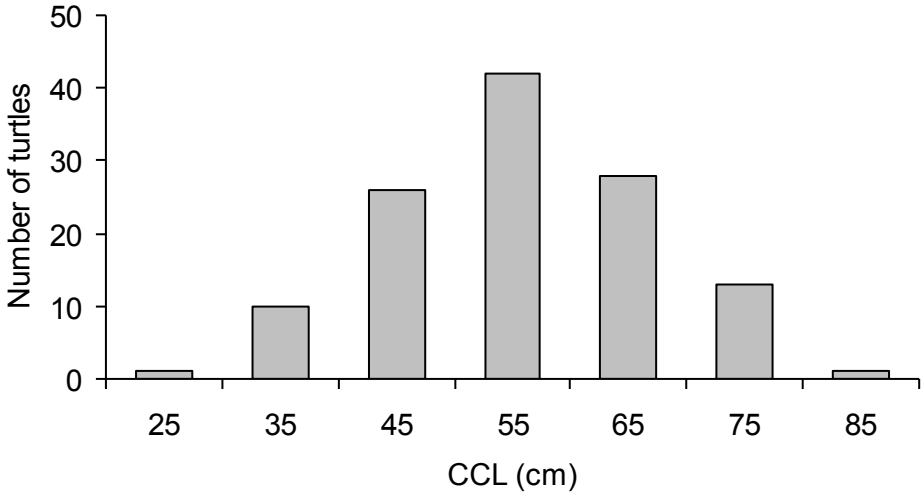

Fig. 2. Frequency distribution of curved carapace lengths (CCL) of 121 loggerhead turtles incidentally caught by bottom trawlers in the Gulf of Manfredonia.

The value of the dispersion parameter of the overall ZIP model (φ) was close to 1 (φ = 0.99), indicating that the model fitted the data quite well. The logistic component of the model gave a probability p = 0.46 of zero turtle by-catch and therefore a probability 1 - p = 0.54 that sea turtle by-catch followed a Poisson distribution with mean (λ) = 0.17, yielding a mean value of 0.09 (± 0.01 SE) turtles day^{-1} vessel^{-1}. Since a difference by month was detected (Kruskal-Wallis test; H = 17.7; P < 0.01; n = 671), in contrast with vessels (Kruskal-Wallis test; H = 1.0; NS; n = 671), another ZIP model was run on data aggregated by month in order to calculate mean CR and SE for each month. Monthly CRs ranged between 0.01 and 0.15 turtles day^{-1} vessel^{-1}, with higher CRs in Oct-Dec and Jun-Jul than in Apr-May (Fig. 3; Table 2). Considering the average fishing days per month as 13.1 (mean of the fishing days per month per vessel), CRs ranged from 0.13 and 1.96 turtles month^{-1}.

Table 2. Results of the ZIP model based on turtle by-catch data (response variable) with pair-wise comparison with only one covariate (month) from seven bottom trawlers fishing in the Gulf of Manfredonia.

	Logistic regression part			Poisson regression part		
Factors	Coefficient	z-value	P-value	Coefficient	z-value	P-value
Apr vs Jun	8.84	0.04	NS	2.25	1.98	0.05
Apr vs Nov	-7.39	0.00	NS	1.31	2.01	0.04
Apr vs Oct	7.43	0.04	NS	2.10	2.32	0.02
Jun vs May	-7.36	-0.03	NS	-3.41	-2.22	0.03
Jul vs May	-7.92	-0.01	NS	-2.92	-2.06	0.04
Nov vs May	0.83	0.00	NS	-2.47	-2.37	0.02

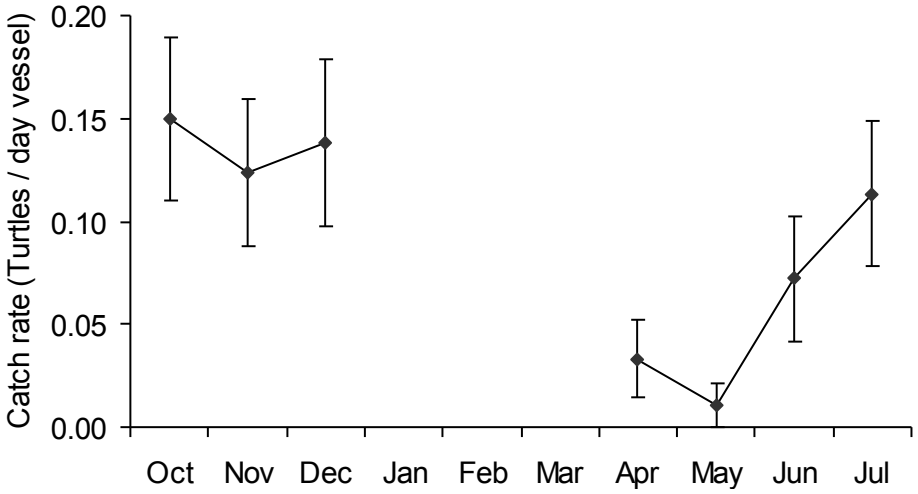

Fig. 3. Mean and SE sea turtle catch rates (turtle per day per vessel) by bottom trawlers in the Gulf of Manfredonia from October 2010 to July 2011.

The overall mean CR was 8.6 (SD: 2.4) turtles yr^{-1} $vessel^{-1}$. If this catch rate is applied to the 204 bottom trawlers based at the port of Manfredonia, the total catch by the local trawl fleet would be 1749 (SD: 484) turtles yr^{-1}, which concerns only the months adequately monitored in this study and therefore represents an underestimation of the actual annual catch.

Most fishermen (10 out of 11 interviewed boats or 90.9%) declared that turtle catch is increasing in the study area while one fisherman declared that the trend is stable.

DISCUSSION

Present results provide the first evidence of the importance of the Gulf of Manfredonia as a neritic foraging ground for the loggerhead sea turtle in the Mediterranean. Comparison with other Mediterranean areas (Table 3) indicates that turtle density in the study area is one of the highest known so far. Moreover, the re-capture of two turtles in the same area after 2-5 months suggests that part of the turtles are resident in the area and not just migrating along the Adriatic coasts (Schofield et al., 2010).

The highest CRs were observed in the months Jun-Jul and Oct-Dec, suggesting higher turtle occurrence during these months and during the fishing closure in Aug-Sep, then during the period Apr-May. Such a seasonal variation of turtle occurrence in the study area may be due to several factors, but a major one is probably temperature, that drops in the range 9-15°C during Jan-Apr in the shallow waters of the Gulf of Manfredonia, rising to about 18°C in May and over 23°C in June (source: monthly SST contours by Maptool, www.seaturtle.org, derived from NOAA GOES Daily SST satellite data). For comparison, lower turtle occurrence during winter was explained by low temperatures in the north Adriatic (<11-12°C; Lazar et al., 2003) and in the Ligurian Sea (12-13°C; Lauriano et al., 2011).

Table 3. Sea turtle catch rates per vessel, by bottom trawling in the Mediterranean.

Country	Area	Turtle year^{-1}	Turtle month^{-1}	Turtle day^{-1}	Source
Italy	Gulf of Manfredonia	8.6	0.13-1.96	0.01-0.15	present study
Algeria		1.41			(Laurent, 1990)
Croatia		3-10			(Lazar and Tvrtković, 1995)
Egypt		1.72			(Nada and Casale, 2011)
France	Mainland	0-3			(Laurent, 1991)
Greece	Thracian Sea (Aegean)			0.0625	(Margaritoulis et al., 2003b)
Italy	North-West Adriatic			0.052-0.438	(Vallini et al., 2003; Casale et al., 2004)
Italy	Central Med - Lampedusa			0.376	(Casale et al., 2007a)
Italy	Central Med - Other	38-161			(Casale et al., 2007a)
Spain	North		0.07		(Alvarez de Quevedo et al., 2006)
Spain	Balearic		0.018		(Carreras et al., 2004)
Tunisia	Gulf of Gabes			0.121	(Jribi et al., 2007)
Turkey	South	8.5-11			(Oruç et al., 1997; Oruç, 2001)

The Gulf of Manfredonia is frequented by loggerhead turtles of a wide range of sizes. Bottom trawlers capture turtles while they are at the sea bottom, probably feeding on benthic preys, and the capture of very small individuals (min: 28.5 cm CCL) further supports the recent "opportunistic model" in which loggerhead turtles take advantage of the peculiar oceanographic features of the Mediterranean to start feeding on benthic preys earlier (Casale et al., 2008) than they do in other areas like in the Atlantic ocean (Bolten, 2003). The south Adriatic and Ionian Seas are developmental areas for juveniles in the first years of life (Casale et al., 2010) which predominantly freed upon pelagic preys, but present results indicate that they take the opportunity of shallow areas like the Gulf of Manfredonia and possibly others to feed on benthic preys as well. The proportion of turtles > 70 cm CCL, representing the adult size range for Mediterranean loggerheads (Margaritoulis et al., 2003a; Casale et al., 2005), indicates that the Gulf is also an inter-breeding foraging area for adults. Actually, the proportion of turtles in this size range (11.6%; n = 121) is not lower than the one observed in the wider neritic area of the north Adriatic (6.6%; n = 61) (Casale et al., 2004), that is well known as a foraging ground for adults breeding in Zakynthos (Greece) (Schofield et al., 2010; Zbinden et al., 2011).

While the Mediterranean is frequented by loggerhead turtles belonging to two Regional Management Units (Wallace et al., 2010), available data indicate that the Adriatic is a foraging ground for the Mediterranean loggerheads only, at least from rookeries in Greece, Turkey and Cyprus (Lazar et al., 2004b; Giovannotti et al., 2010), therefore these, in particular Greece, are the most likely rookeries of origin for the turtles foraging in the Gulf of Manfredonia.

Since the period Jan-Mar was excluded from the analysis due to strikes which reduced the fishing effort, probably the annual catch rate per vessel and consequently the

total number of capture events per year by the large trawl fishing fleet of Manfredonia is higher than 1700. The level of associate mortality needs proper investigation, but it is probably low due to the short tow duration, which is the main parameter affecting mortality caused by forced apnoea (Sasso and Epperly, 2006). In the north Adriatic, a mortality rate of 0.6% was observed from trawlers with a mean tow duration of 78 min (Casale et al., 2004), comparable to the one adopted by the Manfredonia trawlers, while a specific study in the Gulf of Mexico reported very low mortality from tow durations below 60 min (Sasso and Epperly, 2006).

According to fishermen, turtle occurrence is increasing in the Gulf of Manfredonia, in contrast to negative trends reported by fishermen from other Mediterranean areas, such as the Balearic islands (Spain), Egypt and the area between Sicily and Tunisia (Carreras et al., 2004; Casale et al., 2007a; Nada and Casale, 2011). Trends of sea turtle populations are very difficult to obtain, especially at sea. The most used index of turtle abundance is the number of nests, but it has intrinsic fluctuations and it is an index of current adult female abundance, not of the current population which is mostly made by juveniles. Current population trends will be evident at nesting sites only after a long time, due to the long maturation of loggerhead turtles that in the Mediterranean takes about 15-28 years (Casale et al., 2009; Casale et al., 2011). The major nesting site from which most of the turtles foraging in the study area probably originate is Zakynthos (Greece), where no clear nesting trend has been reported so far (Margaritoulis, 2005). The trend reported by fishermen in the present study either may reflect the current trend of the population that will be observed on Zakynthos in the future or may be the combination of trends and change of foraging area by different sub-populations or could be due to a misperception by the fishermen.

This can only be assessed by a medium-long term monitoring project using catch rates as an index and by assessing the origin of turtles through genetic markers. The peculiar features of the Gulf of Manfredonia, i.e. a relatively small area frequented by high numbers of turtles of a wide range of size (age) classes and accessible through the collaboration of a large fleet of trawlers with several hundreds of captures per year, make it a valuable index site for studying current trends of sea turtles population at sea as well as other aspects of sea turtle biology and conservation.

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