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Tag recoveries of the loggerhead sea turtle *Caretta caretta* in the eastern Adriatic Sea: implications for conservation

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Data on tag recoveries of 31 adult female and two juvenile loggerhead turtles (*Caretta caretta*) along the eastern Adriatic coast were analysed. All adult females originated from Mediterranean nesting areas: 29 from Greece, one from Cyprus and one from Turkey. This is the largest aggregation of long-distance tag recoveries in the Mediterranean for the loggerhead population nesting in Greece. The short period elapsed between the last observation of some turtles on the nesting beach and their recovery suggests the existence of a migratory pathway from the Ionian Sea into the Adriatic. Recoveries of some turtles within a period of a year indicate that loggerheads reside in the Adriatic for some time, suggesting that some individuals may demonstrate a level of site fidelity for these marine habitats. The high concentration of tag returns in the shallow northern Adriatic highlights this region as an important feeding habitat, for the population nesting in Greece in particular. The Ionian–Adriatic loggerheads form an important management sub-unit for this nesting population.

INTRODUCTION

The Mediterranean basin contains one of the largest populations of the endangered loggerhead sea turtle *Caretta caretta* (Linnaeus 1758). Although the latest colonization happened about 12,000 years ago from nesting colonies in the western Atlantic, recent studies suggest that loggerheads in the Mediterranean have genetically differentiated, forming several management units (Margaritoulis et al., 2003). Therefore, for planning an effective regional conservation strategy it is important to understand how turtles move through the basin and what linkages exist between the reproductive, feeding and wintering habitats they use.

Data on the movements of loggerheads in the Mediterranean basin are rather scarce. The first studies were based upon analyses of tag-returns (Margaritoulis, 1988; Argano et al., 1992) and by-catch (Camiñas & De la Serna, 1995), whilst satellite tracking has only been used on a few individuals (Hays et al., 1991; Bentivegna, 2002; Godley et al., 2003). Hence, present knowledge on loggerhead migration in the Mediterranean is a conjecture mostly based on recoveries of tagged turtles. These long-term studies, limited by the low recapture rate ranging from 2.2% (Margaritoulis, 1988) to 4.8% (Argano et al., 1992), suggest a wide dispersion of loggerheads throughout the region, including movements between the Mediterranean and the Atlantic.

Grouped tag recoveries support the hypothesis of the turtle's non-random dispersal (Meylan, 1995). Indeed, numerous recaptures of adult female loggerheads tagged in Greece suggested the existence of a wintering area in the Gulf of Gabès in Tunisia (Margaritoulis, 1988). The subsequent study of Laurent & Lescure (1994) in the Gulf of Gabès supported this hypothesis, and has shown that the region holds benthic foraging habitats shared by adults and juveniles.

Groombridge (1989) and Argano et al. (1992) speculated as to the possible importance of the Adriatic as another wintering and/or foraging area for loggerheads. However, only 13 tag recoveries in the Adriatic Sea, of which six in the eastern part, within the first decade of tagging programmes in the Mediterranean (Margaritoulis, 1988; Argano et al., 1992) gave little subsistence to this hypothesis. Recent estimations have pointed to a by-catch of about 2500 turtles yearly in the eastern Adriatic trawl fishery (Lazar & Tvrtković, 1995), and additional 3600 specimens caught in the western Adriatic (Casale et al., in press). Since the nesting of loggerheads along the Adriatic coasts is exceptionally scarce (Margaritoulis et al., 2003), the presence of so many turtles in these waters may be explained by immigrations from rookeries outside the Adriatic. Hence, with this paper we attempt to answer the question which loggerhead nesting populations are utilizing the Adriatic Sea, and are therefore affected by Adriatic fisheries as the main threat to sea turtles in this area.

MATERIALS AND METHODS

The study area incorporated 138,590 km of the eastern Adriatic Sea, covering territorial waters of four countries with the total mainland coastline of 2091 km (Figure 1). The most belongs to Croatia (85% or 1777 km), followed by Montenegro (249 km), Slovenia (44 km), and Bosnia and Herzegovina (21 km) (Bertić, 1987). The results are based upon recoveries of tagged loggerhead turtles

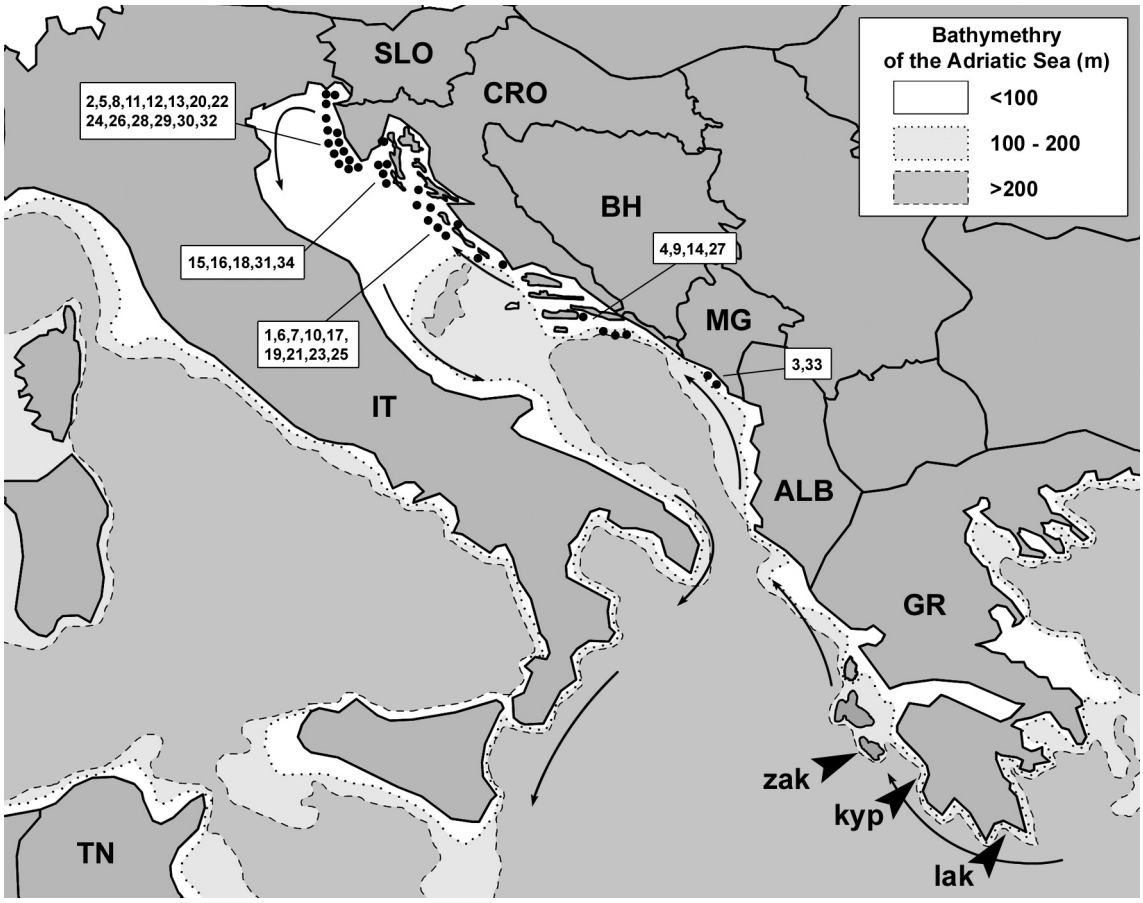

Figure 1. Map showing the recoveries of tagged loggerhead turtles *Caretta caretta* in the eastern Adriatic Sea. Numbers in boxes refer to respective record numbers (No.) in Table 1. (→, direction of prevalent surface currents, simplified from Cushman-Rosini et al., 2001; zak, Zakynthos Island; kyp, Kyparissia Bay; lak, Lakonikos Bay; IT, Italy; SLO, Slovenia; CRO, Croatia; BH, Bosnia and Herzegovina; MG, Montenegro; ALB, Albania; GR, Greece; TN, Tunisia).

reported by fishermen and local inhabitants between 1993 and December 2002.

In Croatia, fishermen and coastal inhabitants were approached, through a widespread public awareness campaign carried out by the Adriatic Marine Turtle Programme (AMTP), and were encouraged to provide basic information on recoveries such as species identification, tag code and return address, date and locality of finding, condition of specimen (dead, alive, injured) and recovery method. The data were transmitted to the AMTP centre at the Croatian Natural History Museum through a national network that includes four state marine research institutions along the Croatian coast. In Slovenia, systematic data collection and an 'at-sea' loggerhead tagging programme were initiated in 1998 by the Aquarium Piran (V. Žiža, personal communication). In other countries involved in the study (13% of the mainland coastline) there was no systematic tag collection; they were directly reported to the tagging institution.

RESULTS

We present data on 34 recoveries of tagged loggerhead turtles (Table 1). Twenty-nine of these (85.3%) come from Croatia, three (8.8%) from Slovenia, and two (5.9%) from Montenegro (Figure 1). Twenty-eight recoveries (82.4%) were reported to the AMTP, and six (17.6%) directly to the tagging institution. The recovery of one specimen (No. 1, Table 1) was reported to the AMTP eight years after the capture.

The method of recovery was distributed as follows: 22 (64.7%) in fisheries, seven (20.6%) stranded dead on the beach, two (5.9%) floating dead in the sea, one (2.9%) encountered alive by a diver, while in two cases (5.9%) the method was unknown. Out of the 22 recoveries reported in fishing gear, 14 (63.6%) were captured in trawls. Twelve out of these 14 turtles were certainly alive and released, while the condition of two individuals (Nos. 6 and 28, Table 1) is unknown; it can not be excluded they were dead, which indicates a mortality rate in the trawls up to 14%. Eight recoveries (36.4%) resulted from incidental capture in gill nets, five of these being recovered dead. Hence, the mortality in gill nets was 62.5%.

The 34 recoveries reported refer to 33 turtles, as one individual (A578) was recovered twice within the study area (recoveries Nos. 20 and 22, Table 1). Thirty-one of these turtles were adults and two were juveniles. All adults were females, tagged at Mediterranean nesting beaches: 29 (93.5%) in Greece, one in Cyprus, and one in Turkey (Table 1). All females coming from Greece were tagged by ARCHELON—the Sea Turtle Protection Society of Greece (STPS), at three major nesting localities: Island of Zakynthos, Kyparissia Bay and Lakonikos Bay (Table 1, Figure 1). In two cases (Nos. 13 and 33, Table 1)

Table 1. *Recoveries of tagged female and juvenile (marked with *) loggerhead sea turtles* Caretta caretta *in the eastern Adriatic Sea reported between 1993 and December 2002.*

		Data on recovery					Data on the last observation/tagging				ET
No.	Tag	Date	Locality	Country	Meth	Con	Date	Institution	Locality	Country	(days)
1§	K600	1990: AUG 14	Dugi Otok Island	CRO	T	A	1988: JUN 23	STPS	KYP	GR	782
2	E147	1993: NOV 07	Sv.Ivan Island	CRO	S	D	1993: JUL 26	STPS	KYP	GR	104
3	A423 E221	1993: DEC 07	Bigovo	MG	?	?	1993: AUG 10	STPS	ZAK	GR	119
4	A386 A493	1994: AUG 20	Mljet Island	CRO	G	D	1993: AUG 04	STPS	ZAK	GR	381
5	E461	1994: NOV 17	W Istrian Penninsula	CRO	T	A	1994: JUN 28	STPS	ZAK	GR	142
6	A199	1995: JAN 10	Glavat Island	CRO	T	?	1994: JUL 10	STPS	ZAK	GR	184
7	P4862	1995: MAY 07	Sukoan	CRO	G	D	1993: JUL 12	STPS	KYP	GR	664
8	E076 E077	1995: JUN 10	Galijola Island	CRO	G	D	1993: JUL 17	STPS	ZAK	GR	699
9	E894	1995: SEP 01	Mljet Island	CRO	G	D	1995: JUL 19	STPS	ZAK	GR	44
10	A605	1996: FEB 12	Premuda Island	CRO	?	?	1995: JUL 24	STPS	KYP	GR	203
11	E043 95091	1996: JUN 04	W Istrian Penninsula	CRO	S	D	1995: AUG 06	STPS	ZAK	GR	303
12	410 18	1996: AUG 01	Piran Bay	SLO	T	A	1995: JUL 25	CWS	LAR	CYP	371
13	?	1996: AUG 14	W Istrian Penninsula	CRO	G	A	?	STPS	?	GR	?
14	E087 E096	1996: AUG 18	Mljet Island	CRO	G	D	1995: JUL 29	STPS	ZAK	GR	386
15	E107	1997: FEB 20	Susak Island	CRO	S	D	1993: JUN 18	STPS	KYP	GR	1343
16	E883	1997: SEP ?	Vele Srakane Island	CRO	S	D	1995: JUL 07	STPS	ZAK	GR	787–816
17	E866	1998: MAR ?	Dugi Otok Island	CRO	S	D	1995: JUL 06	STPS	ZAK	GR	969–999
18	E716 E717	1998: JUN 08	Unije Island	CRO	F	D	1995: JUN 18	STPS	ZAK	GR	1086
19	A628 C6311	1998: DEC 20	Dugi Otok Island	CRO	T	A	1995: JUL 13	STPS	KYP	GR	1256
20	A578 H150	1999: JUL 08	Cape Kabul	CRO	T	A	1998: AUG 14	STPS	LAK	GR	328
21	H088	2000: JAN 10	Tramerka Island	CRO	T	A	1995: JUL 29	STPS	ZAK	GR	1626
22	A578	2000: JUN 26	Brioni Islands	CRO	T	A	1999: JUL 08	AMTP	CK	CRO	354
23	Y5842	2000: AUG 21	Primosten	CRO	F	D	1995: JUL 08	STPS	KYP	GR	1871
24*	Z0521 Z0522	2000: OCT 30	W Istrian Penninsula	CRO	G	A	2000: MAY 31	CHE	PO	IT	152
25	RE140	2001: AUG 30	Dugi Otok Island	CRO	T	A	2001: JUN 09	STPS	LAK	GR	82
26	ZA 307	2001: NOV 18	Brijuni Islands	CRO	T	A	2001: JUL 15	STPS	ZAK	GR	126
27	KA 090	2002: MAR 05	Korcula	CRO	I	A	2001: JUL 21	STPS	KYP	GR	227
28	H 938	2002: MAY 15	Brijuni Islands	CRO	T	?	1999: JUL 27	STPS	KYP	GR	1023
29	KA 051	2002: JUN 04	Gulf of Trieste	SLO	T	A	2001: JUN 13	STPS	KYP	GR	356
30*	A2229 A2229	2002: JUN 16	Piran Bay	SLO	G	A	2001: OCT 10	AQP	PIR	SLO	249
31	A 626	2002: AUG 29	Unije Channel	CRO	T	A	1995: JUL 30	STPS	KYP	GR	2587
32	TR-A0206	2002: OCT 19	Porec	CRO	S	D	1998: JUN-SEP	HAC	BEL	TUR	1509–1601
33	?	2002: OCT 28	Bar	MG	T	A	?	STPS	?	GR	?
34	ZA 437	2002: NOV 23	Plomin luka	CRO	S	D	2002: JUN 28	STPS	ZAK	GR	148

§, Recovery reported in October 1998. Country: CRO, Croatia; MG, Montenegro; SLO, Slovenia; GR, Greece; CYP, Cyprus; IT, Italy; TUR, Turkey. Meth, method of recovery: G, captured in gill net; T, captured in trawl; S, stranded; F, floating dead in the sea; I, sighting; ?, unknown. Con, condition of turtle: D, dead; A, alive; ?, unknown. Institution: STPS, ARCHELON, the Sea Turtle Protection Society of Greece; CWS, Cyprus Wildlife Society; CHE, Chelon Sea Turtle Conservation and Research Programme; AQP, Aquarium Piran; HAC, Hacettepe University; AMTP, Adriatic Marine Turtle Programme. Locality of the last observation/tagging: KYP, Kyparissia Bay; ZAK, Zakynthos Island; LAK, Lakonikos Bay; LAR, Lara Beach; CK, Cape Kabul; PO, Po River Delta; PIR, Piran Bay; BEL, Belek. ET, elapsed time between the last record of specimen and recovery.

the fishermen checked only the tagging institution and tag return address. So although we know that they were tagged by STPS in Greece, the tag codes, dates of tagging and precise nesting (tagging) place remain unknown. Both recovered juveniles (Nos. 24 and 30, Table 1) were tagged in the Adriatic Sea, following incidental capture in fisheries.

DISCUSSION

Our results identify the eastern Adriatic Sea as a habitat shared by different nesting populations of the loggerhead turtle. Presently, these waters contain the highest concentration of long-distance tag recoveries in the Mediterranean for loggerheads from the rookeries in Greece. Recoveries of 29 adult females originally tagged in Greece show that the eastern Adriatic Sea represents a major migration corridor for part of this nesting population. Although we cannot reconstruct their migratory pathways, in the cases of individuals Nos. 9 and 25 (Table 1), only 44 days and 82 days elapsed, respectively, between their last observation in Greece and their recovery in Croatia. Additionally, Argano et al. (1992) reported an adult loggerhead recovered in the Italian northern Adriatic waters 46 days after its tagging on Zakynthos (F79 in Argano et al., 1992). If these three females followed the shortest route they must have travelled at least 700 km (No. 9), 1200 km (No. 25) and 1100 km (F79) with a minimal average speed of 0.7, 0.6, and 1.0 km h^{-1}, respectively. Bentivegna (2002) and Godley et al. (2003) recorded average travel rate of 1.2 and 1.3–1.7 km h^{-1} for loggerheads during pelagic crossings. Calculated speeds of travel in our case are lower, but they are based on three assumptions: (i) that these three females started their migration at the day of their last observation on the nesting beach; (ii) that they were recovered in the Adriatic at the day of their arrival; and (iii) that they have followed the shortest route. However, it is more likely that the periods of migration were shorter than the calculated elapsed times (Table 1), which could explain the lower speeds of travel in our study. Therefore, it is very probable that these three turtles migrated directly from the Ionian Sea into the Adriatic. We recovered another five females (Nos. 2, 3, 5, 26 and 34, Table 1) within 104–148 days after their last observation in Greece, which could also suggest a direct movement from reproductive habitats in Greece into the Adriatic Sea.

The highest concentration of tag returns (28 out of 34) came from the shallow (<100 m) northern Adriatic (Figure 1) which host rich benthic communities. As adult sea turtle migrations seem to be resource-driven (Plotkin, 2003), these waters may present a destination for loggerhead movements into the Adriatic. Indeed, an on-going study on foraging ecology of loggerheads in the eastern Adriatic (Lazar et al., 2002) supports the hypothesis of a trophic role of the Adriatic for a part of the Mediterranean loggerhead population (Argano et al., 1992; Affronte & Scaravelli, 2001), and suggests that the Adriatic, and its northern part in particular, contain benthic feeding habitats for this species. On the other hand, the northern Adriatic is also the most heavily fished area in the Adriatic, sustaining about half of the eastern Adriatic fishing fleet (Cetinić, 1989). Hence, such imbalance in the number of tag recoveries between the northern and the central Adriatic may not only be caused by a difference in the abundance of turtles, but also by the higher fishing effort in the northern region.

It seems that the majority of adult female loggerheads in the Adriatic belong to a population nesting in Greece. Nonetheless, marine habitats in the Adriatic are shared by both adult and juvenile loggerheads (Affronte & Scaravelli, 2001; Lazar & Tvrtković, in press). Although genetic analyses would give an insight into stock composition of juvenile loggerheads in the Adriatic Sea, it may be assumed that most of them also originate from the population nesting in Greece based on: (i) the bias of tagged adult females from the Greek nesting population; (ii) the proximity of nesting beaches in Greece; and (iii) the dominant surface current system of the Ionian–eastern Adriatic area. Several authors have pointed out the role of currents in the distribution of hatchlings and pelagic juveniles (Bolten & Balazs, 1995; Meylan, 1995; Musick & Limpus, 1997). Although turtles can travel against sea currents (Meylan, 1995), favourable surface circulation may facilitate their transportation. A prevailing surface current enters the Adriatic along the eastern coast moving to the north (Cushman-Rosini et al., 2001), passing the loggerhead nesting beaches in the Ionian Sea (Figure 1). This current may influence the movement of hatchlings and small juveniles, partially directing their migrations into the Adriatic. However, it is likely that juveniles from other rookeries also frequent these waters. Considering a trophic role of the Adriatic Sea for both juvenile and adult loggerheads, their movements into the Adriatic may be defined as denatant, feeding migrations (Musick & Limpus, 1997).

Some authors have already suggested that loggerheads exhibit site fidelity for marine habitats (Limpus et al., 1992; Musick & Limpus, 1997; Godley et al., 2003), similar to the one documented for reproductive grounds (Plotkin, 2003). Indeed, our results suggest that loggerheads are not just travellers through the Adriatic. Repeated recovery of adult female A578 after 354 days a few kilometres from the original capture point, and the juvenile loggerhead No. 30 recaptured after 249 days, 10–15 km from the site of release, support this hypothesis. Another juvenile (No. 24, Table 1) tagged near the Po River Delta in Italy (G. Gerosa, personal communication) was recaptured about 100 km away in Croatian waters after 152 days. Affronte & Scaravelli (2001) reported the recovery of a juvenile loggerhead near Ravena in Italy, 225 days after the tagging in Slovenia, 140 km away from the tagging site. All these data suggest that loggerheads do reside in the Adriatic for a period of time. Furthermore, it seems that they do exhibit site fidelity for foraging habitats, but for wider areas such as the northern Adriatic. Such *sensu lato* concept of the site fidelity in our case could be the result of shallowness and hence the availability of benthic resources through the whole northern Adriatic area.

Fisheries interaction represents the main threat to loggerheads in the Adriatic Sea. Although we should not over-interpret the limited number of recoveries resulting from fisheries by-catch in our study, the mortality in trawls seems to be relatively low and comparable to 0–10% recorded in the rest of the Mediterranean (Margaritoulis et al., 2003). However, there are two

additional things to consider in regard to this fishery: first, there are no data on the effect of delayed mortality, and second, the fact that 68.5% out of 594 vessels of the eastern Adriatic fishing fleet are trawlers (Cetinić, 1989). Therefore, their impact on the loggerheads could still be substantial. In contrast, we recorded a high mortality rate (62.5%) for turtles captured in gill nets. Despite small sample size (N=8) our results concur with the conclusion that gill nets are the fishing tool most lethal for sea turtles in the Mediterranean (Argano et al., 1992, Margaritoulis et al., 2003).

It is worth noting that only 17.6% of the recoveries were reported directly from fishermen to the tagging institution. This fact, and the high number of tag recoveries in Croatia on the other hand, highlight the importance of (i) organizing an education and awareness programme at national level, and (ii) a nationwide network for data collecting as a prerequisite to enhance tag recovery rates. The low number of reported tag recoveries in the eastern Adriatic between 1981/1982 and 1990 (Margaritoulis, 1988; Argano et al., 1992) might therefore be explained by the lack of such an organizational scheme before the AMTP was founded in 1993. Consequently, the number of tag recoveries in Croatia in the next decade (1993–2002) increased more than seven fold.

With more than 60% of the documented nests laid annually in the Mediterranean, the rookeries in Greece account for the largest loggerhead nesting population in the region. Tags have been recovered in the greatest numbers from two main regions: the Adriatic Sea, and the Gulf of Gabès in Tunisia (Margaritoulis et al., 2003). The northern and the central Adriatic, together with the Gulf of Gabès, are at the same time the two most extensive shallow (<200 m) regions in the Mediterranean, with approximate areas of 102,000 km and 77,000 km, respectively (Margaritoulis et al., 2003). Such a high number of tag recoveries coinciding with these two regions suggest that the Adriatic Sea and the Gulf of Gabès host major neritic habitats for loggerheads in the Mediterranean.

Population models clearly showed that the protection of eggs and hatchlings alone will not solve the problem of declining sea turtle populations. Population analyses have stressed the importance of increasing the survival probability of individuals in the life stages with the highest elasticity and sensitivity values as a conservation priority for population viability and recovery (Heppell et al., 2003). This emphasizes the significance of reducing mortality in larger size-class individuals in marine habitats. Consequently, our results show that the viability of the loggerhead population nesting in Greece is partially dependent on the mitigation of 'at-sea' threats in the Adriatic Sea. The Ionian–Adriatic loggerheads form an important part of a management unit, and therefore the reduction of fishery-related mortality should be underlined as a management priority for loggerheads in the Adriatic Sea. An effective conservation strategy is likely to enhance the viability prospects of the loggerhead population nesting in Greece.

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