Estimating the number of green and loggerhead turtles nesting annually in the Mediterranean

Annette C. Broderick, Fiona Glen, Brendan J. Godley and Graeme C. Hays

Abstract Most species of marine turtle breed every two or more years and it is the norm for females to lay more than one clutch of eggs within a nesting season. Knowing the interval between breeding seasons and the clutch frequency (number of clutches laid by an individual in a breeding season) of females allows us to assess the status of a nesting population. At Alagadi Beach, Northern Cyprus, over a period of 6 years (1995–2000), we attributed 96% of green *Chelonia mydas* and 80% of loggerhead *Caretta caretta* turtle clutches to known individual females. This intensive level of monitoring enabled us to estimate the clutch frequency for both species. Using four different methods we estimated clutch frequency to be 2.9–3.1 clutches per female for green turtles and 1.8–2.2 clutches per female for loggerhead turtles. The median interval between nesting seasons for green turtles was 3 years, and for loggerhead turtles it was 2 years. Utilizing these parameters and available data from other beaches that are monitored regularly, we estimate that there are 2,280–2,787 loggerhead and 339–360 green turtles nesting annually at these sites in the Mediterranean. This highlights the Critically Endangered status of this population of green turtles. Furthermore, as conventional beach patrols underestimate clutch frequency, these population estimates are likely to be optimistic.

Keywords *Caretta caretta*, *Chelonia mydas*, clutch frequency, Cyprus, inter-nesting, marine turtles, Mediterranean, re-migration.

Introduction

Assessing the population size of marine species is a difficult task, particularly in those species that occupy different habitats during their life cycle and migrate large distances. However, some species breed onshore, providing an opportunity to gain an indication of the status of a population (e.g. penguins, Guinard *et al.*, 1998; sealions, Reyes *et al.*, 1999; sea turtles, Meylan, 1982). In species that produce a single clutch or brood every year, an accurate estimate of the entire breeding population can be made in one study year. In species such as marine turtles estimates are confounded by the fact that females usually lay several clutches in a breeding season and undertake cyclical migrations from feeding grounds to nesting sites at variable intervals, most commonly 2–3 years (Miller, 1997). Few studies have been able to accurately assess the frequency of breeding of marine turtles because of the difficulty in monitoring extensive nesting beaches or large numbers of nesting females with sufficiently high observer effort to generate meaningful results (Bjorndal, 1980; Mortimer & Carr, 1987; Johnson & Ehrhart, 1996).

Both the loggerhead turtle *Caretta caretta* and green turtle *Chelonia mydas* nest in the Mediterranean and are listed on Appendix 1 of CITES, prohibiting any international trade among contracting parties. The loggerhead turtle is globally categorized as Endangered on the 2000 IUCN Red List (Hilton-Taylor, 2000), using criteria A1abd; i.e. a reduction of at least 50% over the last 10 years or three generations based on direct observation (a), an index of abundance (b) and levels of exploitation (d). The green turtle is globally categorized as Endangered, but the Mediterranean sub-population of the turtle is categorized as Critically Endangered based on criteria A1a, B1 + 2ce, E; i.e. population reduction of at least 80% over the last 10 years or three generations (A), a limited extent of occurrence or area of occupancy (B), and a probability of extinction in the wild of at least 50% within 10 years or three generations (E). This categorization makes the Mediterranean population the most endangered green turtle population in the world.

The loggerhead is the most abundant marine turtle species in the Mediterranean, with an estimated 2,000 females nesting annually (Groombridge, 1990). The biology of this species in the region has recently been reviewed by Margaritoulis *et al.* (in press). The main nesting concentrations are in Greece, Turkey and Cyprus, with

Annette C. Broderick (Corresponding author), **Fiona Glen**, **Brendan J. Godley** and **Graeme C. Hays** Marine Turtle Research Group, School of Biological Sciences, Singleton Park, University of Wales, Swansea, SA2 8PP, UK. E-mail: MTN@swan.ac.uk

Received 14 February 2001. Revision requested 24 August 2001. Accepted 18 February 2002.

some as yet unquantified nesting in Libya (Laurent, 1997). Minor nesting aggregations have been described in Egypt, Lebanon, Israel, Italy, Syria and Tunisia (Margaritoulis *et al.*, in press). Loggerhead turtles nesting in the Mediterranean have been shown to have diverged genetically from those in the Atlantic (Bowen *et al.*, 1993; Laurent *et al.*, 1993; Laurent *et al.*, 1998), and genetic analyses from several nesting areas in Turkey showed differentiation among rookeries (Schroth *et al.*, 1996).

The Mediterranean green turtle population has been shown to be discrete from that of the wider Atlantic (Bowen *et al.*, 1992; Encalada *et al.*, 1996), and nesting is much more localized than in the loggerhead turtle, with most nesting occurring in Turkey (Baran & Kasparek, 1989; Gerosa *et al.*, 1998) and Cyprus (Demetropoulos & Hadjichristophorou, 1989; Broderick & Godley, 1996), and with small numbers in Israel (Kuller, 1999) and Egypt (Clarke *et al.*, 2000). The nesting population has been estimated at 300–400 females annually (Groombridge, 1990). The genetic isolation of the Mediterranean populations of both species suggests that they are not sustained by immigration of individuals from rookeries in the Atlantic, highlighting the importance of regional conservation measures.

Many studies of marine turtle populations rely on annual nest counts to assess the status of a population. However, without information on clutch frequency, a change in the number of nests recorded may be attributed to a change in the number of females nesting whilst merely reflecting annual variation in reproductive output. In addition, data regarding the interval between breeding seasons provide crucial information on recruitment, longevity and survivorship within a population. In the Mediterranean no data are available regarding the breeding frequency of green turtles and the only data for the loggerhead turtle come from the Greek island of Cephalonia, where a small population of females have been recorded breeding, on average, every 2.56 years (modal interval of 2 years; Hays & Sutherland, 1991).

Estimates of the population sizes of these species in the Mediterranean have not been based upon reproductive parameters of females nesting in this region, because these data have not been available. Accumulating data on the nesting frequency of marine turtles in the Mediterranean is the key to obtaining a full appreciation of the number of females remaining in this region. The study reported in this paper was based on Alagadi Beach, Northern Cyprus, one of the few sites in the Mediterranean where both green and loggerhead turtles nest. The relatively small number of nests laid on this short beach allowed us to undertake intense monitoring and obtain accurate estimates of the breeding frequency of individuals. Utilizing our data and those available from beach monitoring programmes elsewhere in the Mediterranean, we estimate the number of females breeding annually in the Mediterranean populations of loggerhead and green turtles.

Methods

This study was conducted on Alagadi beach (35°33N, 33°47E), Northern Cyprus, located in the Eastern basin of the Mediterranean Sea (Fig. 1). To either side of this 2 km beach the shore is rocky and the nearest nesting beaches are 50 km and 15 km to the west and east, respectively.

Alagadi Beach was monitored every night of the entire nesting season, which runs from late May until mid August, from 1993–2000 (in 1992 the beach was monitored sporadically from early July). Over the study period, a large number of individuals were involved in monitoring and collecting data. Three to five groups of 2–3 personnel patrolled the beach at 15–30 minute intervals, with observer effort increasing in magnitude and efficiency with time because of the addition of more personnel and the introduction of handheld VHF radios.

Any female that was encountered was observed until she was laying, and was then examined for existing flipper tags. If she was not already tagged, flipper tags were placed on the trailing edge of both fore-flippers after egg laying was complete and the female had started to cover the eggs with sand using her hind flippers. In 1992 and 1993 flipper tags were Jumbotags (Dalton Supplies Ltd, Chichester, UK), for 1994–1997 Supertags (Dalton Supplies Ltd, Chichester, UK) were used, and for 1998–2000 titanium turtle tags were used (Stockbrands Ltd, Perth, Australia). Since 1997 passive integrated transponders (PIT tags) have also been used. These are

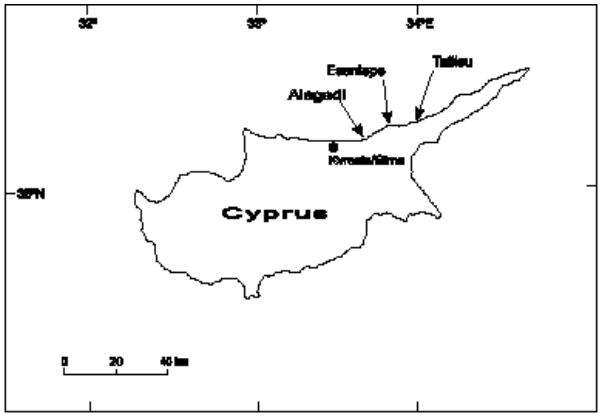

Fig. 1 Map of the Eastern Mediterranean showing Cyprus and Alagadi Beach. The nearest nesting beaches to Algadi Beach, at Esentape and Tatlisu, are indicated.

injected subcutaneously into the shoulder muscle of the female on one or both sides (Godley *et al*., 1999). If nesting was not observed, track morphology and discovery of the eggs was used to establish whether a clutch had been deposited.

As a result of tagging and subsequent re-observation within each season it was possible to assess inter-nesting intervals (the number of days between egg laying and the next observed egg laying). When turtles were observed in subsequent seasons it was possible to determine their re-migration interval (number of years since last observed breeding season).

We used four methods to estimate clutch frequency of individuals (the number of clutches laid in a season):

Method 1. From our data the number of clutches recorded for each female in each year could be calculated. This value was termed observed clutch frequency (OCF; Frazer & Richardson, 1985; Johnson & Ehrhart, 1996).

Method 2. From frequency histograms of inter-nesting intervals (Fig. 2) it was apparent that some females were re-nesting after intervals corresponding to two or three inter-nesting periods, suggesting that they had laid one or more clutches during this interval that had not been observed. OCF was therefore corrected to take these missed nests into account. This value is referred to as estimated clutch frequency (ECF; Frazer & Richardson, 1985; Johnson & Ehrhart, 1996).

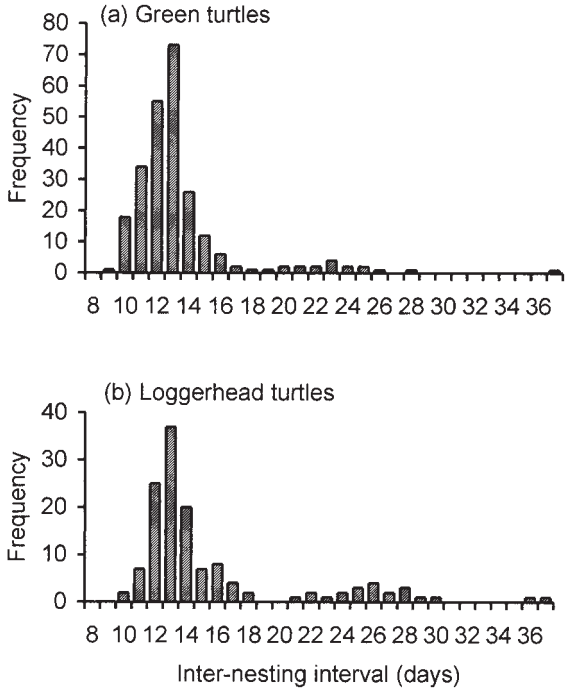

Fig. 2 Inter-nesting intervals recorded for (a) green and (b) loggerhead turtles nesting at Alagadi beach over 1993–2000.

Method 3. If all the females nesting on Alagadi beach were observed at some point in the season then the number of females observed can be used to estimate clutch frequency. We thus calculated clutch frequency by dividing the total number of clutches laid in a season by the number of known females nesting in that year.

Method 4. To account for the proportion of clutches that could not be attributed to an individual female, adjusted values were calculated by dividing OCF (method 1) by the proportion of total nests attributed to individual females in a year (see Table 1).

In addition to data from Alagadi, data sets from other Mediterranean nesting beaches were examined to assess current trends in nesting numbers.

Results

The modal inter-nesting interval for green turtles was 13 days, with the shortest being 9 days (mean = 12.5, SD = 1.65, $n = 203$; Fig. 2). The inter-nesting intervals for loggerhead turtles were commonly longer than for green turtles, although 13 days was again the modal interval (mean = 13.4, SD = 1.62, $n = 111$; Fig. 2). Intervals of $\geqslant 20$ days were assumed to have been the result of intervening clutches not having been observed.

The four methods of calculating clutch frequency gave values ranging from 1.9–3.5 clutches per season for green turtles and 1.2–4.6 for loggerhead turtles (Table 1). As a result of a lower surveying effort in 1993 and 1994 the percentage of clutches that could be attributed to known females was lower in both species. Since 1995, for both species, this percentage has been $>70\%$, and therefore these data (1995–2000) were pooled. The pooled data gave us estimates of clutch frequency of 2.9–3.1 for green turtles and 1.8–2.2 for loggerhead turtles, and these values were used to derive estimates of the number of nesting females. The proportion of females laying 1, 2, 3, 4 or 5 clutches (over 1995–2000) is illustrated in Figure 3 using the data resulting from method 2 (ECF).

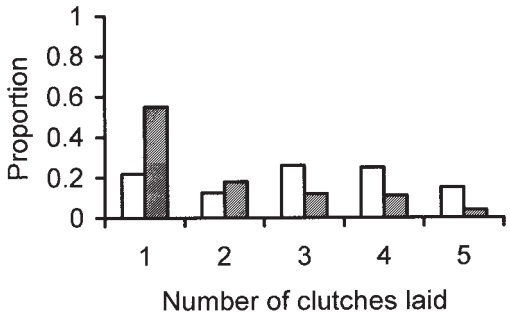

Fig. 3 Proportion of females laying 1, 2, 3, 4 or 5 clutches as calculated by method 2 (see text for details); green turtle (unshaded) and loggerhead turtle (shaded).

Table 1 Number of clutches laid (with percentage of clutches attributed to known individuals), number of known individuals nesting, percentage re-migrants, and clutch frequency calculated by four different methods for green and loggerhead turtles nesting at Alagadi Beach in each of the years 1993–2000 and for the pooled data set of 1995–2000. (Methods: 1, mean number of clutches per female observed (±SD); 2, mean number of clutches per female corrected for missed nesting events (±SD); 3, number of clutches laid in a season divided by number of known females nesting in that year; 4, method 1 divided by the proportion of clutches attributed to known individuals).

				Clutch Frequency				
Year	Number of clutches (% attributed)	Number of known nesting females	% re-migrants	Method 1 (OCF)	Method 2 (ECF)	Method 3	Method 4	Range
Green Turtles								
1993	50 (67)	16	0	2.0 ± 1.1	2.1 ± 1.2	3.1	3.0	2.0–3.1
1994	68 (63)	22	18	1.9 ± 1.1	2.1 ± 1.3	3.1	3.0	1.9–3.1
1995	64 (95)	19	32	3.1 ± 1.4	3.3 ± 1.5	3.4	3.3	3.1–3.4
1996	8 (75)	3	67	2.0 ± 1.0	2.0 ± 1.0	2.7	2.7	2.0–2.7
1997	12 (100)	6	50	2.8 ± 1.4	2.8 ± 1.4	2.0	2.8	2.0–2.8
1998	111 (89)	32	47	3.1 ± 1.2	3.4 ± 1.4	3.5	3.5	3.1–3.5
1999	8 (100)	4	50	2.0 ± 1.2	2.0 ± 1.2	2.0	2.0	2.0–2.0
2000	81 (96)	29	60	2.7 ± 1.2	2.7 ± 1.2	2.8	2.8	2.7–2.8
1995–2000	284 (96)	93	48	2.9 ± 1.3	3.0 ± 1.4	3.1	3.1	2.9–3.1
Loggerhead Turtles								
1993	41 (26)	9	0	1.2 ± 0.4	1.6 ± 1.1	4.6	4.6	1.2–4.6
1994	95 (40)	32	6	1.4 ± 0.6	1.5 ± 0.8	3.0	3.5	1.4–3.5
1995	95 (72)	45	11	1.6 ± 0.9	1.7 ± 1.1	2.1	2.2	1.6–2.2
1996	60 (77)	24	38	1.9 ± 1.1	2.0 ± 1.3	2.5	2.5	1.9–2.5
1997	57 (84)	23	14	2.1 ± 1.1	2.3 ± 1.4	2.5	2.5	2.1–2.5
1998	38 (71)	19	37	1.5 ± 0.8	1.7 ± 1.1	2.0	2.1	1.5–2.1
1999	53 (85)	27	26	1.8 ± 1.1	2.0 ± 1.2	2.0	2.1	1.8–2.1
2000	63 (90)	32	38	1.7 ± 1.0	1.8 ± 1.1	2.0	1.9	1.7–2.0
1995–2000	366 (80)	170	25	1.8 ± 1.0	1.9 ± 1.2	2.1	2.2	1.8–2.2

Over the years of this study the proportion of nesting females that are re-migrants has fluctuated (see Table 1). In Figure 4 re-migration intervals recorded for both species from 1995–2000 are presented. Tagging began in 1992 and so only short re-migration intervals could have been recorded before 1995, we therefore excluded re-migration data from 1993 and 1994 when calculating median re-migration intervals. For green turtles the median re-migration interval was 3 years (inter-quartile range 2–3 years, $n = 46$) and for loggerhead turtles 2 years (inter-quartile range 2–3 years, $n = 44$). There is considerable variation in the observed patterns of re-migration in both species (Table 2).

Trends in nesting data for loggerhead turtles were examined at the following sites in the Mediterranean:

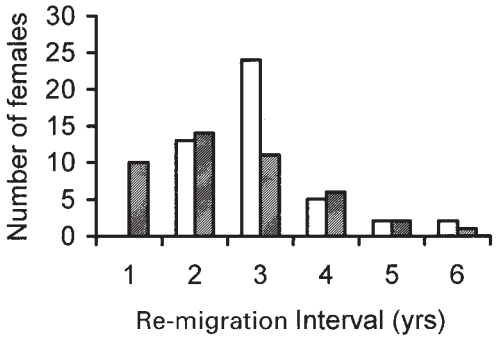

Fig. 4 Re-migration intervals at Alagadi Beach over 1995–2000; green turtle (unshaded) and loggerhead turtle (shaded).

Table 2 The sequences of re-migration intervals (in years) recorded for individual green and loggerhead females nesting at Alagadi Beach in more than 2 seasons (1992–2000).

Green turtles		Loggerhead turtles	
Re-migration intervals	Number of females	Re-migation intervals	Number of females
2-2	1	3-3	1
3-2	4	3-4	1
3-3	1	4-1	1
3-4	1	1-1-1	1
4-3	1	2-2-2	1
5-2	1	2-2-4	1
2-3-2	1	2-1-1-1-1	1
2-3-3	1		
2-4-2	1		
3-3-2	3		

Alagadi, Northern Cyprus (this study, $n = 8$ years, 1993–2000; Table 1); Cephalonia, Greece (Houghton *et al.*, 1998, $n = 15$ years, 1984–1998); Zakynthos, Greece (Margaritoulis & Dimopoulos, 1995; Dimopoulos & Margaritoulis, 1997, $n = 11$ years, 1984–1995); and Israel (Kuller, 1999, $n = 6$ years). Nesting data for green turtles were examined from three sites: Israel (Kuller, 1999, $n = 8$ years, 1993–2000); Akyatan, Turkey (Aureggi *et al.*, 2000; Gerosa *et al.*, 1998, $n = 5$ years, 1994–1998); and Alagadi, Northern Cyprus (this study, $n = 8$ years, 1993–2000; Table 1). Time series analysis did not reveal any autocorrelation in the datasets, and subsequent regression analysis did not indicate any significant trends. Figure 5 illustrates two of these data sets; the number of loggerhead turtle nests laid at Zakynthos (1984–1995) and green turtle nests at Akyatan (1994–1998). As there did not appear to be any positive or negative trend in nesting numbers, we used the mean annual number of nests (Tables 3 & 4) to give an estimate of the total number of females nesting annually in the Mediterranean. Dividing by 2.9 and 3.1 for green turtles and 1.8 and 2.2 for loggerhead turtles (our range of clutch frequency calculated from the 1995–2000 data), gave an estimate of, on average, 339–360 green and 2,280–2,787 loggerhead turtles nesting each year in the Mediterranean.

In the years 1996–2000 night-time surveys were conducted at other nesting beaches around the coast of Cyprus. Of the turtles observed at these other sites, 12.5% (7 of 56) of green and 15% (6 of 40) of loggerhead turtles were also recorded nesting at Alagadi Beach in

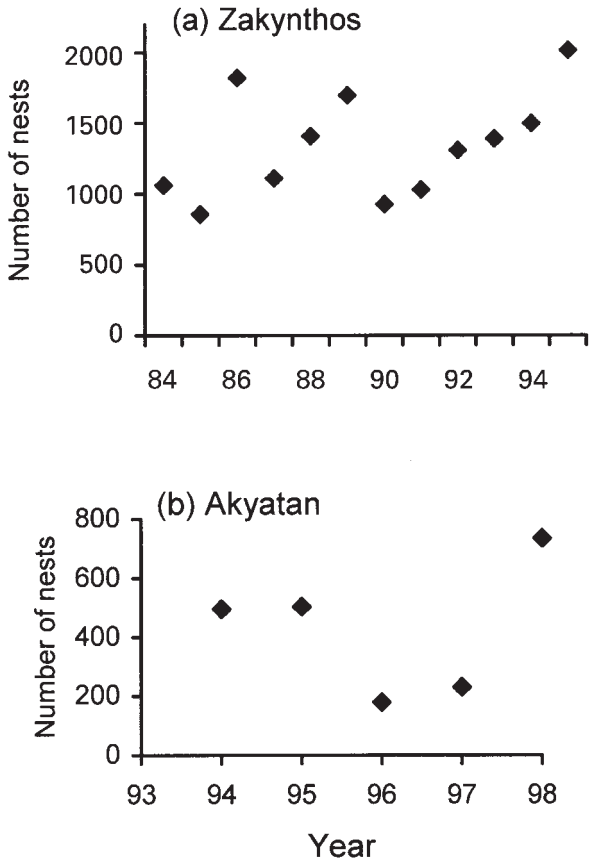

Fig. 5 (a) Number of loggerhead turtle nests recorded at Zakynthos, Greece 1984–1995 and (b) Number of green turtle nests recorded at Akyatan, Turkey 1994–1998.

Table 3 Mean number of nests per season, number of years surveyed, mean number of nesting females per year and data sources for green turtles nesting annually in the Mediterranean, with totals.

Nesting site	Mean number of nests/season (range)	No. years surveyed	Mean no of nesting females/year (range)	Source
Cyprus				
North	297 (135–461)	8	96–102 (44–159)	Broderick & Godley, 1993; Broderick & Godley, 1995; Broderick *et al.*, 1997; Broderick *et al.*, 1999; Glen *et al.*, 2000; Godley & Broderick, 1994; Godley & Kelly, 1996; Godley *et al.*, 1998.
South	*75 (73–78)		25 (25–25)	Demetropoulos & Hadjichristophorou, 1989.
Israel	5 (0–13)	8	1–2 (0–5)	Kuller, 1999; Z. Kuller, pers. comm.
Turkey				
Akyatan	429 (179–735)	5	138–148 (58–253)	Aureggi *et al.*, 2000; Gerosa *et al.*, 1998.
Göksu	12 (3–20)	4	3–4 (0–7)	Glen *et al.*, 1997; Peters & Verhoven, 1992; van Piggelen, 1993; Yerli & Canbolat, 1998.
Kazanli	165 (128–216)	3	53–57 (41–74)	Baran & Kasparek, 1989; Coley & Smart, 1992; Yerli & Demirayak, 1996; Yerli & Canbolat, 1998.
Samandag	64 (21–126)	3	20–22 (7–43)	Yerli & Demirayak, 1996; Yerli & Canbolat, 1998.
Total	1047 (539–1622)		339–360 (175–567)	

*Nesting data is not available for southern Cyprus; this figure is based on an estimate of 25 nesting females (Demetropoulos & Hadjichristophorou, 1989).

Table 4 Mean number of nests per season and mean number of nesting females per year of loggerhead turtles nesting annually in the Mediterranean. Nesting data are from Margaritoulis *et al.* (in press). Diffuse nesting also occurs at other sites but is as yet unquantified.

Nesting site	Mean no. of nests/season (range)	Mean no of nesting females/year (range)
Cyprus	572 (404–775)	260–318 (184–431)
Greece	3,035 (2,012–4,472)	1,380–1,686 (915–2,484)
Israel	33 (10–52)	15–18 (5–29)
Tunisia	10 (5–15)	5–6 (2–8)
Turkey	1,366 (944–1,771)	621–759 (429–984)
Total	5,016 (3,375–7,085)	2,280–2,787 (1,534–3,936)

the same season. However, only 5% (3) of green and 5% (2) of loggerhead females nesting at these other sites had nested at Alagadi in other years.

Figure 3 illustrates the numbers of both species that were recorded laying only one clutch at Alagadi Beach. To investigate the likelihood that these females might have been nesting elsewhere we examined the number of females laying only one clutch in a season for the years 1995–1997 and the proportion that returned to nest at Alagadi in future years (1996–2000). The probability of re-migrating to Alagadi after laying a single clutch in a season was 0.3 for green turtles and 0.1 for loggerhead turtles. In comparison, the probability of females returning to nest at Alagadi after laying multiple clutches in a previous season was 0.8 for green turtles and 0.4 for loggerhead turtles. This demonstrates that females laying a single clutch have a lower site fidelity to Alagadi and we conclude that a large proportion of these individuals are likely to be laying additional clutches elsewhere.

Discussion

Using the first long-term data sets on clutch frequency and re-migration intervals of both green and loggerhead turtles nesting in the Mediterranean, we have estimated that 339–360 green and 2,280–2,787 loggerhead females breed annually in the region. Whilst there are a number of additional sites where nesting of the loggerhead turtle remains unquantified, there is no indication of any breeding sites for the green turtle other than those presented here. Monitoring of the nesting grounds of both species in the Mediterranean is currently insufficient. Many surveys are sporadic and do not encompass the entire nesting season. In the case of the green turtle, whose nesting numbers have been shown to fluctuate dramatically from year to year (e.g. at Alagadi eight clutches were recorded in 1996 and 111 in 1998), long-term annual monitoring is a necessity (Broderick *et al.*, 2001). In addition, given the Critically Endangered status of this population in the Mediterranean, urgent action is required to ensure that all major sites are both monitored and protected.

Prior to this study, population estimates for marine turtles in the Mediterranean were based on nesting counts and estimates of breeding frequency from turtles in other areas. The high observer effort (80% of loggerhead and 96% of green turtle clutches were observed during 1995–2000), relatively short nesting beach, and low number of turtles nesting at Alagadi enabled us to obtain a high degree of accuracy in our estimates. The high level of nesting success (over 40% of all nesting activities resulted in laying), in comparison to other studies (Coley & Smart, 1992; Godley *et al.*, 2001), suggests that such intensive monitoring did not disturb nesting females. Even with such high observer effort it is likely that we have produced an underestimate of clutch frequency, because of poor nest site fidelity, tag loss and possible inaccuracies in the four methods used to estimate clutch frequency. Method 1 (OCF), which uses the actual number of clutches that females were observed laying, gives an absolute minimum clutch frequency. Method 2 (ECF) takes into account the problem of nest site fidelity to some degree by adjusting values from method 1 to allow for missed nesting, which is apparent when a female returned to nest after an interval corresponding to two inter-nesting intervals. However, when a female nested only once no correction was possible and thus this method is still likely to result in an underestimate of clutch frequency. Methods 3 and 4 assume that all nesting females have been identified in a season. In years where 100% of activities were observed this may indeed be the case; however, these females may still be nesting elsewhere in addition to Alagadi. Of the four methods, method 2 (ECF) is likely to produce the most accurate yet conservative estimate.

To obtain more definitive estimates of clutch frequency we would need data from all possible nesting beaches in a region, which is impractical. Even with unlimited man-power one could never be sure that a female had not gone further afield to nest. Satellite telemetry studies may provide the answer to this problem (Hays *et al.*, 1991; Hays, 1992), but the method is expensive and transmitters have a low retention rate when attached to females during the nesting season (Luschi *et al.*, 1998).

At present, the best assumption that can be made is that the clutch frequency of individuals nesting at Alagadi is similar to that of individuals at other nesting sites in the Mediterranean. Although long-term studies at other nesting sites have been conducted, these data have not yet been published. Different populations of marine turtles may experience differing environmental conditions at their foraging and nesting grounds, all of which will affect their ability to allocate resources to

breeding (Tiwari & Bjorndal, 2000). In addition, migration between these sites will utilize energy resources, and differences between migratory routes may be reflected in the reproductive output of individuals within a population. With respect to the green turtle, the only other important nesting populations in the Mediterranean are found in Turkey. It is likely that the proximity of individuals nesting in Cyprus and Turkey results in them experiencing similar environmental conditions and thus having a similar breeding frequency. Nesting sites of the loggerhead turtle cover a much wider region of the Mediterranean, possibly subjecting individuals to differing environmental conditions. For the green turtle, our estimates of clutch frequency (2.9–3.1 clutches per season) and re-migration intervals (3 years) are similar to those found in populations nesting outside the Mediterranean (Van Buskirk & Crowder, 1994; Hirth, 1997). For the loggerhead turtle, our estimates (1.8–2.2 clutches per season, re-migration interval of 2 years) are generally less than those recorded outside the Mediterranean (Dodd, 1988; Van Buskirk & Crowder, 1994). This may be related to the fact that loggerhead turtles nesting in the Mediterranean are markedly smaller than females of populations nesting elsewhere (Margaritoulis, 1989; Broderick & Godley, 1996; Tiwari & Bjorndal, 2000). Within the Mediterranean, green turtles nesting in Turkey are of a similar size and have a similar clutch size to those in Cyprus (Coley & Smart, 1992; Gerosa *et al*., 1995; Broderick & Godley, 1996). Loggerhead turtles nesting in Greece, however, are larger than those nesting in Cyprus and lay, on average, larger clutches (Margaritoulis, 1989), whilst those nesting in Turkey are similar in both aspects to those in Cyprus (Peters & Verhoeven, 1992; Kaska, 1993). Our studies in Cyprus, however (Broderick, 1997), have shown that clutch frequency is not related to size of female or clutch size.

The values estimated in this study of 2,280–2,787 loggerhead and 339–360 green turtles nesting annually are similar to those of Groombridge (1990) of 2,000 loggerhead and 300–400 green turtles nesting annually. Groombridge (1990) arrived at this estimate by assuming that individuals of both species laid on average three clutches in a season. This value of clutch frequency is similar to the estimate obtained for green turtles from this study; however, it is an overestimate for the loggerhead turtle and results in an underestimate of the population size.

Whilst further detailed studies of marine turtles in the Mediterranean will allow us to estimate population size with greater accuracy, populations of both species are relatively small. In light of these results, particular attention must be afforded to all major nesting areas of these species in the Mediterranean, but particularly to those of the Critically Endangered Mediterranean population of the green turtle. In a recent review, Kasparek *et al*. (2001) estimated that nearly 80% of all green turtle nests in the Mediterranean are laid at just five key sites. Protection and intensive monitoring of these sites is an achievable goal and one that the Regional Activity Centre for Specially Protected Areas under the Mediterranean Action Plan of the United Nations Environment Programme has deemed a priority. Nesting females are a crucial part of the population, but we know virtually nothing about the other stages of the life cycle of these species and have no knowledge of the status of males or juveniles within this population. Further studies into all aspects of the life cycle of these species are necessary to increase the chances of their survival in the Mediterranean.

Acknowledgements

We thank all members of the Marine Turtle Conservation Project 1992-2000, the Department of Environmental Protection and the Society for the Protection of Turtles in Northern Cyprus. Field work was supported by British Association of Tortoise Keepers, British Chelonia Group, British Ecological Society, Carnegie Trust, Cross Trust, European Commission DG1B/1A, Institute of Biology, Glasgow Natural History Society, Glasgow University Court, MEDASSET UK, People's Trust for Endangered Species, North of England Zoological Society, and Zebra Foundation. This work was supported by grants from the Natural Environment Research Council of the UK (NERC), the Department of the Environment, Transport and Regions (DETR) Darwin Initiative Programme for the Survival of the species, and the Foreign and Commonwealth Office Environment Fund for the Overseas Territories. B.G. is supported by a NERC Fellowship. The manuscript has improved considerably as a result of comments received from three anonymous referees.

References

Aureggi, M., Gerosa G. & Yerli, S.V. (2000) Five years of research at Akyatan Beach (Turkey): one of the main nesting sites for the green turtle, *Chelonia mydas*, in the Mediterranean. *Biogeographica*, **21,** 555–560.

Baran, I. & Kasparek, M. (1989) *Marine Turtles Turkey: Recommendations for Conservation and Management.* Report for WWF, Gland, Switzerland.

Bjorndal, K.A. (1980) Demography of the breeding population of the green turtle, *Chelonia mydas*, at Tortuguero, Costa Rica. *Copeia*, **1980,** 525–530.

Bowen, B.W., Meylan, A.B., Ross, J., Limpus, C., Balazs, G. & Avise, J.C. (1992) Global population structure and natural history of the green turtle (*Chelonia mydas*) in terms of matriarchal phylogeny. *Evolution*, **46,** 865–991.

Bowen, B., Avise, J.C., Richardson, J.I., Meylan, A.B., Margaritoulis, D. & Hopkins-Murphy, S.R. (1993) Population structure of loggerhead turtles (*Caretta caretta*) in the northwestern Atlantic Ocean and Mediterranean Sea. *Conservation Biology*, **7,** 834–844.

Broderick, A.C. (1997) *The reproductive ecology of marine turtles*, Chelonia mydas *and* Caretta caretta, *nesting at Alagadi, northern Cyprus, eastern Mediterranean.* PhD thesis, University of Glasgow, UK.

Broderick, A.C. & Godley, B.J. (1993) *Glasgow University Turtle Conservation Expedition to Northern Cyprus 1993 – Expedition Report.* Unpublished report.

Broderick, A.C. & Godley, B.J. (1995) *Glasgow University Turtle Conservation Expedition to Northern Cyprus 1995 – Expedition Report.* Unpublished report.

Broderick, A.C. & Godley, B.J. (1996) Population and nesting ecology of the green turtle, *Chelonia mydas*, and the loggerhead turtle, *Caretta caretta*, in northern Cyprus. *Zoology in the Middle East*, **13,** 27–46.

Broderick, A.C., Godley, B.J., Kelly, A. & Mcgowan, A. (1997) *Glasgow University Turtle Conservation Expedition 1997: Expedition Report.* Unpublished report.

Broderick, A.C., Glen, F. & Godley, B.J. (1999) *Marine Turtle Conservation Project; Northern Cyprus – Project Report 1999.* Unpublished report.

Broderick, A.C., Godley, B.J. & Hays, G.C. (2001) Trophic status drives inter-annual variability in nesting numbers of marine turtles. *Proceedings of the Royal Society London B*, **268,** 1481–1487.

Clarke, M., Campbell, A.C., Hameid, W.S. & Ghoneim, S. (2000) Preliminary report on the status of marine turtle nesting populations on the Mediterranean coast of Egypt. *Biological Conservation*, **94,** 363–371.

Coley, S.J. & Smart, A.C. (1992) The nesting success of green turtles on beaches at Kazanli, Turkey. *Oryx*, **26,** 165–171.

Demetropoulos, A. & Hadjichristophorou, M. (1989) Sea turtle conservation in Cyprus. *Marine Turtle Newsletter*, **44,** 4–6.

Dimopoulos, D. & Margaritoulis, D. (1997) *1997 Short Report on Sea Turtle Conservation on the Island of Zakynthos, Greece.* Submitted to the Standing Committee of the Bern Convention.

Dodd, C.K. Jr. (1988) *Synopsis of the Biological Data on the Loggerhead Sea Turtle* Caretta caretta *(Linnaeus 1758)*. Fish and Wildlife Service, US Department of the Interior. *Biological Report*, **88 (14)**.

Encalada, S.E., Lahanas, P.N., Bjorndal, K.A., Bolten, A.B., Miyamoto, M.M. & Bowen, B.W. (1996) Pyhlogeography and population structure of the Atlantic and Mediterranean green turtle (*Chelonia mydas*): a mitochondrial DNA control region sequence assessment. *Molecular Ecology*, **5,** 473–484.

Frazer, N.B. & Richardson, J.I. (1985) Annual variation in clutch size and frequency for loggerhead turtles, *Caretta caretta*, nesting at Little Cumberland Island, Gerogia, USA. *Herpetologica*, **41,** 246–251.

Gerosa, G., Casale, P. & Yerli, S.V. (1995) Report on a sea turtle nesting beach study (Akyatan, Turkey), 1994. In *Proceedings of International Congress of Chelonian Conservation* (ed. B. Devaux), pp. 173–180. Editions SOPTOM, Gonfaron, France.

Gerosa, G., Aureggi, M., Casale, P. & Yerli, S.V. (1998) Green turtle nesting at Akyatan beach Turkey, 1994-1997. *Marine Turtle Newsletter*, **81,** 4–5.

Glen, F., Godley, B.J., Kelly, A. & Broderick, A.C. (1997) Marine turtle nesting in the Göksu Delta, Turkey, 1996. *Marine Turtle Newsletter*, **77,** 17–19.

Glen, F., Broderick, A.C., Godley, B.J. & Reece, S. (2000) *Marine Turtle Conservation Project, Northern Cyprus Annual Report 2000.* Unpublished report.

Godley, B.J. & Broderick, A.C. (1994) *Glasgow University Turtle Conservation Expedition to Northern Cyprus, 1994: Expedition Report.* Unpublished report.

Godley, B. & Kelly, A. (1996) *Glasgow University Turtle Conservation Expedition to Northern Cyprus 1996: Expedition Report*. Unpublished report.

Godley, B.J., Thomson, R. & Broderick, A.C. (1998) *Glasgow University Turtle Conservation Expedition 1998. Expedition Report*. Unpublished report.

Godley, B.J., Broderick, A.C. & Moraghan, S. (1999) Short-term effectiveness of Passive Integrated Transponder (PIT) tags used in the study of Mediterranean marine turtles. *Chelonian Conservation & Biology*, **3(3),** 477–479.

Godley, B.J., Broderick, A.C. & Hays, G.C. (2001) Nesting of green turtles (*Chelonia mydas*) at Ascension Island, South Atlantic. *Biological Conservation*, **97,** 151–158.

Groombridge, B. (1990) *Marine Turtles in the Mediterranean: Distribution, Population Status, Conservation.* Council of Europe Environment Conservation and Management Division. Conservation, Nature and Environment Series, No. 48. Strasbourg.

Guinard, E., Weimerskirch, H. & Jouventin, P. (1998) Population changes and demography of the Northern Rockhopper Penguin on Amsterdam and Saint Paul islands. *Colonial Waterbirds*, **21,** 222–228.

Hays, G.C. (1992) Assessing the nesting beach fidelity and clutch frequency for sea turtles by satellite tracking. In *Wildlife Telemetry: Remote Monitoring and Tracking of Animals* (eds I.G. Priede & S.M. Swift), pp 203–213. Ellis Horwood, New York.

Hays, G.C. & Sutherland, J.M. (1991) Re-migration and beach fidelity of loggerhead turtles nesting on the island of Cephalonia Greece. *Journal of Herpetology*, **25(2),** 232–233.

Hays, G.C., Webb, P.I., Hayes, J.P., Priede, I.G. & French, J. (1991) Satellite tracking of a loggerhead turtle (*Caretta caretta*) in the Mediterranean. *Journal of Marine Biological Association of the UK*, **71,** 743–746.

Hilton-Taylor, C. (compiler) (2000) *2000 IUCN Red List of Threatened Species*. IUCN, Gland, Switzerland and Cambridge, UK.

Hirth, H.F. (1997) *Synopsis of the Biological Data on the Green Turtle*, Chelonia mydas *(Linnaeus 1758)*. Fish and Wildlife Service, US Department of the Interior. *Biological Report*, **97(1),** 1–120.

Houghton, J.D.R., Suggett, D.J., Maynard, S.J., Sharpe, S. & White, M. (1998) *Expedition Report. Kefalonian Marine Turtle Project*. Unpublished report.

Johnson, S.A. & Ehrhart, L.M. (1996) Reproductive ecology of the Florida green turtle: clutch frequency. *Journal of Herpetology*, **30(3),** 407–410.

Kaska, Y. (1993) *Investigation of* Caretta caretta *population in Patara and Kizilot.* Masters thesis. Dokuz Eylul University, Izmir, Turkey.

Kasparek, M., Godley, B.J. & Broderick, A.C. (2001) Nesting of the Green Turtle, *Chelonia mydas*, in the Mediterranean: a review of status and conservation needs. *Zoology in the Middle East*, **24,** 45–74.

Kuller, Z. (1999) Current status and conservation of marine turtles on the Mediterranean coast of Israel. *Marine Turtle Newsletter*, **86,** 3–5.

Laurent, L. (1997) Assessment of sea turtle nesting activity in Libya. *Marine Turtle Newsletter*, **76,** 2–6.

Laurent, L., Lescure, J., Excoffier, L., Bowen, B., Domingo, M., Hadjichristophorou, M., Kornaraki, L. & Trabuchet, G. (1993) Genetic studies of relationships between Mediterranean and Atlantic populations of loggerhead turtle *Caretta caretta* with a mitochondrial marker. *Compte Rendu de l'Académie des Sciences, Paris*, **316,** 1233–1239.

Laurent, L., Casale, P., Bradai, M.N., Godley, B.J., Gerosa, G., Broderick, A.C., Schroth, W., Schierwater, B., Levy, A.M., Freggi, D., Abd El-Mawla, E.M., Hadoud, D.A., Gomati, H.E., Domingo, M., Hadjichristophorou, M., Kornaraky, L., Demirayak, F. & Gautier, C. (1998) Molecular resolution of marine turtle stock composition in fishery by-catch: a case study in the Mediterranean. *Molecular Ecology*, **7,** 1529–1542.

Luschi, P., Hays, G.C., Del Seppia, C., Marsh, R. & Papi, F. (1998) The navigational feats of green sea turtles migrating from Ascension Island investigated by satellite telemetry. *Proceedings of the Royal Society of London B*, **265,** 2279–2284.

Margaritoulis, D. (1989) Loggerhead sea turtle nesting: Kiparissia Bay, Greece. In *Proceedings of the 9th Annual Workshop on Sea Turtle Conservation and Biology* (compilers S.A. Eckert, K.L. Eckert & T.H. Richardson), pp. 105–106. NOAA Technical Memorandum NMFS-SEFSC-232.

Margaritoulis, D. & Dimopoulos, D. (1995) *The Loggerhead Sea Turtle* Caretta caretta *on Zakynthos: Population Status and Conservation Efforts During 1994.* Sea Turtle Protection Society of Greece, Athens, Greece.

Margaritoulis, D., Argano, R., Baran, I., Bentivegna, F., Bradai, M.N., Camiñas, J.A., Casale, P., De Metrio, G., Demetropoulos, A., Gerosa, G., Godley, B.J., Haddoud, D.A., Houghton, J., Laurent, L. & Lazar, B. (in press) Loggerhead Turtles in the Mediterranean: present knowledge and conservation perspectives. In *Ecology and Conservation of Loggerhead Sea Turtles* (eds A. Bolton & B. Witherington). University of Florida Press.

Meylan, A.B. (1982) Estimation of population size in sea turtles. In *Biology and Conservation of Sea Turtles* (ed. K. Bjorndal), pp. 135–138. Smithsonian Institution Press, Washington DC, USA.

Miller, J.D. (1997) Reproduction in sea turtles. In *The Biology of Sea Turtles* (eds P. Lutz & J.A. Musick), pp. 51–81. CRC Press, Boca Raton, Florida, USA.

Mortimer, J.A. & Carr, A. (1987) Reproduction and migrations of the Ascension Island green turtle (*Chelonia mydas*). *Copeia*, **1987,** 103–113.

Peters, A. & Verhoeven, K.J.F. (1992) *Breeding Success of the Loggerhead*, Caretta caretta, *and the Green Turtle*, Chelonia mydas, *in the Göksu Delta, Turkey.* Rapport 310. Department of Animal Ecology, University of Nijmegen, The Netherlands.

Reyes, L.M., Crespo, E.A. & Szapkievich, V. (1999) Distribution and population size of the southern sea lion (*Otaria flavescens*) in central and southern Chubut, Patagonia, Argentina. *Marine Mammal Science*, **15,** 478–493.

Schroth, W., Streit, B. & Schierwater, B. (1996) Evolutionary handicap for turtles. *Nature*, **384,** 521–522.

Tiwari, M. & Bjorndal, K.A. (2000) Variation in morphology and reproduction in the loggerheads, *Caretta caretta*, nesting in the United States, Brazil and Greece. *Herpetologica*, **56(3),** 343–356.

Van Buskirk, J. & Crowder, L.B. (1994) Life-history variation in marine turtles. *Copeia*, **1994,** 66–81.

van Piggelen, D.C.G. (1993) *Marine Turtle Survey in the Göksu Delta, Turkey, June–August 1991*. Report 314. Department of Animal Ecology, University of Nijmegen, The Netherlands.

Yerli, S.V. & Canbolat, A.F. (1998) Results of a 1996 Survey of Chelonia in Turkey. *Marine Turtle Newsletter*, **79,** 9–11.

Yerli, S. & Demirayak, F. (1996) *Marine Turtles in Turkey. A Survey on Nesting Site Status.* Unpublished report. DHKD, Istanbul, Turkey.

Biographical sketches

Annette Broderick is a post-doctoral researcher and Brendan Godley a NERC Fellow based at the University of Wales, Swansea. They are co-editors of the Marine Turtle Newsletter (http://www.seaturtle.org/mtn). Fiona Glen is a research assistant studying for her PhD at the University of Wales, Swansea. Graeme Hays is a Senior Lecturer at the University of Wales, Swansea. The research group conducts fundamental and applied research into marine turtles at Ascension Island, Brazil, Cyprus, Great Britain, Greece, Guinea Bissau, Turkey and the UK Caribbean Overseas Territories. The work described in this paper is that resulting from the Marine Turtle Conservation Project, a partnership with the Society for the Protection of Turtles in Northern Cyprus and the local Department of Environmental Protection.