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Down but not out: marine turtles of the British Virgin Islands

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Abstract

We present the result of a multi-annual assessment of the spatio-temporal patterns of marine turtle nesting, and foraging in the Eastern Caribbean archipelago state of the British Virgin Islands. Despite exploitation over several centuries, three species (leatherback *Dermochelys coriacea*, green *Chelonia mydas* and hawksbill *Eretmochelys imbricata* turtles) are still nesting and green and hawksbill turtles are found foraging. Leatherback turtles are showing signs of a recovery co-incident with the implementation of an effective moratorium on adult take. When compared with historical data we demonstrate an apparent reduction in nesting levels in green and hawksbill turtles and a nesting range contraction in green turtles. Despite current conservation steps, it will be a decade or more before evidence of recovery can be expected in the two hard-shelled species. Coupled with wider biological knowledge, our findings offer insights into the relative resilience of the different species to exploitation pressure. Additionally, the intra-annual temporal and spatial spread of nesting demonstrated underlines the difficulties of monitoring such a multi-species assemblage in such a diffuse archipelago.

Introduction

Marine turtles in the Caribbean have been subject to exploitation for many centuries, which has resulted in large-scale reductions in population numbers (Parsons, 1962; Eckert, 1995; Jackson, 1997; Meylan, 1999; Bell *et al*., 2006). The loss of nesting populations are believed to have wide-ranging ecological consequences (Jackson *et al*., 2001) and recently there have been pleas for conservation programs in the Caribbean to alter their remit by focusing on the many small, widespread nesting populations still remaining (McClenachan, Jackson & Newman, 2006) and the international scope of conservation needed (Blumenthal *et al*., 2006).

Effective management of sea turtle stocks, in the form of active conservation measures in conjunction with a reduction in exploitation pressure, has recently seen some Caribbean sea turtle populations showing signs of recovery over relatively short time frames (Garduno-Andrade *et al*., 1999; Dutton *et al*., 2005; Troëng & Rankin, 2005). The British Virgin Islands (BVI, 18°30′N, 64°30′W) has a history of sea turtle exploitation followed by steadily increasing conservation measures and management (Fiedler & Jarvis, 1932; Eckert, Overing & Lettsome, 1992; Hastings, 1992). However, current published information on the status and trends of nesting and foraging sea turtle populations in the archipelago is lacking.

Sea turtles have always been part of the commercial fishery in the BVI with early records showing large quantities of meat and shell being exported during the 1920s (Fiedler & Jarvis, 1932). More recently, 1825 hard-shelled turtles (green and hawksbill) were landed as part of the legal fishery from 1981 to 1985, while several hundred individuals of both species were estimated to have been killed incidentally over the same time frame (Hastings, 1992). Additionally, leatherback turtles have been, and still are, highly prized in the BVI for their meat and oil (Hastings, 2003; M. Hastings, pers. obs.). Records from the 1920s show that as many as six nesting females were taken each night (Eckert *et al*., 1992). By the 1960s, it was still common for two nesting females to be harvested each night, although by the mid 1980s this population was at critically low numbers with only one or two females nesting each season. The protective legislation, The Turtles Ordinance 1959, was amended in 1986 to limit sea turtle harvest and protect eggs and nesting females, which greatly reduced the local commercial turtle fishery and effectively imposed a moratorium on leatherback turtle harvest (Hastings, 1992). Green and hawksbill turtles are still legally harvested in the BVI for subsistence purposes, with the current harvest being restricted to an open season from 1 December to 31 March in any year, and permits the take of green (carapace length >61 cm) and hawksbill turtles (carapace length >38.1 cm) at sea (Richardson, P.B. *et al*., 2006). The total annual harvest in recent years has been estimated at 150–200 green and hawksbill turtles (Godley *et al*., 2004). There are no quota limits and no study has been undertaken to estimate the sustainability of the current fishery. Coupled with legislative change, ever-increasing public sensitization and active research have been growing in the BVI and direct exploitation continues to decline (Hastings, 2003; Godley *et al*., 2004).

Other than leatherback turtle nesting data, which have been collected annually since 1986, nesting information is scant for the other turtle species. Over a 12-day period in July 1981, Fletemeyer (1984), using a combination of 6.8 h of aerial surveying, an unspecified number of beach walks and interviews with local fisherman and government officials, estimated that 75 ± 25 (range = 50–100) green and 50 ± 25 (range = 25–75) hawksbill turtles were nesting annually in the BVI. Hastings (1992) reported one green and four hawksbill turtle nests and one nest of unknown species, in 1990. In 1991, one green and 16 hawksbill turtle nests were found in addition to two nests of unknown species. However, the island of Anegada, thought to be the main nesting location for both species in the territory, was not included in any of the surveys in 1990 or in 1991 (Hastings, 1992). Twenty years have elapsed since the introduction of protective legislation in the BVI and with the current trend of some Caribbean turtle populations showing signs of increasing (Garduno-Andrade *et al*., 1999; Dutton *et al*., 2005; Troëng & Rankin, 2005; Richardson, J.I. *et al*., 2006), it is timely to revisit the status of marine turtles in the archipelago.

In this paper we present detailed monitoring data to provide an assessment of the nesting populations of leatherback, green and hawksbill turtles in terms of magnitude, range and seasonality in the BVI; a first in the case of the latter two species. We also present the long-term trend of leatherback turtle nesting in the BVI since the introduction of protective legislation. Furthermore, we provide information on the spatial distribution and size classes of the foraging population of green and hawksbill turtles in the BVI. The overall aims of this study are (1) to present data that can be used as a reference point for future surveys; (2) to elucidate the current spatio-temporal trends of nesting; (3) to gain insight into the current size ranges and an indication of relative abundance of local foraging aggregations.

Materials and methods

Study site

Biogeographically, the BVI forms part of the Puerto Rican Bank along with Puerto Rico and the US Virgin islands (excluding St Croix) and consists of *c*. 43 islands and cays, of which 16 are inhabited (Fig. 1a). Effectively monitoring such a large and diffuse archipelago presents many challenges to local government agencies and conservationists with limited resources. Exhaustive surveying of the entire BVI archipelago was not possible and therefore we used an approach consisting of synthesis of past monitoring data, seasonally targeted aerial surveying, and nesting beach surveys to gain an insight into the spatio-temporal patterns of nesting sea turtle populations of the BVI. In addition to the nesting surveys, we initiated an in-water capture program to establish the magnitude and size classes of the foraging populations of green and hawksbill turtles. The details of each specific methodology are given below.

Aerial surveys

Location of current turtle nesting sites across the archipelago was gathered using focused aerial surveying, which covered all the potential nesting beaches in the BVI archipelago and effectively repeated those areas surveyed by Fletemeyer (1984). The peak months of hard-shelled nesting in the region occur between May and August (US Virgin Islands, Hillis & Mackay, 1989; Antigua, Richardson, Bell & Richardson, 1999; Cayman Islands, Aiken *et al*., 2001). Financial restrictions meant that we conducted three aerial surveys in 2004 and three surveys in 2005 (six aerial surveys in total) between 25th May and 31st August. The mean number of days between surveys in each year was 17.7 ± 4.7 days ($n = 4$ inter-survey periods) and was dictated by plane availability. All surveys were conducted in a Cessna Blackhawk and commenced at 08.00 h and lasted on average 73.6 ± 3.3 min. The variance in flight times depended on the weather and on the number of activities encountered. Flights started and finished from the island of Anegada, and followed a set route throughout the archipelago (Fig. 1a) covering all the potential turtle nesting beaches. During each survey the aircraft maintained a steady airspeed of 180 km h^{-1} at a height of 170 m above sea level and two observers surveyed beaches for fresh turtle tracks. Once tracks were encountered, the aircraft circled overhead until the species was identified and where possible nesting confirmed following Schroeder & Murphy (1999). Nesting activity was recorded on Anegada, Tortola and Sandy Cay during aerial surveying. All three nesting species (leatherback, green and hawksbill turtles) were represented and 23/25 turtle tracks (five leatherback, seven green and 11 hawksbill turtle tracks) were ground truthed during beach patrols, with species identification being confirmed correct in all cases. The two remaining hawksbill activities (Sandy Cay) were not ground truthed.

Beach surveys of Tortola and nearby islands

Monitoring Tortola's leatherback turtle nesting beaches is conducted by BVI Conservation and Fisheries Department (BVICFD) personnel and has been ongoing since 1986 (see Hastings, 2003 for an overview). Before 1994, leatherback turtle nesting activity was assessed retrospectively with beach surveys being conducted bi-weekly from mid-March to mid-June although the total number of surveys and personnel involved in each year is unknown. Since 1994, nightly beach patrols have been conducted between March and August on the main leatherback turtle nesting beaches and beach wardens cover the remaining Tortola beaches every 4–5 days. Beach wardens cover all beaches on Tortola

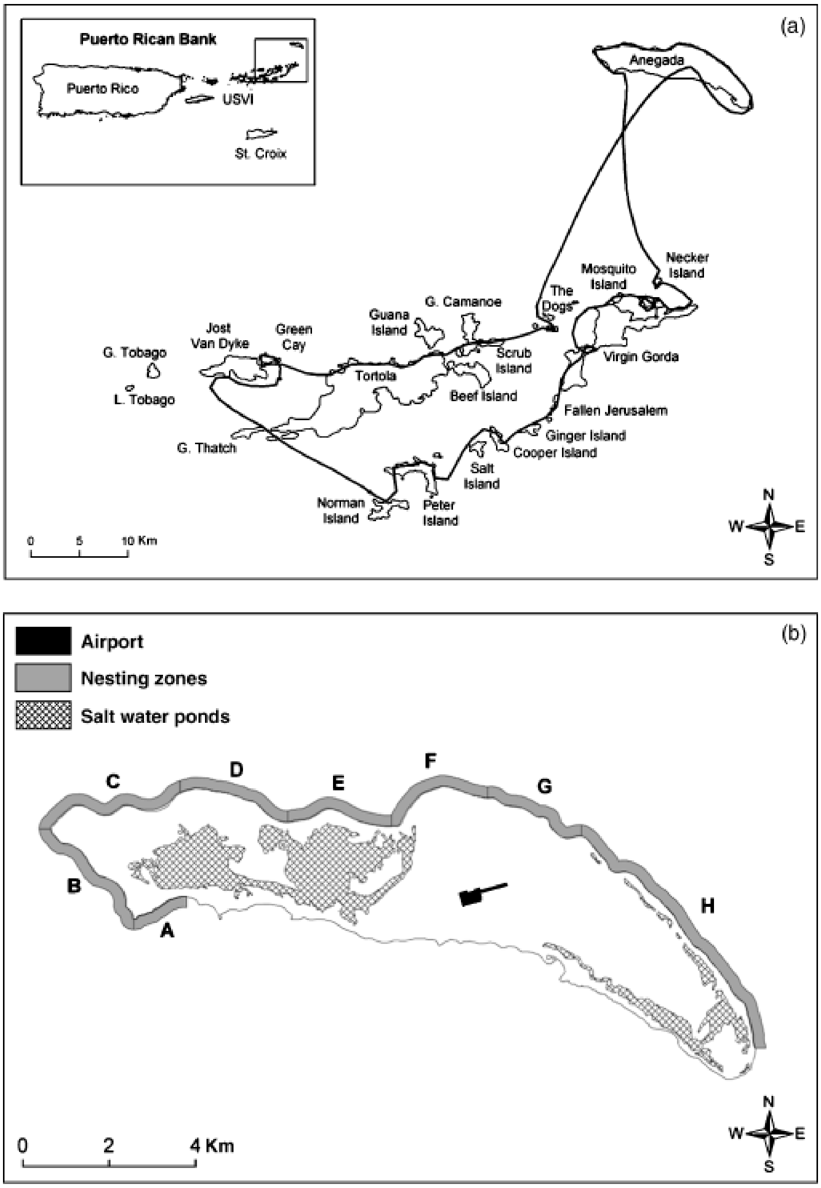

Figure 1 Map of the British Virgin Islands (BVI) and the monitoring locations for sea turtle nesting in the BVI by (a) aerial surveying and (b) foot patrols on the beach sections of Anegada. Inset in (a) shows location of the Archipelago in relation to the Puerto Rican Bank.

at least once every 7 days as part of their daily duties throughout the year, which is more than adequate to ensure that all turtle nesting activities are detected (Bjorndal *et al.*, 1999). Occasional female hawksbill turtles and or tracks are encountered during leatherback turtle surveys by the BVICFD staff. However, the majority of nesting green and hawksbill turtle nesting attempts on islands other than Tortola and Anegada are recorded in an opportunistic manner and are primarily reported to BVICFD by a network of local interested residents and tourists.

Beach surveys of Anegada

Foot patrols for sea turtle nesting activity were conducted between 17 November 2003 and 22 September 2005. The northern and western coastline of Anegada, containing sea turtle nesting habitat, was arbitrarily divided into manageable portions (Fig. 1b). The remainder of the southern coastline of Anegada is rocky or mangrove-fringed shoreline and therefore has no suitable habitat for nesting sea turtles. The frequency of surveying was irregular and designed to elucidate general spatio-temporal patterns of nesting and offer an approximate indication of the magnitude of nesting for the different species. In total, 181 foot surveys of the nesting beach sections of Anegada were conducted, and there was some variation in the number of surveys that each section received (Table 1). The mean number of foot surveys per section was $= 22.6 \pm 1.53$, $n = 8$ sections. For most beach sections the majority of surveys were concentrated during the peak months of the nesting season (Table 1), with the rest of the surveys spread evenly through the rest of the calendar year. Our surveys effectively covered two complete

Table 1 The number and seasonal breakdown of nesting beach surveys that took place on Anegada between November 2003 and September 2005

		Number of surveys								
		November 2003 to October 2004				November 2004 to October 2005				
Beach	Length of beach (km)	January–March	April–June	July–September	October–December	January–March	April–June	July–September	October–December	Total number of surveys
A	1.47	0	3	5	2	2	1	6	2	21
B	2.97	0	3	5	2	2	1	6	2	21
C	3.27	0	3	5	2	2	1	5	2	20
D	2.74	0	3	5	2	2	1	3	2	18
E	2.78	0	3	5	2	2	1	4	2	19
F	1.81	0	3	7	2	2	1	7	2	24
G	2.75	1	3	8	2	2	1	9	2	28
H	7.00	1	3	10	2	2	1	9	2	30

turtle nesting seasons. All beach surveys took place during daylight hours and subsequently any sea turtle tracks that were encountered were assessed retrospectively. Each track was identified to species and nesting was confirmed following Schroeder & Murphy (1999).

Foraging

To sample foraging populations of green and hawksbill turtles we carried out an extensive in-water capture programme that consisted of a territory wide effort based from Tortola and a concentrated effort in Anegada. All sampling took place in shallow (<15 m) coastal waters. A total of 294.75 h were spent in-water sampling from Tortola, with the mean number of hours per day sampling being 3.13 ± 0.02 h, $n = 95$ days. In contrast, 542.75 h were spent sampling at Anegada with the mean number of hours per day sampling being 4.98 ± 0.14 h, $n = 109$ days. Turtles were captured by hand via a combination of free diving or the rodeo-style method (Ehrhart & Ogren, 1999) with all subsequent measurements being conducted in the same way. Each turtle that was caught was given a unique numbered set of inconel flipper tags attached to the trailing edge of each fore flipper proximal of and adjacent to the first large scute (Balazs, 1999) and a series of biometric data were taken. Local fisherman on Anegada, using set nets targeting turtles, provided a small number of turtles (10 green, two hawksbill turtles) for measuring before consumption. Using a flexible measuring tape, we measured the curved carapace length notch to tip (CCLn-t) and the curved carapace width (CCW) (Bolten, 1999). We also measured the straight carapace length notch to tip (SCLn-t) and the straight carapace width (SCW) using large vernier callipers (Bolten, 1999).

Statistical analyses

All statistical analyses were carried out using GenStat Release 7.1 (GenStat, 2003). All tests were parametric and two-tailed unless the data violated the assumptions of normality in which case non-parametric equivalents were used. To assess the foraging size class distributions of turtles caught at Anegada and Tortola, we used the Kolmogorov–Smirnov two-sample test. This test compares the two empirical cumulative distribution functions in order to try and detect differences in the shape of the underlying distributions with the test statistic being the absolute difference between the cumulative distribution functions and converted to a χ^2 equivalent for ease of interpretation (GenStat, 2003). Means $\pm$ one standard error are presented throughout, unless otherwise stated.

Results

Nesting

The total number of leatherback turtle nests recorded in the BVI ranged between 0 and 65 nests between 1986 and 2006 (Fig. 2). Despite the number of leatherback turtle nests dropping to zero in 1989, the long-term trend, since this minima, has generally been a steady increase since the early 1990s with year accounting for 63% of the variance in the total number of nests (linear regression: $F_{1,20} = 34.8$, $P<0.001$, Fig. 2). The survey regime before 1994 was different and could potentially cause bias but there is still a significant effect of year on the number of leatherback nests if the data before 1994 are excluded (linear regression: $F_{1,12} = 8.1$, $P<0.02$, $r^2 = 0.37$). It should be noted that the inclusion of a quadratic and/or a polynomial term did not improve the r^2 value of the model and hence we present the basic linear regression for simplicity. Therefore, we are confident that the general trend of increasing nest numbers is real and not an artefact of variable monitoring effort. Furthermore, analysis of the same data utilizing an Autoregressive Integrated Moving Average (ARIMA) approach to account for the same females re-nesting every 2–3 years returns the same positive significant effect of year, with all the autoregressive parameters being non-significant. However, following a peak of nesting in 2003, the total number of nests has been slightly lower in the most recent seasons (Fig. 2).

A total of 26 green and 24 hawksbill turtle nests were recorded on Anegada between November 2003 and September 2005. During the same time period members of the public

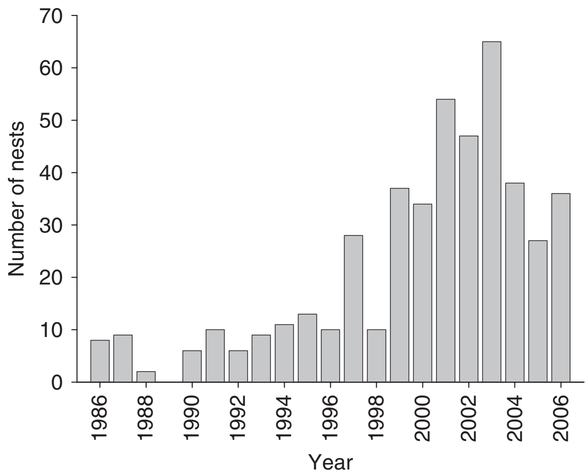

Figure 2 The number of leatherback turtle *Dermochelys coriacea* nests recorded in the British Virgin Islands from 1986 to 2006. Linear regression: $y = -4.67 + 2.42x$, $r^2 = 0.63$.

reported an additional 18 turtle nests from several different islands (Tortola: one green and 11 hawksbill turtle nests; Beef Island: two hawksbill nests; and single hawksbill nests from each of Cooper Island, Saba Rock, Sandy Cay and Virgin Gorda).

Spatially, leatherback turtle nesting is confined to the north shore of Tortola, with occasional nests on the west coast of Anegada and a rare nest on Virgin Gorda (Fig. 3a). In contrast, green turtle nesting is almost entirely confined to the north shore beaches of Anegada with a rare nest occurring on the south-west coast of Tortola (Fig. 3b). It should be noted that the entire south coast of Anegada is completely unsuitable for any nesting turtle species. Hawksbill nesting was much more widely distributed throughout the BVI (Fig. 3c) with nesting occurring on seven different islands during the time frame of this study although the vast majority of hawksbill nesting occurs on the west and north shores of Anegada (Fig. 3c). Comparison with the combined historical nesting records (Fletemeyer, 1984; Hastings, 1992) shows that there has been a significant decrease in the number of islands with green turtle nesting (Fisher's exact test: $P = 0.03$), with only two islands hosting green turtle nesting now, compared with 10 islands historically. The hawksbill turtle nesting range shows no significant change (Fisher's exact test: $P = 0.59$), with seven islands hosting nesting today compared with 10 previously (Fig. 3b and c, respectively). It should be noted that the islands found to have nesting in the 1990/1991 study were recorded as having nesting in 1981 and therefore combining the historical records makes no difference to the overall result.

The main nesting season for leatherback turtles in the BVI is from March to June with a peak in nesting numbers occurring in May (Fig. 4a). Very few leatherback turtle nests have been recorded outside this time period and there is very little overlap in nesting with the other two nesting species. The green turtle nesting season is likely to be from June to

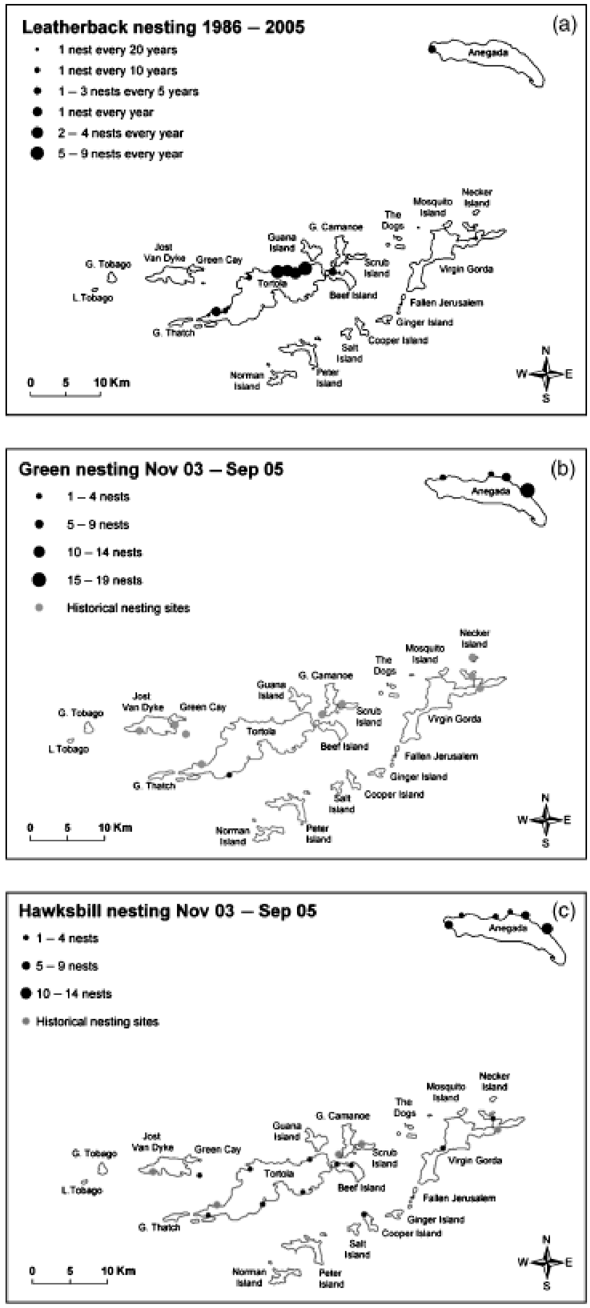

Figure 3 The locations and number of nests for (a) leatherback sea turtles *Dermochelys coriacea* based on 20-year data; (b) green sea turtles *Chelonia mydas* from November 2003 to September 2005 and (c) hawksbill sea turtles *Eretmochelys imbricata* from November 2003 to September 2005 in the British Virgin Islands archipelago. Historical records of nesting locations from Fletemeyer (1984) and Hastings (1992).

September with the main peak of nesting activity occurring in August (Fig. 4b). Similar to the green turtle nesting season, the hawksbill turtle demonstrates a main peak of nesting activity in August although nesting is more protracted occurring throughout September and October, with a small number of nests recorded throughout most months of the year (Fig. 4c).

Foraging

Foraging aggregations of sea turtles are widespread and abundant in the shallow coastal waters of the BVI. In total, 172 green turtles and 328 hawksbill turtles were caught in the waters of the BVI and the distribution of captures for each species in the archipelago from Tortola and Anegada are shown in Fig. 5a–d, respectively. There was no significant difference in the shapes of the size class distributions of foraging green turtles that were caught from Tortola or from Anegada (Kolmogorov–Smirnov two sample test: $\chi^2 = 1.5$; $P = 0.47$; Fig. 6a and c). Nor was there a difference in the shapes of the size class distributions of foraging hawksbill turtles (Kolmogorov–Smirnov two-sample test: $\chi^2 = 1.5$; $P = 0.47$; Fig. 6b and d).

Overall, 1.65 ± 0.13 and 5.71 ± 0.41 turtles were caught per day from Tortola and Anegada, respectively. These values equate to a catch per unit effort of 0.53 and 1.1 turtles h^{-1} for Tortola and Anegada, respectively. It should be noted that these values include processing time estimated at approximately 15 min per turtle.

Discussion

Three species of sea turtle are still nesting in the BVI but these populations no doubt represent depleted populations when compared with historical records and ranges (Fletemeyer, 1984; Eckert *et al.*, 1992; Hastings, 1992; Jackson, 1997), with the numbers of all three nesting species still appearing to be critically low. It would appear that the number of nesting female leatherback turtles are showing signs of recovery as the number of annual nests has risen over the past 10 years and in all likelihood the implementation of a moratorium on harvest in 1986 is a contributory factor. Since 1994, the monitoring effort of Tortola's leatherback beaches has been consistent and we believe these increases to be genuine and not an artefact of variable monitoring effort, although the same cannot be said for nesting numbers before 1994. The rise in the number of leatherback nests in the BVI is also mirrored in the nearby nesting beaches of St Croix, US Virgin Islands (Dutton *et al.*, 2005), although elsewhere in the Caribbean, leatherback nesting numbers appear to be either stable or slightly declining (Troëng, Chacón & Dick, 2004). Furthermore, a similar pattern of slightly reduced nesting numbers following peaks in 2001 and 2003 has been demonstrated at the nearby leatherback rookery at St Croix (Garner, Garner & Coles, 2006; P. H. Dutton, pers. comm.).The observed variation in the total number of nests over the last few years is most likely to be a result of the inter-annual variability in nesting numbers, coupled with the female condition, which will affect the total number of nests a female lays in a given season (Miller, 1997; Broderick, Godley & Hays, 2001). It could be argued that because the leatherback turtles are long-lived and take a decade or more to reach sexual maturity, the observed sharp

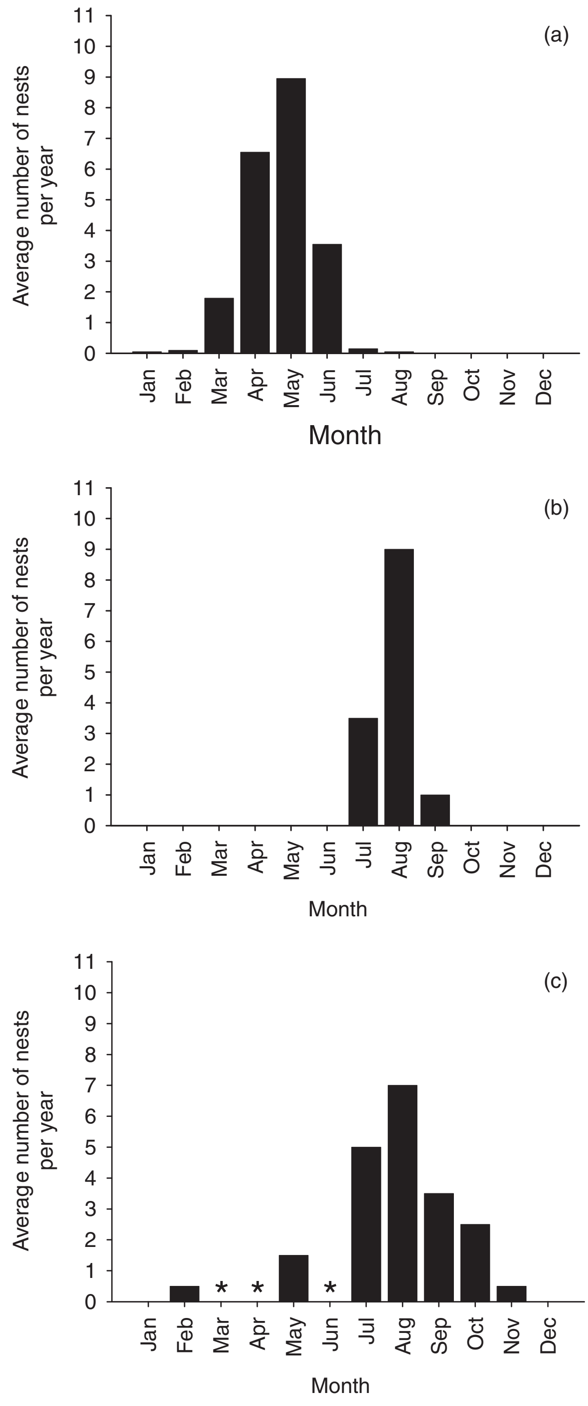

Figure 4 The seasonality of nesting in the British Virgin Islands for (a) leatherback turtles *Dermochelys coriacea* based nesting data from 1986 to 2006; (b) green turtles *Chelonia mydas* based on two years of nesting data (November 2003 to October 2005) and (c) hawksbill turtles *Eretmochelys imbricata* based on two years of nesting data (November 2003 to October 2005). *No systematic surveys were conducted during these months on Anegada.

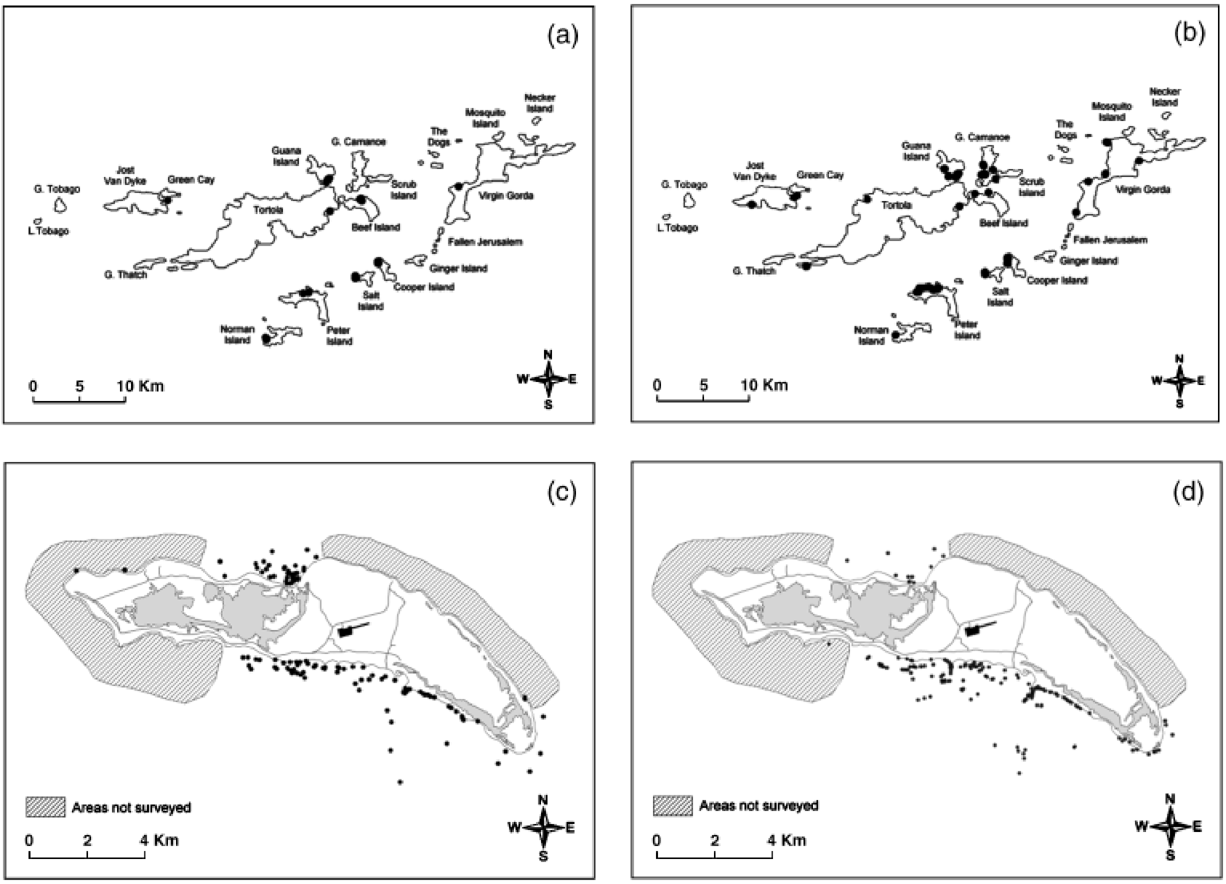

Figure 5 The capture locations of foraging (a) green turtles *Chelonia mydas* and (b) hawskbill turtles *Eretmochelys imbricata* captured by Tortola based efforts and those for foraging (c) green and (d) hawskbill turtles captured in Anegada. Shaded areas in (c, d) indicate areas not systematically surveyed due to turbidity or difficult boat access.

increases in nesting numbers are due to variable survey effort. However, we believe that this is not the case here for several reasons. Firstly, we are dealing with a meta-population that includes highly protected populations in the US Virgin Islands and Puerto Rico (Dutton *et al*., 1999, 2005) and leatherback turtles are known to be less site faithful, in terms of nesting, than was originally thought (Rivalan *et al*., 2006; Georges *et al*., 2007). Secondly, results elsewhere suggest that colonization can sometimes involve a large number of animals over a short time scale, for example over one or a few decades (Rivalan *et al*., 2006). Thirdly, leatherback sea turtles have one of the shortest generation times, *c*. 10 years, of all sea turtle species (Zug & Parham, 1996), which would fit with our observed increases, and finally, leatherback turtles are no longer being butchered on the BVI nesting beaches.

Tortola certainly appears to be the heart of leatherback turtle nesting in the BVI with only sporadic nests occurring on two other islands. Leatherback turtles have specific nesting requirements and are known to prefer to nest on 'high energy' beaches with steep slopes, deep-water approaches and absence of any fringing reef (Mrosovsky, 1983; Eckert, 1987; Eckert *et al*., 1989), which are in abundance on the north shore of Tortola. However, it is surprising that green turtles do not nest on these same beaches because the two species are known to nest on the same beaches at other sites (Whitmore & Dutton, 1985; Bjorndal & Bolten, 1992). Green turtles are thought to show a higher degree of site fidelity than the other turtle species (Miller, 1997; Bjorndal, Bolten & Troëng, 2005; Richardson J.I. *et al*., 2006; Rivalan *et al*., 2006; Formia *et al*., 2007; Georges *et al*., 2007) and in all likelihood the green turtle nesting population on Tortola, the most populated island in the BVI, was effectively lost, possibly due to human exploitation, before surveys began in the early 1980s. Fletemeyer (1984) recorded 19 green turtle nests on eight different islands and 20 hawksbill turtle nests on five islands during 6.8 h of aerial surveying over a 12-day period in July 1981 and suggested that 75 green and 50 hawksbill turtles were nesting each year. These estimates of nesting female numbers multiplied by the mean number of clutches per season would equate to approximately 220 green and 137 hawksbill clutches per nesting season in the early 1980s (Green turtles: mean number of clutches per season = 2.93; hawksbill turtles: mean number of clutches per season = 2.74, Miller, 1997). Furthermore, 70 foot surveys of 18 beaches in July

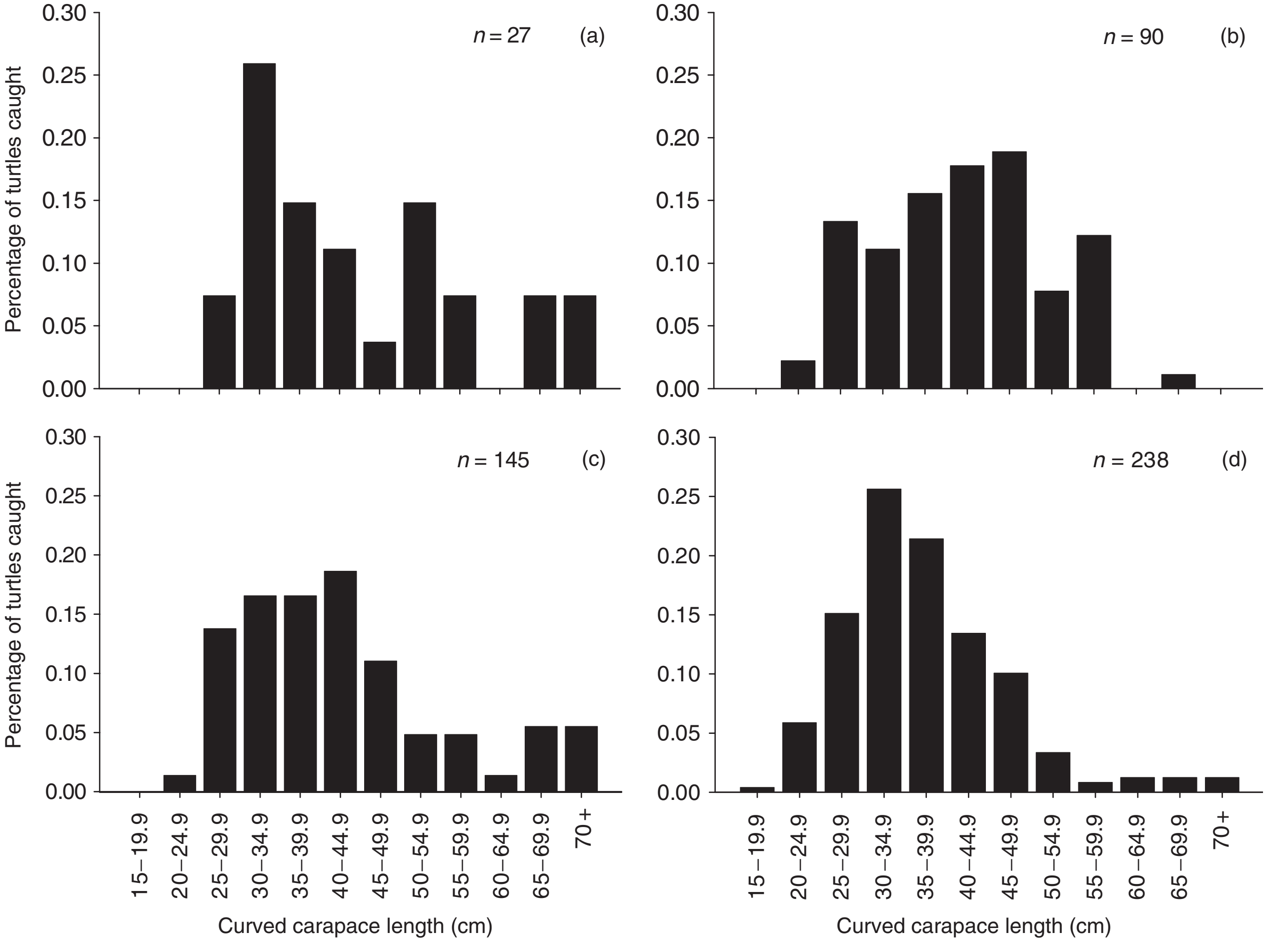

Figure 6 Size class distribution of captured (a) green turtles *Chelonia mydas* from Tortolan-based efforts; (b) hawksbill turtles *Eretmochelys imbricata* from Tortolan-based efforts; (c) green turtles from Anegada and (d) hawksbill turtles from Anegada.

1990 and 78 surveys of 23 beaches between August and November 1991 resulted in only one green turtle nest being recorded each year (Hastings, 1992). Hastings (1992) also reported four hawksbill turtle nests in 1990 and 16 hawksbill turtle nests in 1991 from the same surveys. However, it should be noted that Anegada was not surveyed in either of these years. We recorded only 26 green turtle nests on two islands (25 nests on Anegada, one nest on Tortola) and 24 hawksbill turtle nests over the course of two complete nesting seasons, which included 7.3 h of aerial surveying of the entire archipelago and exhaustive foot surveys of both Tortola and Anegada. Our findings would seem to indicate that there has been a reduction in the magnitude of both hard-shelled species and a reduction in the spatial distribution of nesting green turtles throughout the territory since the early 1980s (Fig. 3b), with Anegada being the last stronghold for both hard-shelled species in the BVI. However, it should be noted that the lack of systematic monitoring of hard-shell nesting means that firm conclusions regarding population trends cannot be made due to potential bias caused by sampling effort and the inter-annual variability in nesting. Indeed, other monitoring projects in the Caribbean have shown that both green and hawksbill nesting numbers are on the increase (Garduno-Andrade *et al.*, 1999; Troëng & Rankin, 2005; Richardson J.I. *et al.*, 2006; Beggs, Horrocks & Krueger, 2007; but see Bell *et al.*, 2007). Nevertheless, unlike the other two turtle species, hawksbill turtles typically have a more widespread nesting distribution in the BVI, characteristic of their less-rigid nesting requirements (Horrocks & Scott, 1991) and this attribute may make hawksbill turtles in the BVI and elsewhere more resilient to local extirpation but conversely makes active monitoring and conservation efforts aimed at this species more difficult to implement. Indeed, if one considers the slightly perverse perspective of actively making the nesting populations of all three species in the BVI extinct, then it would be easiest to accomplish for green turtles due to their high site fidelity and strict nesting beach requirements. Extirpation of Leatherbacks would be more difficult because, although they have strict nesting beach requirements, they are not very site faithful and recruitment will occur from other populations. Hawksbills would be most resilient because of their flexible nesting requirements, making nesting most diffuse.

Our monitoring data clearly show that the peak of leatherback turtle and hard-shelled turtle nesting is temporally separated in the BVI, with leatherback turtle numbers peaking in May while the hard-shelled species are centred about August, and these findings mirror the patterns shown by neighbouring nesting populations of leatherback turtles (US Virgin Islands, Garner *et al.*, 2006; Central America Caribbean coast, Troëng *et al.*, 2004), green turtles (Costa Rica, Troëng & Rankin, 2005) and hawksbill turtles (US Virgin Islands, Hillis & Mackay, 1989; Antigua, Richardson *et al.*, 1999; various locations in the Caribbean Sea, Chacón, 2004). The dichotomy in nesting peaks, coupled with the extended hawksbill turtle nesting season, effectively complicates monitoring by prolonging the turtle nesting season from March to November. To intensively monitor nesting of this multi-species assemblage, in such a diffuse archipelago, would require resources that are currently beyond local government capacity. However, our survey regime has shown that targeted bouts of focused fieldwork can still provide valuable and reliable insights into sea turtle nesting ecology in terms of magnitude and seasonality and that such temporally targeted bouts of fieldwork at index sites offers the potential for future trend detection.

We spent a large number of hours sampling the foraging turtle assemblage in the waters of the BVI, and in terms of capture frequency (CPUE) our figures (0.57 turtles h^{-1} Tortola and 1.1 turtles h^{-1} Anegada) are comparable with those reported from various sites at Mona Island, Puerto Rico (range 0.48–2.38 turtles h^{-1}; León & Diez, 1999) and Jaragua National Park and Cabo Rojo, Domincan Republic using similar methodology (range 0.86–3.43 turtles h^{-1}; León & Diez, 1999). Our CPUE estimates are minimum estimates as they incorporate processing time, and therefore the relatively high relative abundance of turtles inhabiting the waters of the BVI indicates that it is an important foraging ground for both species in the region. Our results from the in-water capture programme showed that green and hawksbill sea turtles constitute the vast majority of the foraging sea turtle population in the BVI, although loggerhead turtles are occasionally reported (S. Gore, pers. obs.). Foraging green and hawksbill turtles can be found throughout the archipelago, highlighting the difficulty of setting conservation priorities, although there are pockets of higher relative abundance. Anegada is without question a highly important area for both species, especially for small (<40 cm SCL), turtles and foraging turtle stocks appear to be healthy. It is most likely that foraging stocks are mainly from the major rookeries elsewhere in the Caribbean and a full genetic assessment of the foraging populations is currently being undertaken.

It is interesting to note that there were few large (>60 cm SCL) individuals of both species captured during the in-water study, particularly as there are active breeding populations of both green and hawksbill turtles. Hawksbills >60 cm SCL accounted for only 3% (10/328) of those caught at Anegada and Tortola combined, whereas 7% (14/197) of hawksbill turtles at Mona and Monito islands, Puerto Rico (Diez & van Dam, 2002) and 44% (47/106) at the southern Great Barrier Reef feeding ground (Limpus, 1992) caught during similar in-water studies were >60 cm SCL and CCL, respectively. A similar pattern exists for green turtles with 13% (22/172) of those individuals caught at Anegada and Tortola combined being >60 cm SCL whereas 18% (24/135) of green turtles at Culebra (Collazo, Boulon & Tallevast, 1992) and 22% (31/141) at Great Inagua, Bahamas (Bjorndal & Bolten, 1988) were >60 cm SCL.

Human consumption could be responsible for the apparent lack of large turtles although the depth of the water where search efforts were focused, is in all likelihood the major influence on these results. Shallow inshore areas were the focus of our in-water work; indeed, 73% of all captures at Anegada were in water <1 m in depth and the maximum depth of a capture at Anegada was 4.8 m. Models of optimal diving behaviour suggest that smaller individuals should seek prey items in shallower water and larger individuals in deeper water, even though small individuals are capable of diving to greater depths (Mori, 2002). Large adult and near-adult hard-shelled turtles may not use the same foraging grounds as smaller turtles and a concept of sequential developmental habitats, typically of increasing depth with increasing body size (Ehrhart & Redfoot, 1995; Musick & Limpus, 1997), has been used to explain the size class differences found at different foraging grounds. There may be a dichotomous shift from developmental foraging habitat to adult foraging habitat and this has been used to explain the size class distributions of immature hawksbills on the southern Great Barrier Reef (Limpus, 1992) and green turtles in the Gulf of California, Mexico (Seminoff *et al.*, 2003). This may be especially true for hawksbill turtles at Anegada, with small turtles inhabiting the shallow warm waters and associated patch reefs and sea grass beds, growing until they reach a threshold limit, *c.* 50–55 cm SCL. Once the size threshold is reached, individuals may then relocate to the deeper waters of the outer reef wall habitat when they are large enough to avoid predation by the majority of large predatory fish species. Although logistically challenging, an assessment of the size classes of turtles inhabiting the deeper waters of the outer reef wall coupled with tagging would be useful in evaluating whether a size-related shift in foraging habitat is actually occurring at these sites.

Nesting leatherback turtles in the BVI have shown a steady increase since the early 1990s and it is highly likely the moratorium on leatherback turtle harvesting has been a factor in the rise in nesting females. However, nesting populations from the BVI, US Virgin Islands, Puerto Rico and possibly other islands in the Antilles are all thought to contribute to a larger regional metapopulation (Dutton *et al.*, 2005). Therefore, the rise in nesting numbers in the BVI may, in part, be attributable to supplementation of individuals from other nearby rookeries that are also on the increase (Dutton *et al.*, 2005). Irrespective of the true source of the increase in nesting leatherback turtles in the BVI, it is clear that conservation measures aimed at reducing the pressure on nesting female turtles can aid the recovery of nesting populations in a relatively short time frame (Bjorndal *et al.*, 1999; Balazs & Chaloupka, 2004; Dutton *et al.*, 2005; Troëng & Rankin, 2005). In contrast to the leatherback turtle situation, the number of nesting hard-shelled turtles in the BVI appears to have decreased markedly from the numbers reported in the early 1980s by Fletemeyer (1984). It is not possible to generate any current trend for the number of nesting hard-shelled turtles because data will need to be gathered over extended time periods as a result of inter-annual variability in nesting numbers, which is especially prolific in green turtles (Broderick *et al.*, 2001). We have, however, highlighted the current spatio-temporal patterns of nesting and have provided a baseline to direct future monitoring. Any recovery of hard-shelled nesting numbers would be expected to take longer than the leatherback turtles due to inter-specific differences in time to maturity and site fidelity. Leatherback turtles are thought to reach maturity between 9 and 14 years old (Zug & Parham, 1996), while hard-shelled turtle maturity estimates range between 20 and 40 years for some populations (Boulon, 1994; Chaloupka & Limpus, 1997; Bjorndal, Bolten & Chaloupka, 2000; Diez & van Dam, 2002; Balazs & Chaloupka, 2004). Furthermore, tagging and genetics studies have shown that leatherback turtles are not particularly site faithful (Rivalan *et al.*, 2006; Georges *et al.*, 2007), unlike green turtles (Bjorndal *et al.*, 2005; Formia *et al.*, 2007) and hawksbill turtles (Richardson J.I. *et al.*, 2006).

Despite being constrained by resources, we have gained significant insights into the spatial distribution and seasonality of nesting sea turtles of the BVI as well as highlighting the widespread stocks of foraging juveniles in BVI waters. These are relevant to the conservation of nesting and foraging sea turtle stocks in the BVI and the wider Caribbean. This loss of sea turtle numbers is thought to be one of the first steps in the dismantling of Caribbean marine ecosystems and it has been suggested that protection of small nesting populations needs to be more strongly advocated (McClenachan *et al.*, 2006). When given complete protection, nesting populations of sea turtles in the Caribbean seem to have the capacity to recover relatively rapidly (Garduno-Andrade *et al.*, 1999; Dutton *et al.*, 2005; Troëng & Rankin, 2005; but see Bell *et al.*, 2006) and the leatherback turtle population of the BVI appears to be demonstrating this effect. We have shown evidence strongly suggestive of a reduction in nesting levels for green and hawksbill turtles, as well as a reduction in the nesting range for green turtles, and despite current conservation steps being undertaken (Hastings, 2003), it might be a decade or more before positive signs of recovery could be evidenced in these hard-shelled species. The intra-annual temporal and spatial spread of nesting of the three turtle species also highlight the difficulties faced by, generally under-resourced, local government agencies in monitoring such a multi-species assemblage in a widespread archipelago like the BVI.

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