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Marine turtle harvest in a mixed small-scale fishery: Evidence for revised management measures

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ABSTRACT

Small-scale fisheries (SSF) account for around half of the world's marine and inland fisheries, but their impact on the marine environment is usually under-estimated owing to difficulties in monitoring and regulation. Successful management of mixed SSF requires holistic approaches that sustainably exploit target species, consider non-target species and maintain fisher livelihoods. For two years, we studied the marine turtle fishery in the Turks and Caicos Islands (TCI) in the Wider Caribbean Region, where the main export fisheries are queen conch (*Strombus gigas*) and the spiny lobster (*Panulirus argus*); with fin-fish, green turtles (*Chelonia mydas*) and hawksbill turtles (*Eretmochelys imbricata*) taken for domestic consumption. We evaluate the turtle harvest in relation to the other fisheries and recommend legislation and management alternatives. We demonstrate the connectivity between multi-species fisheries and artisanal turtle capture: with increasing lobster catch-per-unit-effort (CPUE), hawksbill catch increased whilst green turtle catch decreased. With increasing conch CPUE, hawksbill catch declined and there was no demonstrable effect on green turtle catch. We estimate 176–324 green and 114–277 hawksbill turtles are harvested annually in TCI: the largest documented legal hawksbill fishery in the western Atlantic. Of particular concern is the capture of adult turtles. Current legislation focuses take on larger individuals that are key to population maintenance. Considering these data we recommend the introduction of maximum size limits for both species and a closed season on hawksbill take during the lobster fishing season. Our results highlight the need to manage turtles as part of a broader approach to SSF management.

1. Introduction

Small-scale fisheries (SSF) are estimated to account for more than half of the world's marine and inland fish catch (FAO, 2010). The majority of the world's fishers are located in developing countries and operate using small boats of <12 m in length (FAO, 2010). The terms 'small-scale' and 'artisanal' are often used interchangeably. However, SSF are generally commercial fisheries even when they retain traditional aspects (Chuenpagdee et al., 2006). Definitions aside, 'small-scale' does not necessarily mean small impact (McCluskey and Lewison, 2008; Alfaro-Shigueto et al., 2010); catch by individual fishers might not always be substantial, but fleets can be sizeable and have large impacts on coastal wildlife (Alfaro-Shigueto et al., 2011; Mangel et al., 2010; Peckham et al., 2007; Soykan et al., 2008). With SSF dominating the continental shelf (Stewart et al., 2010), environmental impact is likely to be concentrated in coastal areas that are already likely to be subject to other human pressures (Dunn et al., 2010).

SSF are generally managed by biologically based control measures for single species, e.g. catch quotas, gear restrictions, effort limits, fishing seasons. Most SSF, however, operate as multi-species or mixed fisheries (Salas et al., 2007) and as such, single-species based management approaches tend to fail, having indirect effects on other fisheries and fisher behaviours (Béné and Tewfik, 2001). Multi-species or ecosystem-based management approaches that assess multiple biological stocks and their

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interactions and account for the complexities of fisher behaviours, fleet dynamics, socioeconomic drivers and maintain livelihoods are badly needed for mixed SSF (Andrew et al., 2007; Béné and Tewfik, 2001; FAO, 2010; Fanning et al., 2011). Knowledge of the dynamics of the whole SSF is key to managing healthy coastal ecosystems and supporting communities that rely on them.

Understanding the impacts of SSF on coastal ecosystems, however, is hindered by a paucity of quantitative information on catches, fishery effort and employment in SSF because of their complexity and the generally poor institutional capacity in developing countries to collect relevant data (Dunn et al., 2010; FAO, 2010; Salas et al., 2007). This in turn hinders the formulation of appropriate policies and management in the SSF sector (Andrew et al., 2007; FAO, 2010).

In this paper, we assess a multi-species SSF in the Turks and Caicos Islands (TCI), a UK Overseas Territory (UKOT) in the Wider Caribbean Region (WCR). We examine the artisanal take of two sympatric sea turtle species, the green turtle (*Chelonia mydas*) and hawksbill turtle (*Eretmochelys imbricata*), alongside two of the most important and valuable fisheries in the Caribbean – the Queen Conch (*Strombus gigas*) and the Spiny Lobster (*Panulirus argus*) (FAO, 2007). Lobster and conch represents almost all of the TCI fishery export, principally to USA markets (Department of Environment and Maritime Affairs – TCI, unpublished data; FAO, 2007). Lobster catch-per-unit-effort (CPUE: kg/fisher/day) has been steadily declining (Tewfik and Béné, 2004) and despite claims that the TCI conch fishery is at maximum sustainable yield (currently 760 metric tonnes; FAO, 2007), signs of overfishing have been reported since the early 1990s (Medley and Ninnes, 1999; Ninnes, 1994). Green and hawksbill sea turtles are largely harvested for personal consumption, and although the TCI turtle fishery can be considered artisanal and incidental to the lobster and conch fisheries, it is thought to be the largest regulated and legitimate turtle fishery in the UKOTs (Richardson et al., 2009), and possibly second in magnitude, only to Nicaragua (Lagueux et al., 2003). A minor artisanal fin-fish fishery also exists in TCI for local consumption, and is likely to develop in the coming years; reliable information on this fishery is absent at present and is therefore unable to be assessed here. The fisheries operate together as a multi-species or mixed SSF, catching lobster, conch, fin-fish and sea turtles during single trips. The mixed SSF is characterised by artisanal free-diving fishers usually operating in crews of two or three from *ca.* 6 m fibreglass powerboats. Most catch is landed at various fish processing plants within the TCI, with a relatively small quantity being marketed directly to local restaurants for local consumption.

There is a paucity of up-to-date published information on contemporary small-scale marine turtle fisheries, data from which inform relevant management practices. Current data on the size and structure of this fishery are scarce (Richardson et al., 2009; Rudd, 2003). With recent turtle fishery closures in the neighbouring Bahamas (Fisheries Resources (Jurisdiction and Conservation) Regulations, 2009; Government of the Bahamas, 2009) and in Trinidad and Tobago (Protection of Turtle and Turtle Eggs (Amendment) Regulations, 2011; Government of the Republic of Trinidad and Tobago, 2011), and a prevailing protectionist approach to marine turtle conservation within the WCR (see Brautigam and Eckert, 2006; Fleming, 2001; Eckert, 2010), there is a clear need to better contextualise and manage the TCI turtle fishery. At the invitation of the local government, we undertook a two-year study to assess the harvest of marine turtles in TCI. Here we set out to gather data that would inform meaningful suggested changes to current management of the turtle fishery.

2. Material and methods

2.1. Study site

The Turks and Caicos Islands (TCI) is a UK Overseas Territory in the WCR, situated at the southern end of the Bahamas (21°45N, 71°35W). Intensive monitoring was carried out at South Caicos, the main fishing centre of the TCI, with regular visits made to the two most populated islands of Grand Turk and Providenciales (Fig. 1).

2.2. Study species

The green turtle (*C. mydas*) and hawksbill turtle (*E. imbricata*) are listed as endangered and critically endangered respectively (IUCN, 2010). Although the TCI turtle fishery is regulated by the Fisheries Protection Ordinance, 1998 (Government of the Turks and Caicos Islands, 1998), this legislation only protects turtle eggs and nesting females on the beaches and turtles at sea that are smaller than 20 inches (51 cm) carapace length (Richardson et al., 2006).

The spiny lobster (*P. argus*) fishery opens on the 1st August each year and is locally known as “the big grab” when maximum landings are made followed by a gradual decline until closure, usually on 31st March (Tewfik and Béné, 2004). No quota system operates for this fishery.

The queen conch (*S. gigas*) fishing season runs from 15 October to 15 July or until the export quota (currently 1.6 million lb/0.72 million kg) is reached. The queen conch is listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and in order for TCI to engage in international trade, the fishery must be managed sustainably.

2.3. Monitoring the artisanal turtle fishery and SSF

Collaboration with fishers facilitated direct counts of hawksbill and green turtles landed for local consumption at key fish landing sites, e.g. fish processing plants and public boat docks or jetties. Several, but not all personal jetties used by one or two fishermen were opportunistically monitored. During a two-year survey period (1 December 2008–30 November 2010) dockside observations were made for 544 days at South Caicos, 77 days at Grand Turk and 68 days at Providenciales (Table 1, Appendix Fig A.1). A typical

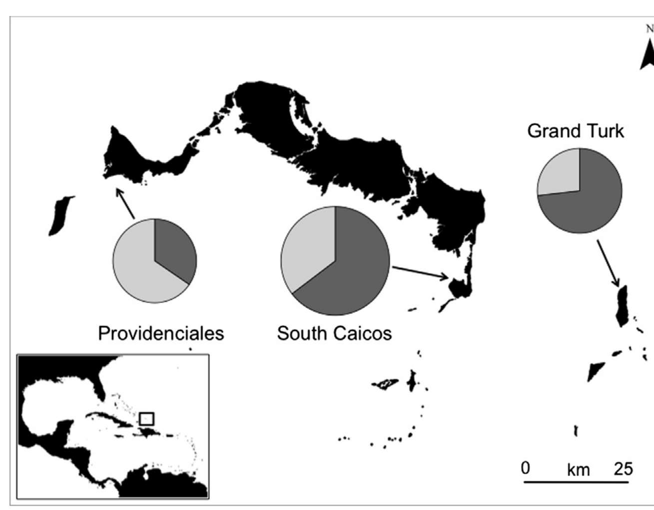

Fig. 1. Map and location of the Turks and Caicos Islands. Pie charts show the proportion of the estimated annual harvest of hawksbill turtles (light grey) and green turtles (dark grey) at each surveyed island and are scaled relative to the estimated harvest of both species combined (see Table 1 for values).

Table 1
Annual harvest estimates green turtles (A) and hawksbill turtles (B) landed at South Caicos (SC), Providenciales and Grand Turk between 1 December 2008–30 November 2010 (Total survey period = 730 days). The Turks and Caicos Islands (TCI) estimate is the sum of each island estimate. 95% confidence intervals (CI) are percentiles of the distribution of bootstrapped estimates. Data are from direct dockside observations. 'Interpolated no. turtles captured concurrently at SC' represents the number of turtles (count plus interpolated) captured at South Caicos at the same time as observations were made at Providenciales or Grand Turk. These values are used in calculating the island harvest estimates (see Methods section 2.4 for details).

	No. survey days	No. survey days when turtles landed	Green turtles				Hawksbill turtles			
			Observed count from all survey days	Interpolated total (count + interpolated)	Interpolated no. turtles captured concurrently at SC	Annual estimate and 95% CI	Observed count from all survey days	Interpolated total (count + interpolated)	Interpolated no. turtles captured concurrently at SC	Annual estimate and 95% CI
South Caicos	544	173	194	237.02	–	119 (98–140)	109	129.31	–	65 (53–77)
Providenciales	68	12	8	–	25.12	38 (0–109)	13	–	11.62	72 (26–177)
Grand Turk	77	16	16	–	23.14	82 (38–128)	7	–	14.89	30 (11–61)
TCI	–	–	218	–	–	239 (176–324)	129	–	–	167 (114–277)

dockside observation would last for about 4 h, usually in the afternoon between 14:00 and sunset or until the last boat had returned to dock. Only counts of turtles that were butchered are included in the analyses; any that were landed and returned to the sea, e.g. perhaps because they were undersize and intercepted by government enforcement officers, were excluded. Associated information about butchered landings, e.g. location and method of and reason for capture, was obtained by informally interviewing fishers. Monthly export fishery records of catch (kg) and effort (boat days) of lobster and conch were collected by government enforcement officers on workday afternoons at the fish processing plants of South Caicos.

2.4. Turtle harvest estimation

We surveyed all key landing sites in South Caicos ($n = 4$) on 75% of days during the survey period (Table 1, Appendix Fig. A.1). To compile a complete dataset of turtle harvest for each species in South Caicos, missing values – days with no dockside coverage – were manually interpolated. To preserve any structure in harvest seasonality and yearly differences that might exist in the South Caicos data, we used the mean number of butchered landings for a particular day of the week for each month in each year. If there were fewer than two days of observations we used the mean number of butchered landings for that day of the week during its quarterly period (in that year) and if there were fewer than two days on which data were recorded in its quarterly period (e.g. Sundays during parts of the year) we extended the search to its half-year period. Interpolations were carried out in MATLAB (v 2008a). Other interpolation methods were trialled, e.g. linear interpolation and cubic-splines, but these did not preserve the inherent seasonality. The estimated harvest at South Caicos is the sum of interpolated values and direct counts.

We surveyed the key landing sites on Providenciales ($n = 3$) and Grand Turk ($n = 1$) for 9% and 11% of the survey period respectively (Table 1, Appendix Fig. A.1), so interpolating missing values for these data was not appropriate. Instead, the data from South Caicos were used to inform the likely harvests at these other islands. Harvest estimates for these two additional sites were calculated by dividing the sum of turtles landed there by the sum of the proportions of interpolated harvest at South Caicos on the 68 and 77 days of survey at Providenciales or Grand Turk respectively. The estimated TCI harvest is the sum of the three island estimates. All 95% confidence intervals of harvest estimates were taken from the percentiles of the distribution of 10,000 randomised bootstrap estimates, and calculated using R (v 2.13; R Development Core Team, 2011).

2.5. Size classes of the harvest

Carapace length of 765 animals (green turtles $n = 453$; hawksbill turtles $n = 312$) from the fishery and our in-water surveys was measured to the nearest mm using a flexible tape measure along the carapace mid-line from the nuchal notch to the longest caudal tip (Curved Carapace Length – CCL, Bolten, 1999). The size of harvested turtles combined from throughout TCI was compared (Mann–Whitney U test) to those captured during our in-water catch-mark-recapture surveys (see Richardson et al., 2009 for details of in-water survey methods and context). We estimate minimum adult carapace size to be 97 cm for green turtles, and 78 cm for hawksbill turtles based on mean minimum sizes of nesting females recorded in the region (Hirth, 1997; Witzell, 1983).

Harvested turtles were weighed prior to slaughter (green turtles $n = 120$; hawksbill turtles $n = 79$) using Kern digital scales for turtles under 50 kg (±0.05 kg) or Salter analogue scales for those weighing over 50 kg ($\pm$0.5 kg). Where turtle weight was unknown but size was measured (n = 39 green turtles, n = 29 hawksbills), CCL was converted to weight using power curve parameters (weight = 8.0×10^{-5}.CCL$^{3.07}$, r^2 = 0.98 for green turtles and 6.0×10^{-5}.CCL$^{3.14}$, r^2 = 0.93 for hawksbills). For each species, total annual landing biomass was estimated using an Horvitz–Thompson-like estimator (Horvitz and Thompson, 1952) by dividing the sum weight of the observed and converted harvest by the proportion of these to the estimated annual TCI harvest (i.e. green turtles: 159 of 239 = 0.665; hawksbill turtles: 108 of 167 = 0.647). Confidence limits were calculated by multiplying the average harvested (observed and converted) turtle weight $\pm$1.96 SE by the estimated annual TCI harvest $\pm$95% CI. Edible mass (kg of meat etc.) of a subsample of green turtles (n = 7) and hawksbill turtles (n = 12) was measured by weighing body parts that were going to be consumed. Edible mass was plotted against total body weight and the parameters from the line of best fit used to estimate edible mass of green (n = 159) and hawksbill turtles (n = 108) of known and converted weight. The edible mass of the annual harvest was calculated as above, by scaling up the average and 95% confidence limits of edible mass to the annual harvest estimates.

2.6. Seasonality of turtle harvest

Yearly, monthly and daily patterns of interpolated totals of green and hawksbill turtles landed at South Caicos were assessed statistically against the null hypotheses that average turtle catch is approximately the same on every day of the week in each month and year. Research year, month and day of week were included as fixed factors with their two-way interactions in three-way crossed Permutational Analyses of Variance (PERMANOVAs) using PERMANOVA+ in PRIMER v6 (Anderson et al., 2008). Models were carried out on Euclidean distance with 9999 permutations of residuals under a reduced model and Type III (partial) sums of squares.

2.7. Small-scale fishery interactions

We compared mean turtle catch at South Caicos with lobster and conch fishing seasons, survey year and their interactions using two-way PERMANOVAs. Fishing seasons were categorised as: both fisheries open, both closed, lobster fishery open (conch closed), and conch fishery open (lobster closed). We used generalised linear models (GLMs) with negative binomial errors (using the MASS package in R: Venables and Ripley, 2002). Interpolated monthly totals of hawksbill and green turtle landings were used as response variables (n = 24) and related to explanatory variables: survey year, fishing season, conch and lobster fishery CPUE, and catch in the other turtle species. CPUE (kg boatday^{-1}) was used as an explanatory variable because catch and effort were strongly collinear (Pearson's correlation: Lobster r = 0.92; Conch r = 0.96). Minimally adequate GLMs were derived by model simplification and Information Criterion (IC) model selection (Akaikes (AIC) and Bayesian (BIC)) following stepwise deletion and sequential Chi-squared likelihood-ratio tests. Model residuals were checked for autocorrelation and conformity to assumptions.

3. Results

3.1. Turtle harvest estimation

We recorded 194 green turtles and 109 hawksbill turtles landed at the South Caicos docks during 544 days of observation in this two-year study; turtles were landed on 32% (173 of 544) of the observation days. By interpolating the missing days when data were not gathered (186 days over two years), we estimate that 119 (95% CI: 98–140) green and 65 (95% CI: 53–77) hawksbill turtles yr^{-1} are harvested in South Caicos annually (Table 1). At Providenciales, turtles were landed on 18% (12 of 68) of the days of observation and we estimate the annual harvest to be 38 (95% CI: 0–109) green and 72 (95% CI: 26–177) hawksbill turtles yr^{-1}. For Grand Turk where turtles were landed on 21% (16 of 77) of the days of observation, an estimate of 82 (95% CI: 38–128) green and 30 (95% CI: 11–61) hawksbill turtles are harvested yr^{-1} (Table 1; Fig. 1). The total annual TCI harvest is estimated at 239 (95% CI: 176–324) green turtles, and 167 (95% CI: 114–277) hawksbill turtles.

3.2. Size classes of the harvest

Harvested turtles were significantly larger (CCL) than those captured during our in-water surveys (Fig. 2A and B) (green turtles: n = 453, W = 12949, P < 0.0001; hawksbills: n = 312, W = 4194, P < 0.0001). Although harvested green turtles during the two-year study were all below the estimated minimum breeding size recorded at nearby nesting grounds (>98 cm Hirth, 1997), 11% (n = 12) of harvested hawksbill turtles were within the size of breeding individuals (>78 cm Witzell, 1983). Fifty percent (n = 77) of harvested green turtles and 33% (n = 36) of harvested hawksbill turtles were below the current legal size limit of 51 cm CCL; this does not include those released alive by government enforcement officers, as records of these were not always kept.

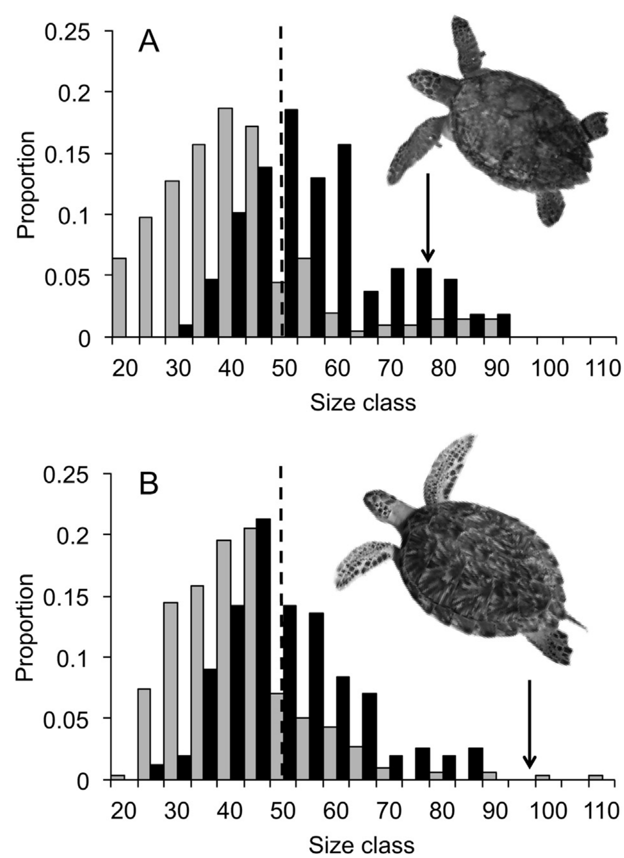

Fig. 2. Size-class (CCL, cm) histograms of curved carapace length of A) hawksbill (n = 312) and B) green turtles (n = 453) sampled during the two-year study (December 2008–November 2010). Turtles sampled from in-water surveys (light grey) and harvested turtles (dark grey) are combined from all islands. Minimum legal size limit (51 cm CCL) is shown with a dashed line, and likely minimum breeding sizes (see text) are indicated with arrows. Photos show juvenile hawksbill (A) and green turtles (B) (courtesy of T. Stringell and P. Richardson respectively).

Harvested turtles that were weighed ranged between 2.4 and 67.1 kg ($n = 120$) and between 5.0 and 93.0 kg ($n = 79$) for green turtles and hawksbills respectively. The mean weight (including those converted from CCL) of harvested green and hawksbill turtles was 18.8 kg (SE = 1.2, $n = 159$) and 23.8 kg (SE = 1.9, $n = 108$) respectively and represents 66.5% and 64.7% of the estimated green turtle and hawksbill harvest. Approximately 4.48 (between 2.90 and 6.82) metric tonnes of green turtles and 3.98 (between 2.30 and 7.61) metric tonnes of hawksbill turtles were therefore landed annually. There was a linear relationship between edible mass and total weight ($r^2 = 0.96$, hawksbills; $r^2 = 0.85$, green turtles: Appendix Fig. A.2). The mean proportion of edible mass for green turtles and hawksbills was 0.67 and 0.52 respectively and smaller turtles yielded proportionally more edible mass than larger turtles (Appendix Fig. A.2). This artisanal fishery produced between 1.91 and 4.29 (mean 2.88) metric tonnes of green turtle edible mass and between 1.14 and 3.87 (mean 2.00) metric tonnes of hawksbill edible mass.

3.3. Seasonality of harvest

Fewer hawksbills were landed in South Caicos in the second year (Pseudo-$F_1 = 5.76$, $P_{perm} = 0.017$) and the harvest differed significantly by month (Pseudo-$F_{11} = 3.68$, $P_{perm} = 0.001$) and day of the week (Pseudo-$F_6 = 5.01$, $P_{perm} = 0.001$). The structure in hawksbill harvest is driven by low catches on Sundays (see Appendix Fig. A.3A) and high catches in March, June and August (Fig. 4) and contributes to the seasonality consistently between years: two-way interactions were not significant. Numbers of green turtle captures were not significantly different between years but there was significant structure by month (Pseudo-$F_{11} = 2.24$, $P_{perm} = 0.015$) and day of week (Pseudo-$F_6 = 2.28$, $P_{perm} = 0.04$) which were not consistent between years: all two-way interactions were significant ($P_{perm} < 0.05$) (Appendix Fig. A.3B).

3.4. Small-scale fishery interactions

Hawksbill catch was higher when the lobster fishery was open and the conch fishery closed than in other levels of season (Fig. 3: Pseudo-$F_3 = 4.49$, $P_{perm} = 0.009$) and there was no significant effect of year or interaction. Green turtle catch was largely driven by significant differences between seasons in the first year when highest catch occurred with the conch fishery open and lobster fishery closed (season: Pseudo-$F_3 = 6.82$, $P_{perm} = 0.007$). This pattern was not consistent across years (year; Pseudo-$F_1 = 12.84$, $P_{perm} = 0.003$; interaction: Pseudo-$F_3 = 5.76$, $P_{perm} = 0.007$) and in year two no apparent differences occurred between seasons.

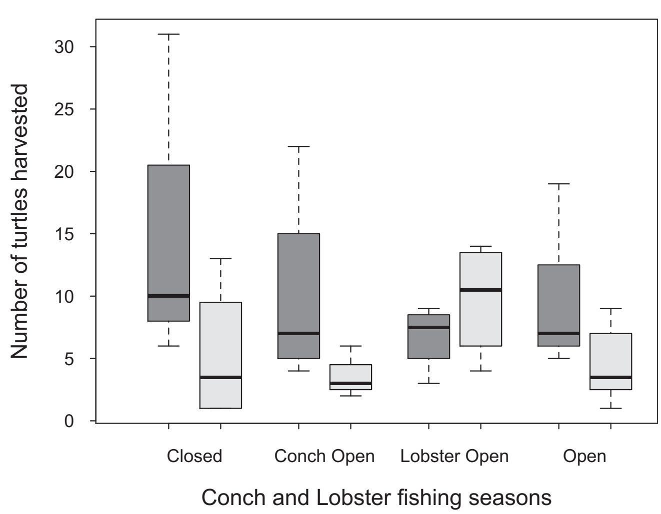

Fig. 3. Green turtle (dark grey) and hawksbill turtle (light grey) harvest at each of four categories of conch and lobster fishery seasons at South Caicos. Closed and Open categories refer to both fisheries together. 'Conch Open' represents periods when the conch fishery is open and lobster fishery closed, and *vice versa* for 'Lobster Open'. Data from December 2008 to November 2010 (24 months).

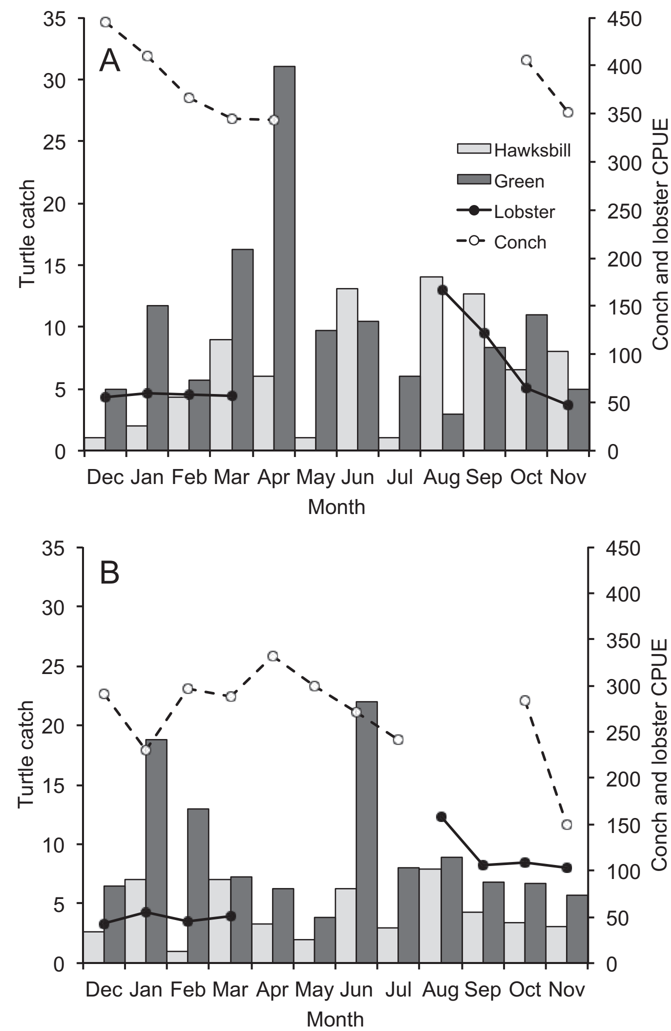

Fig. 4. Hawksbill (light grey) and green turtle (dark grey) interpolated monthly landings during A) year one: 1 December 2008–30 November 2009, and B) year two: 1 December 2009–30 November 2010. Fishing CPUE (kg boat days^{-1}) for lobster (filled circles and solid line) and conch (open circles and dashed line) export fisheries at South Caicos are superimposed.

In both years, peak lobster CPUE (kg boat days^{-1}) occurred at the opening of the lobster fishery (1 August) and declined and stabilised until it closed on 31 March (Fig. 4A and B; see Appendix Fig. A.4 for separate catch and effort plots). Parsimonious GLM models indicated that as lobster CPUE increased so did hawksbill catch (GLM: χ^2 LR$_1 = 3.73$, $P = 0.05$), but green turtle catch declined (GLM: χ^2 LR$_1 = 3.56$, $P = 0.06$) (Appendix Fig. A.5). In 2009 (Year 1: Fig. 4A), the conch export fishery closed on 6 April because the quota was reached. In this year both fisheries therefore closed at around the same time and remained so for four months until August. A large peak in green turtle catch in April 2009 was coincident with this closure. In 2010 (Year 2: Fig. 4B) the conch export quota was not reached and the fishery remained open until 15 July creating a period of only two weeks when both fisheries were closed. No corresponding peak in turtle catch of either species was observed during this time. There is a suggestion that with increasing conch CPUE hawksbill catch declines (GLM: χ^2 $LR_1 = 3.09$, $P = 0.08$) but no evidence of a relationship with green turtle catch (GLM: χ^2 $LR_1 = 1.53$, $P = 0.22$) (Appendix Fig. A.5).

4. Discussion

The mixed SSF of TCI is characterised by the targeted fishing of lobster and conch for the export market and the opportunistic catch of several hundred green and hawksbill turtles each year for domestic consumption. Our work in TCI illustrates the connectivity between multi-species fisheries and artisanal turtle capture, and the need to manage turtles as part of a broader approach to SSF management. Seasonality of the turtle harvest appears to be driven primarily by fishery interactions. For example, hawksbill catch is positively dependent on increasing lobster CPUE and inversely related to increasing conch CPUE, and green turtle landings decrease with increasing lobster CPUE. This is almost certainly a result of the different habitats in which these species are found: lobster and hawksbill turtles are most commonly associated with reef habitat, and conch and green turtles with shallow seagrass habitats. Peak hawksbill landings occurred in August and coincided with the opening of the lobster fishing seasons, and in 2009, peak green turtle landings coincided with the closure of both lobster and conch fisheries, demonstrating the potential impact that these fisheries have on marine turtle catch. Our study is the first, of which we are aware, that empirically relates lobster and conch fishing to sea turtle capture. Hawksbill catch in particular is significantly dependent on the catch and effort of these fisheries and legislative measures need to embrace this dependency in order to be effective.

4.1. Seasonality of harvest: closed season

The day-to-day structure of turtle harvest likely reflects the general weekly fishing pattern of the mixed fishery and is likely driven by cultural influences e.g. Christianity, such that there are low catches of hawksbills on Sundays. The seasonality results of this study indicate that time-based management controls will affect turtle species differently. The presence of all hawksbill class-sizes in TCI waters throughout the year, hawksbill nesting dynamics and the effect of TCI's lobster fishery provide support for a closed season as an appropriate and additional integrated measure that would optimally safeguard threatened hawksbill stocks in the region. Regional peak nesting periods for hawksbill turtles (Beggs et al., 2007; McGowan et al., 2008; Moncada et al., 1999) broadly coincided with peak landings of the species, but not for green turtles (Bell et al., 2006; McGowan et al., 2008; Troeng and Rankin, 2005). Breeding adult hawksbills are present in TCI waters throughout the year and around October during the peak reproductive season, and breeding green turtles are present seasonally around August (Author's unpublished data). The capture of turtles during their reproductive seasons is of conservation concern, and is regulated against in several extant turtle fisheries of the WCR by implementing harvest restrictions during these periods (e.g. Bell et al., 2006; McGowan et al., 2008; Richardson et al., 2006).

We therefore suggest prohibition on all take of hawksbill turtles during the eight-month lobster open season (August–March inclusive). This would more-or-less align TCI legislation with that of other UKOTs in the WCR (Richardson et al., 2006). However, although May–October presents an obvious time period for a potential closed season on green turtles, breeding size adults are rarely taken in the harvest (see also Richardson et al., 2009). A closed season on green turtle capture during this period may not be necessary in terms of fishery protection, and is unlikely to be supported by fishers (Campbell et al., 2009). At this time, we do not propose a closed season on green turtle take, and the introduction of, and compliance with the proposed maximum size limit should protect breeding adults from the fishery.

4.2. Turtle harvest estimation

The artisanal marine turtle fishery in TCI is the largest of the UK OTs (Godley et al., 2004b), and our work confirms it as the largest documented legal hawksbill turtle fishery in the western Atlantic. Our harvest estimates are of the few derived by direct observations (Table 2) while most regional estimates are nearly a decade old, and come from fisher interviews, market surveys and logbooks, and as such, may be less accurate (Lunn and Dearden, 2006). For example, previous harvest estimates for TCI that used fisher interviews (Fletemeyer, 1984; Godley et al., 2004a; Richardson et al., 2009) had wider uncertainty and much higher upper estimates (Table 2), as is typical of such studies. Although we are confident in our harvest estimates, we acknowledge that these are likely to be conservative and minimum estimates because not all fishing docks, especially personal jetties, could be systematically surveyed. For example, fishers at North Caicos, Middle Caicos, and Salt Cay undoubtedly contribute further to the annual harvest, although the fishing communities here are not nearly as large as those of the three main islands surveyed. Additionally, we know that some fishers butcher turtles at sea (Authors' unpublished data), and there is likely to be an unknown level of foreign poaching in TCI waters, especially from neighbouring Dominican Republic (Fleming, 2001; Richardson et al., 2009); these catches are not included in our estimates because we cannot confidently ascertain the extent of these practices.

4.3. Size classes of the harvest: maximum size limits

From our data, the capture of subadult and adult turtles is of conservation concern, in particular for the hawksbill turtle given its critically endangered status (IUCN, 2010) and remnant state of nesting populations in the WCR (Blumenthal et al., 2009; Bowen et al., 2007). Eleven percent ($n = 12$) of hawksbills landed in TCI's

Table 2
Comparative reported, legal and substantial (>100) annual turtle harvest estimates from several nations in the Wider Caribbean Region. Harvest estimates for other Caribbean nations can be found in Brautigam and Eckert (2006), Fleming (2001), and Godley et al. (2004b). * denotes a historical quota.

Country	Green turtle	Hawksbill turtle	Year of survey	Method of survey	Source
TCI	176–324	114–277	2008–2010	Direct survey	Present study
TCI	236–1128	184–907	2001–2004	Fisher interview	Godley et al. (2004a),Richardson et al. (2009)
British Virgin Islands	150–450	50–150	2001–2004	Fisher interview	Godley et al. (2004b)
Cuba	280*	500*	1997*	Fishery statistics	Carrillo et al. (1999), Fleming (2001)
St. Vincent and the Grenadines	148–214	251–347	1995–1999	Fisher interview	Grazette (2002) in Brautigam and Eckert (2006)
Grenada	488	294	2001	Fisher interview/market survey	Grazette et al. (2007)
Nicaragua	11,000	180–280	1993–2002	Direct survey	Lagueux et al. (2003)

fishery were of adult size (>78 cm Witzell, 1983) (Fig. 2B) and foraging adult hawksbills are present in TCI waters year-round since nesting activity has been observed throughout the archipelago in every month of the year (Author's unpublished data). Large-sized hawksbill capture is likely to be driven by fisher choice and effort allocation, for example, they are easier to catch than green turtles because they are generally less likely to quickly flee from interaction with humans and are frequently encountered at rest under reef ledges where fishermen dive for lobsters (Authors' pers. obs.).

Despite being the largest green turtle fishery of the UK OTs (Godley et al., 2004b), there were few subadults and no adults captured in the two years of our survey period. The paucity of adult green turtles in the harvest is most likely to be a result of a combination of fisher choice and turtle behaviour; fishermen may be unwilling to pursue large, fast swimming adult green turtles because they are difficult to catch and handle, are possibly costly to catch with respect to fuel used, and presumably compete for boat space with more desirable or profitable catches. Additionally, the scarcity of adults in the harvest may be due to low abundance of foraging adults, and the limited time of the year when breeding adults are present in TCI waters: the green turtle nesting season in TCI is highly seasonal (May–October) (Author's unpublished data). Together with the recovery of major green turtle nesting rookeries in the region (see Broderick et al., 2006, for review), the impact of the TCI fishery on regional green turtle populations is of less concern than that of hawksbills.

Our in-water surveys tended to catch smaller turtles on average than the fishery, probably because our sampling is restricted by safety and logistical constraints to shallower habitats where smaller turtles are typically found: fishermen often fish on outer reefs and in deeper water habitats. These data probably reflect size-class partitioning in the taxa, where increasing body size is coupled with increasing depth (Musick and Limpus, 1997). Nevertheless, it is clear that fishers most frequently select juvenile turtles of approximately 20 kg (or 55 cm CCL) and this may be due to several factors: abundance of these size classes and rates of encounter, capture effort, and fisher choices – taste, processing time and optimal yield of edible mass. Our data suggest that turtles of this size yield proportionally more edible mass than larger turtles (Appendix Fig. A.2), and that proportionally more of the green turtle is consumed than that of the hawksbill. The take of juveniles of this size, however, is likely to be absorbed by the population dynamics without detriment to the populations involved (Heppell and Crowder, 1996).

The current TCI sea turtle fishery legislation (Fisheries Protection Ordinance, 1998 (Government of the Turks and Caicos Islands, 1998): see Richardson et al., 2006, 2009 for reviews) permits the harvest of both species >51 cm length and does not adequately safeguard the survivorship of large juvenile (sub-adult) and reproductive adults, the key life stages in population maintenance for late-maturing, slow-growing species (Carr et al., 1982; Crouse et al., 1987; Crowder et al., 1994; Heppell and Crowder, 1996). Minimum size limits such as these focus take on large individuals and may impede turtle population recovery, even in small but highly regulated turtle fisheries, e.g. Cayman Islands (Bell et al., 2006). The Cayman Islands recently adopted a maximum size limit of 60 cm (Cayman Islands Government, 2008), the first protection measure of its kind in the WCR (Dow et al., 2007). Clearly, in the TCI, a biologically relevant management measure is also needed that discourages the capture of large juveniles (sub-adults) and adult turtles in both species. Moncada et al. (1999) reports that 7% of hawksbill turtles captured in Cuba's historic turtle fishery were sexually mature at 61–65 cm straight carapace length and 100% at >81 cm. We propose an upper size limit of 24 inches (61 cm) shell length for both green and hawksbill turtles, similar to that of the Cayman Islands and deliberately precautionary to protect the age classes of most conservation concern: sub-adults and adults of both species (Crouse et al., 1987; Crowder et al., 1994; Heppell and Crowder, 1996). The suggested size limit received 88% (n = 66) support from the 75 fishers interviewed in September 2011 (Authors, unpublished data). Additionally, because TCI fishers still use imperial measures, it would be relatively practical in terms of compliance and enforcement. Although, approximately 50% of green turtles and 33% of hawksbills landed in the fishery were undersize (Fig. 2) – implying either a disregard, a misunderstanding or a sense of biological inappropriateness (e.g. Raakjær Nielsen, 2003) of the present minimum size limits – consultations with fishers to generate understanding of proposed turtle fishery measures indicated almost unanimous support for maintaining a minimum size limit and introducing a maximum size limit (Richardson, unpublished data).

4.4. Quota management

The fishing community understands the concept of quota because the conch fishery is quota managed (Total Allowable Catch) (Béné and Tewfik, 2001). However, implementing, administering, enforcing and monitoring turtle quota would require considerable capacity – something that is unlikely to be tenable in an already stretched and presently downsizing fisheries department (Forster et al., 2011). A licensing system with personal quota, e.g. Cayman Islands (Bell et al., 2006), may be an option given that all fishermen apply for fishing licences annually, but declaring compliance with personal quota would be unlikely. Supporting biological evidence for turtle quota is not currently available and the impact of such quota on other fisheries is unknown. Therefore, at present we do not advocate quota-based management control measures. Further work is needed to address this possibility.

4.5. Closure of the turtle fishery

In many cases where turtle fisheries have been closed, population recovery has resulted (Balazs and Chaloupka, 2004; Beggs et al., 2007; Broderick et al., 2006; McGowan et al., 2008; Troeng and Rankin, 2005). However, in several WCR states, e.g. Anguilla (Godley et al., 2004b), Montserrat (Richardson et al., 2006), BVI (McGowan et al., 2008), monitoring the biological and social consequences of moratoria or fishery closure has been fiscally challenged and not based on detailed study of the turtle fishery itself or as part of a wider multispecies SSF. This is also the case for recent turtle fishery closures in the WCR, e.g. Bahamas (Fisheries Resources (Jurisdiction and Conservation) Regulations, 2009; Government of the Bahamas, 2009); and Trinidad and Tobago (Protection of Turtle and Turtle Eggs (Amendment) Regulations, 2011; Government of the Republic of Trinidad and Tobago, 2011). Our work with the fishing community over the study period found that communities throughout the TCI strongly contest a ban on both species, expressing particular concern over their removal of artisanal/traditional rights to consume turtles. Compliance with a fishery closure that is unacceptable to the local community, would present significant enforcement challenges (Raakjær Nielsen, 2003; Campbell et al., 2009; Silver and Campbell, 2005). A fishery closure may also criminalise fishers and drive turtle harvest 'underground' and increase butchering at sea, making monitoring catch rates impossible. Furthermore, a permanent closure of the turtle fishery may impact other fisheries, for example, by increasing the capture of lobster, conch, and fin-fish for personal consumption. Further work is needed to establish convincing evidence that, in place of other control measures, a closure of the turtle fishery would be biologically relevant and socially acceptable.

5. Conclusions

In the WCR, the majority of fishers and fisheries are from the SSF sector (Salas et al., 2007). It is therefore important to recognise and mitigate the potential environmental impacts of SSF in this region, consider the complex socio-ecological system associated with SSF (Ostrom, 2009; Liu et al., 2007), and to follow the building trend to develop ecosystem-based management strategies that promote sustainability (Belgrano and Fowler, 2011). Our results indicate that incorporating the interactions of turtle harvests with mixed SSFs is important to the management of turtle fisheries. We demonstrate that the turtle fishery in TCI is closely tied with the mixed SSF, which is strongly influenced by fisher behaviour, choices and their social environment, an aspect frequently disregarded in fishery management and resource exploitation (Hilborn et al., 1995; Ostrom, 2009). We present empirical biological evidence that support simple management measures already used by other turtle fisheries in the WCR: the introduction of maximum size limits for both species and a closed season on hawksbill take during the lobster fishing season. These measures are suggested in addition to the existing provisions and are currently being considered by the TCI Government as part of a revision of the Fisheries Protection Ordinance (Government of the Turks and Caicos Islands, 1998).

Future work could explore a variety of management aspects and tools applicable to this SSF, e.g. Total Allowable Catch quotas for sea turtles and their use in an adaptive management framework, financial management tools such as fines and incentives, multi-species and multi-scale marine management, knowledge use in fisheries management, integrated coastal zone management, spatial management (MPAs for sea turtles), and adaptive governance and participatory strategies. A full discussion of these are beyond the scope of this paper and outwith the data. However, work is currently underway to facilitate a culture of compliance with the new suggested management measures. Work with fishers and other stakeholders in TCI to explore co-management or community-based management options *sensu* Campbell et al. (2009), has been set up to integrate fishing community concerns and opinion in the design and proposed implementation of recommended turtle fishery management measures, including those mentioned here. It is envisaged that stakeholder participation will be key to effective sustainable management of these resources. If these and other measures are incorporated, TCI will become one of the most highly regulated sea turtle fisheries in the WCR and one that has strongly involved the relevant stakeholders in fishery reform.

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Appendix A. Supplementary data

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