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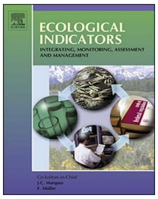

Long-term trends in abundance of green sea turtles (*Chelonia mydas*) assessed by non-lethal capture rates in a coastal fishery

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ABSTRACT

Sea turtle populations underwent severe decline in historical times, mainly through harvesting eggs and adults on nesting beaches. With the reduction of this threat in many areas, coupled with other conservation actions, some populations have demonstrated encouraging recovery, although remaining below their previous levels and undergone additional modern threats such as incidental capture in fisheries and pollution. Trends in sea turtle populations have usually been assessed through monitoring of females or nests on nesting beaches. Here we present data from a 22-year monitoring period for a juvenile green sea turtle *Chelonia mydas* mixed-stock in southeastern Brazil that were incidentally captured in passive non-lethal pound nets. A total of 3639 green turtles were captured in 5323 fishing days.pound^{-1} with mortality rate of 2%. Captures occurred in all months, but bycatch rates, excluding recapture events, were higher in September and October, probably due to the recruitment of turtles migrating from southern areas, as well as recruits from the oceanic zone. Capture rates increased by 9.2% per year in the period from 1995 to 2016, in line with increasing source populations, particularly the main source contributor at Ascension Island, but also Trindade Island (Brazil) and Aves Island (Venezuela). Mean Curved Carapace Length of green turtles was higher during austral summer/early autumn and decreased markedly in May, probably due to the small-sized individuals that recruited to the study site. We show that the incidental capture of sea turtles in non-lethal fisheries, such as Brazilian pound nets, could also provide data on trends of populations nesting in distant places, and can contribute to the assessment of population status of sea turtles within Regional Management Units throughout the Atlantic Ocean.

1. Introduction

Populations of green sea turtles *Chelonia mydas* (Linnaeus, 1758) were estimated to have declined worldwide in historical times, and by 48–66% over the last three generations, with reductions recorded at 55% of the nesting sites (Seminoff, 2002). Comparison with historical information suggests that present day populations represent a tiny proportion of the total that once existed before European colonization, now regarded as ecologically extinct is some places (Jackson et al., 2001). The lack of reliable data on status and trends of sea turtle populations could impair both management strategies and recovery planning of threatened species (Chaloupka et al., 2008a; National Research Council, 2010); green sea turtles are listed as “vulnerable” in Brazil (MMA, 2014) and as “endangered” globally (IUCN, 2016).

Population trends for sea turtles have been determined traditionally through monitoring rookeries, usually by counting the number of nesting females, saturation tagging of females, or indirectly by counting the number of clutches or tracks on the beach (Broderick et al., 2006; Marcovaldi and Chaloupka, 2007; Pfaller et al., 2013; Bourjea et al., 2015). However, as for any long-lived vertebrate, it requires several years of monitoring to reliably detect population trends based on nesting ground data. Even though adult females may return to nesting grounds where they were born to lay their own eggs (Bjorndal et al., 2005), sea turtle species exhibit delayed maturity and individual turtles do not usually nest in every year. The need for assessing populations of both immature and mature sea turtles in the water to complement nesting assessments has been widely recognized (e.g. National Research Council, 2010). However, studies monitoring sea turtle populations based on juvenile stages in foraging grounds are scant (Bjorndal et al., 2005), and are usually based on capture-mark-recapture methods (e.g. Chaloupka and Limpus, 2001; Bjorndal et al., 2005). Some other approaches for identifying trends in sea turtle populations were through

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historical harvest data (e.g. Broderick et al., 2006; Weber et al., 2014), by counting stranded sea turtle carcasses (e.g. Chaloupka et al., 2008b; Monteiro et al., 2016) or on the basis of quantifying sea turtle bycatch rates (but see Epperly et al., 2007; Sasso et al., 2007; Casale et al., 2012). Strandings, despite being an important source of biological data and information on mortality causes (Epperly et al., 1996; Bugoni et al., 2001; Hart et al., 2006; Chaloupka et al., 2008b), are not a reliable indicator of mortality at sea, mainly because stranding probabilities are usually very low and highly variable in space and time, and usually do not exceed 10–20% of total mortality at sea (Epperly et al., 1996). Sea turtle carcasses stranded on the beach rarely present marks that clearly indicate death caused by fishery activities, sometimes as low as 1.2% of carcasses (Monteiro et al., 2016). Few studies have used in-water captures of live sea turtles to estimate population abundance (e.g. Chaloupka and Limpus, 2001; Bjorndal et al., 2005). This is probably because intentional capture programs are expensive and time consuming and require considerable logistical support (Bjorndal et al., 2005).

Incidental capture in fisheries could potentially be a useful source of information for monitoring sea turtle population trends (Chaloupka and Limpus, 2001; Casale et al., 2012). Bycatch in fisheries (sensu Hall, 1996) have been of limited utility for monitoring trends in sea turtle populations because substantial mortality occurs in most fisheries, such as in longline (Lewison et al., 2004; Sales et al., 2008, 2010), trawling (Poiner et al., 1990; Epperly et al., 1996), gill netting (Echwikhi et al., 2010; Fiedler et al., 2012); and also because capture rates vary depending on a fishing fleet's dynamics, such as gear type, size of the fishery, location of fishing grounds, and fishing duration. In addition, observer coverage in fisheries and quality/accessibility to data is limited (Rees et al., 2016). However, when fisheries are non-lethal for sea turtles (i.e. non-lethal bycatch, or "release", as defined by Hall, 1996) incidental capture is a potential tool for monitoring sea turtle population trends. Passive types of fixed fishing gear are used in coastal areas around the world (Nédélec and Prado, 1990), and these include pound nets, corrals, fences, barriers and weirs. In several of these fisheries sea turtle mortality is low because turtles are free to surface to breathe, particularly when the gear is open-roofed, and mesh size is small, making head or flipper entanglement a rare event (Oravetz, 1999; Harms et al., 2003; Gilman et al., 2010).

The green turtle is the most abundant sea turtle species in foraging grounds along the Brazilian coast (Almeida et al., 2011a) and at the Ubatuba coastal region: green turtles account for 98.4% of sea turtle records, including strandings and fisheries bycatch (Gallo et al., 2006). A large number of juvenile green turtles, and occasionally other species, are captured in the pound net fishery (stationary floating weirs) in Ubatuba, São Paulo state, southeastern Brazil, where they are able to surface inside the trap to breathe (Gallo et al., 2006). Long-term monitoring of pound nets in Ubatuba has been conducted by Projeto TAMAR, which has enabled data collection in partnership with fishermen at this important foraging ground for juvenile green turtles (Gallo et al., 2006).

Here we studied the non-lethal pound net fishery at Ubatuba, focusing on: 1) the usefulness in monitoring long-term abundance trends of green turtles; 2) the monthly variations in capture rates; 3) changes in turtle size between months and years; 4) the homogeneity of capture rates across the whole fishery by comparing capture rates among different fishing pounds.

2. Material and methods

2.1. Study area

Ubatuba (23°26′S; 45°04′W) is located on the northern coast of the state of São Paulo, southeastern Brazil. The Ubatuba coastline is about 140 km long, with several bays, rocky shores and about 100 small beaches (Fig. 1). Many beaches are occupied by traditional communities, for which artisanal fishing is the main source of income. Average yearly precipitation is 2616 mm with over 200 mm per month from October to April and average monthly air temperatures between 17.7 °C in July and 24.7 °C in February (Estado de São Paulo, 1996). Monthly mean sea surface temperatures reach maximum value of 28.6 °C in February and minimum of 21.9 °C in July (Valentim et al., 2013). Waters comprises the South Atlantic Central Water (SACW), Tropical Water (TW), and Coastal Water (CW), with stratification in summer (CW predominating in the upper 20 m near the coast, TW offshore, and SACW deeper offshore), and no stratification in winter (Castro-Filho et al., 1987). Tourism is the main economic activity, followed by small scale fishing using purse seine, gillnets and trawlers, among others, which targets mainly sardine, white croaker, blue runner and shrimp (Ávila-da-Silva et al., 2016).

2.2. Fishery description

Pound nets were introduced in Brazil's southeastern region by a Japanese fisherman in the early 1920s (Mussolini, 1980; Seckendorff et al., 2009), and first recorded at Ubatuba in 1942. The gear has varied little since then, although some sites now have made specific adaptions to the gear. In Brazil pound net fishing occurs from Rio de Janeiro to Santa Catarina states (Seckendorff et al., 2009). Pounds are typically installed in bays 8–15 m deep. The nets extend from the surface to the seabed, which allows fish to be caught throughout the water column (Gallo et al., 2006). Pounds are constructed from nets with mesh size 3–10 cm, and comprise two main pieces: a guide fence (barrier) maintained in a vertical position by ballast weights at the bottom and by floats at the top. This net is perpendicular to the shore and will direct any fish swimming parallel to the coast towards the entrance of the trap; the other part is the trap itself, an elliptical chamber where the fish are trapped and kept alive until removal (Seckendorff et al., 2009) (Fig. 2). Fish and turtles enter actively, but once inside are unable to find the exit again. In historical times when fish were abundant, traps were emptied 4–6 times a day (Mussolini, 1980), but now usually 2–3 times a day. Traps are left set in the same place and stay fishing for 24 h a day. Historically, fish collection required two small canoes, a tiny one used to block the entrance with two fishermen onboard, and another with two fishermen onboard that maneuvered along the net, lifting it upward and forcing fish into a small area, where they could be selected according to species, size and commercial value, or discarded. In good weather pound nets usually remain set for 8–12 days, and are then removed for maintenance (cleaning debris and algae, repairs and dyeing; this camouflages the net and reduces biofouling). Traps are not deployed in bad weather, usually worst in the winter months, and so the fishing season occurs mainly from September to May. Fishing pounds have been located at the same points for decades, built near rocky shores protected from waves and always in waters over 6 m depth.

2.3. Data gathering

Interviews with fishermen indicated that the pound net fishery was suitable for long-term monitoring, because the pounds were static, there was a daily fishing routine, and sea turtle bycatch was high (Gallo et al., 2006). Monitoring occurred in two ways: 1) during winter when pound nets were used infrequently, fishermen were visited every two weeks to check if the gear was deployed; 2) during the fishing season researchers visited the pounds whenever a sea turtle had been captured. Fishermen contacted the researchers and kept the turtles aside for measurement and tagging procedures. As captures of sea turtles were frequent, it was possible to monitor continually all pounds for fishing effort, and also note when traps were removed and redeployed, so unmonitored periods were noticed and recorded. Due to intense involvement of fishermen with the project means we are confident that turtle captures or fishing effort had not been omitted by fishermen or overlooked by researchers.

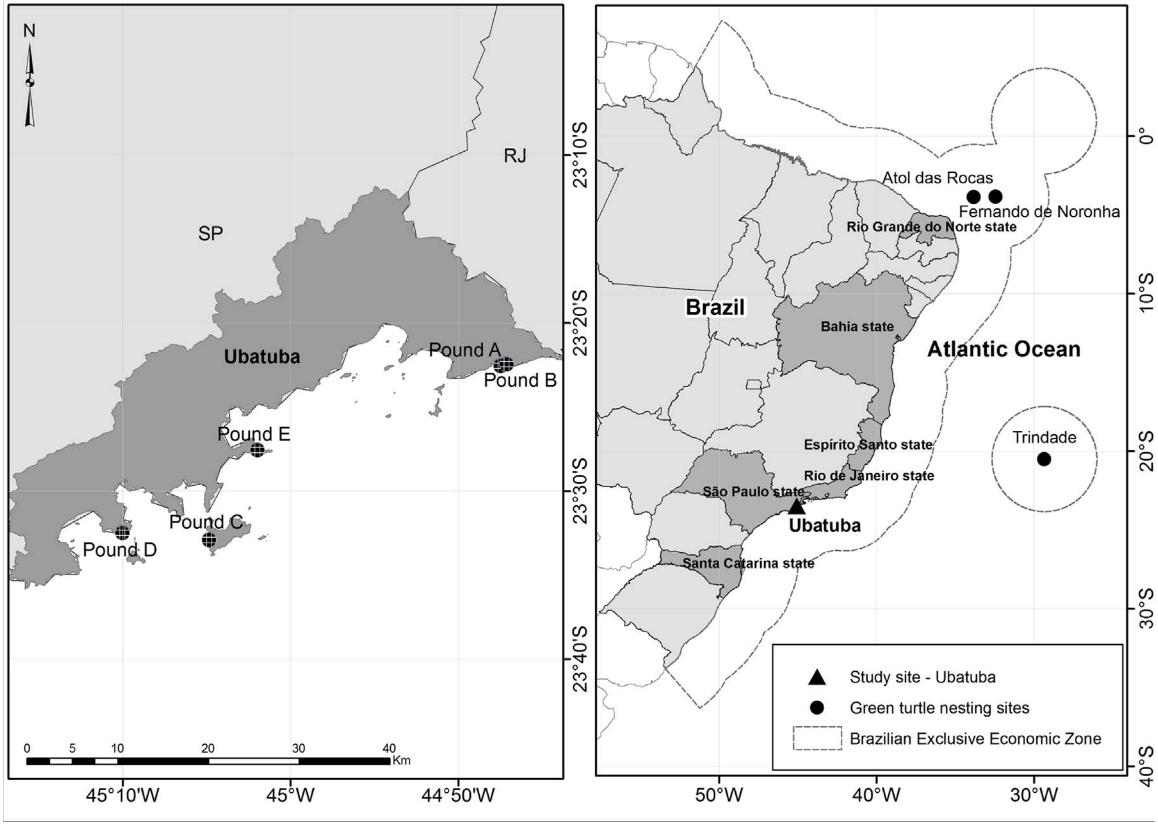

Fig. 1. Study site at Ubatuba, with indications of nesting grounds of green sea turtles *Chelonia mydas* in Brazil and states mentioned in the text. Pound C is located in Anchieta Island.

One pound net at Anchieta Island (Pound C, Fig. 1) was deployed throughout the year, and its fish harvest was also monitored every day. From 1995 to 2016, five out of the eight active pounds in the region were monitored (Table 1). Captured turtles were confirmed to species, then measured (Curved Carapace Length – CCL), tagged on both front flippers (inconel metal tags; style 681, National Band and Tag Co., USA), and released nearby the pound. Fishing effort and capture rates are based on day.pound^{-1}, which means a pound monitored for one fishing day (24 h of deployment). Because most pounds stop operations during austral winter (June to August), a fishing season was defined as a period from September to May next year, and referred to as, for example, fishing season 2000–2001. Data from the scant pounds which operated during winter months were excluded from the analysis of trends in capture rates and trends in CCL, but maintained in other

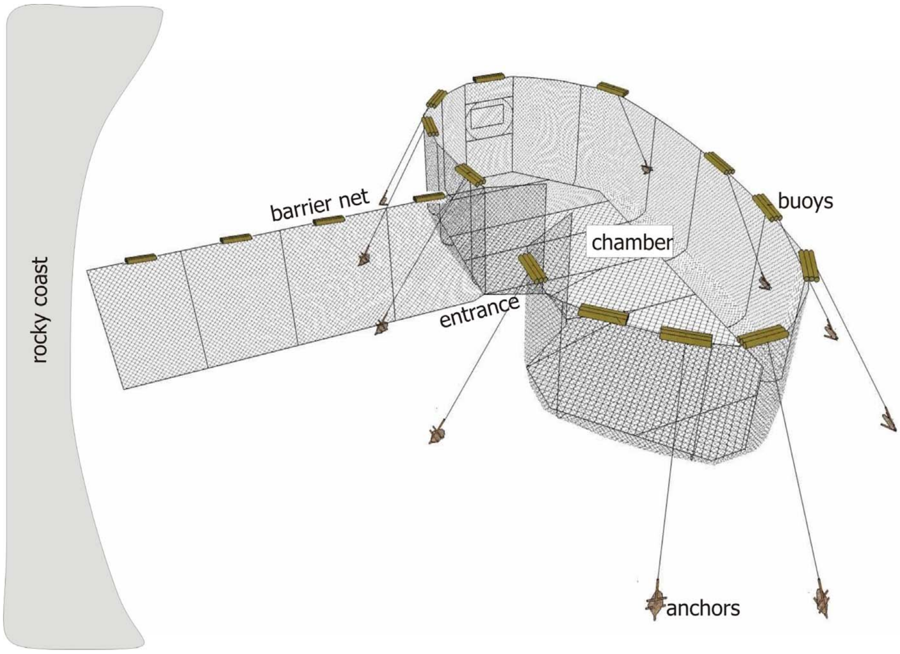

Fig. 2. Illustration of a typical pound net used by fishermen at Ubatuba, southeastern Brazil. Modified from Seckendorff et al. (2009).

Table 1
Variation in fishing effort measured as number of pounds and number in which incidental capture of green sea turtles *Chelonia mydas* was recorded, at Ubatuba, southeastern Brazil during 22 fishing seasons, from January 1995 to April 2016.

Fishing season	No. of fishing pounds monitored (Pound code)	No. of days monitored	No. of green sea turtles captured
1995 (Jan–May)	1 (C)	118	24
1995–1996	1 (C)	191	23
1996–1997	1 (C)	207	61
1997–1998	1 (C)	244	80
1998–1999	1 (C)	231	39
1999–2000	1 (C)	210	43
2000–2001	1 (C)	152	56
2001–2002	1 (C)	176	68
2002–2003	1 (C)	126	52
2003–2004	1 (C)	87	31
2004–2005	5 (C)	286	135
2005–2006	5 (A,B,C,D,E)	345	334
2006–2007	4 (A,B,D,E)	330	207
2007–2008	2 (A,B)	244	157
2008–2009	3 (A,B,C,D,E)	449	210
2009–2010	3 (A,B,D)	276	295
2010–2011	3 (A,B,D)	236	223
2011–2012	2 (B,D)	173	150
2012–2013	2 (B,D)	122	149
2013–2014	2 (B,D)	102	86
2014–2015	2 (A,B)	200	175
2015–2016	3 (A,B, D)	294	339
Winter (June–August)[a]	4 (B,C,D,E)	524	409
Total		5323	3346

[a] Not included in a given fishing season, all winter pooled.

analysis. The number of pounds monitored each year varied between one and five (Table 1). Fishing effort per fishing season ranged between a minimum of 87 days.pound^{-1} in the fishing season 2003–2004 to a maximum of 449 days.pound^{-1} in 2008–2009; the total fishing effort record was 5323 days.pound^{-}1, of which 4799 days.pound^{-1} were from the 22 fishing seasons as defined above.

In order to assess residence time in the study area, a longer tagging period (1991–2016), which included captures and recaptures even if fishing effort was not systematically recorded, were included in the analysis.

2.4. Statistical analysis

Capture rates are reported as number of turtles captured per day per pound (day.pound^{-1}). This became the unit of analysis, i.e. the dependent variable, and was calculated on a monthly basis because fishery records include several days of activity and turtle bycatches. For annual trends, monthly capture rates were again the unit of analysis, with capture rates averaged, and SD calculated.

Recapture rates from a larger dataset, including tagging and recaptures in pound nets not monitored for fishing effort, as well as previously tagged turtles (from 1991 to 1994), were reduced and occurred mostly soon after tagging (see Fig. 3), suggesting that the number of residents in the area is low. Even so, recaptures in monitored pound nets were excluded from the analyses of capture rates and turtle sizes.

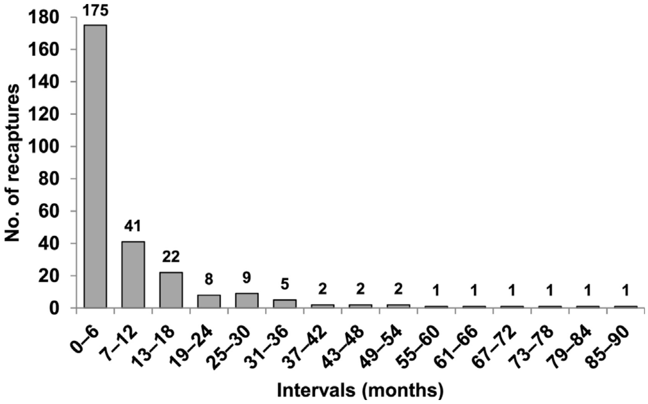

Fig. 3. Intervals of recapture of green sea turtles *Chelonia mydas* captured and tagged in pound nets and recaptured again in pound nets, at a coastal foraging ground in Ubatuba, southeastern Brazil, from 1991 to 2016.

Data were included in a Generalized Linear Model (GLM) to determine the explanatory variables influencing capture of turtles. A constant $c = 0.5$ was arbitrarily added at each capture rate value, as recommended by Yamamura (1999), to overcome problems with zero values, which precludes analysis with log-link function, used with gamma distribution in the GLM. Explanatory variables used in the model were pound (5 levels), fishing season (22 levels), and month (9 levels, as winter months are not part of the fishing seasons and were removed from this analysis), all included in the model as factors, i.e. categorical variables. The model compares in relation to a reference factor, in this case the year 1995 or the fishing season 1995–1996 (first sampling periods), the month April (early in each recruitment every year) and pound A. Interactions between explanatory variables were considered in the models, as they provided more parsimonious models, i.e. lower AIC (Akaike's Information Criterion) values. The GLM was fitted with log-link function, to deal with categorical variables (Grafen and Hails, 2002) and a gamma distribution, as in Brotons et al. (2008).

Furthermore, size at recruitment to the stock was tested by a GLM analysis with parameters month, year and pound, plus interaction among factors. Calendar year was used in this analysis, instead of "fishing season", because the focus in this analysis is on turtles (size), not the fishery as above. Green turtles seem to recruit to the area during the austral autumn (see Results). Thus, by using calendar year the analysis better represent every green sea turtle cohort, instead of two different cohorts if we had used "fishing season". For this GLM the default, i.e. Gaussian distribution and link identity, was used. GLM analysis was carried out in R software (R Core Team, 2015).

The long-term trend in capture rates in pound nets, used as a proxy for the abundance of juvenile green sea turtles in the area, was analysed by Pearson's correlation test. The annual change in capture rates was estimated based on the slope of the linear regression of natural logarithm of capture rates versus year (see Epperly et al., 2007 for details). The proportion of dead green turtle in each pound was compared through a G-test. Correlations and the G-test were run in BioEstat software v. 5.3 (Ayres et al., 2007).

3. Results

A total of 3670 individual sea turtles, of three species, were captured in pound nets at Ubatuba, from 1995 to 2016. Green sea turtles dominated the captures (99.1%, 3639 captures), thus, all further analyses were with this species only (Tables 1 and 2). Captures also included hawksbills, *Eretmochelys imbricata* (23 individuals, one dead), and loggerheads, *Caretta caretta* (eight individuals, all alive).

Table 2
Number of green sea turtles *Chelonia mydas* captured alive and dead in five pound nets at Ubatuba, southeastern Brazil.

Pound	No. alive	No. dead	Mortality rate (%)	Mesh sizes of "chamber" (cm)
Pound A	852	6	0.70	6–7
Pound B	882	35	3.82	11
Pound C	933	9	0.96	4–6
Pound D	833	9	1.07	6–7
Pound E	65	15	18.75	7
Total	3565	74	2.03	

3.1. Mortality of green sea turtles

Seventy-four out of 3639 captured green sea turtles were dead (overall mortality rate = 2.0%), varying from 0.7% in Pound A, to 18.8% in Pound E (Table 2), thus differing significantly among pounds (G-test contingency $2 \times 5 = 75.8$, df = 4, $P < 0.0001$). Pounds E had a mortality rate significantly higher than others, while pounds A, C and D had significantly lower mortality (all mortality rates < 1.1%), and Pound B had intermediate mortality. Because different mortality rates are primarily attributed to pounds, other factors such as year, turtle size, or environmental characteristics had not been statistically analysed.

3.2. Recapture and residency of green turtles

Based on the longer period, from 1991 to 2016, 6525 green sea turtles were captured, with 6865 events (i.e. captures and recaptures pooled, with multiple captures of a single individual summed). Most of the turtles were captured only once ($n = 6253$ turtles, 95.8%), 228 were captured twice, 31 individuals three times, nine individuals four times, one individual five times, two individuals 7 times and a single individual eight times. Median recapture interval was 220 days and ranged from occurring on the same day to almost 15 years later. Recaptures commonly occurred soon after release, with 51.8% recaptured within a month from release, and 64.3% within six months (Fig. 3).

3.3. Capture rates and GLM analyses

Fishing seasons defined for the current study (1995–2016) were monitored for a total of 4799 days.pound^{-1}, during which time 2937 captures of green sea turtle occurred (overall capture rate 0.61 turtles day^{-1}.pound^{-1}). In total, 292 months.pound^{-1} were monitored during fishing seasons, and 322 when winter months were included. Despite not normally distributed (Lilliefors' test $P < 0.01$), capture rates were relatively homogenous, with only 14 months.pound^{-1} showing zero captures, a few high capture rates (up to 6.0 turtles day.pound^{-1} in pound D, in May 2010) and median similar to mean, i.e. 0.56 turtles day.pound^{-1}. All three factors included in the model and their interactions were significant (Tables 3 and 4). Despite the complexity of the model accounting for interactions, this model was the most parsimonious (lowest AIC = 139.9) and explained a major proportion of the variance in data (93.2%; Table 4). Fishing season was the most important factor (34.6% of explicability), followed by the interaction "fishing season:month", which explained 27.5% of the variance in the dataset. Next, "month" explained 15.4% of the variance. Despite significant, "pound" explained a minor proportion of the variation in capture rates, nonetheless it had marked differences in mortality rates, as presented above. The limited number of pounds monitored in some years could have reduced the explicability of this variable.

Captures occurred in all months, from a minimum of 0.52 ± 0.39 turtles day^{-1}.pound^{-1} in February to 1.37 ± 1.12 turtles day^{-1}.pound^{-1} in October, but occurred most frequently in colder months, from July to October (Table 3 and Fig. 4). In the GLM, "month" had high explicability for the model, with September significantly higher than April (151.6%), and November and December significantly lower than April (53.2 and 80.8% lower, respectively). This result is slightly different from the graphical analysis, as winter months were not included in the GLM analysis. The standard deviations for May and October were about twice the SD value of any other month, coinciding with the end and start of fishing seasons, respectively (Fig. 4).

Fishing seasons 2014–2015 and 2015–2016 were demonstrated to be significantly higher (111.9 and 141.5%, respectively) than the reference season (defined as 1995, the first year of monitoring). Capture did not vary significantly between pounds, but interactions with other factors were significant, the reason for keeping "pound" in the GLM analysis (Tables 3 and 4).

Table 3
Coefficients from the selected model (GLM, gamma family with log-link function) with explanatory capture rates (turtles.day^{-1} +0.5) explained by pound, month and fishing season (from September to May), as well as interactions between terms. The intercept represent the capture rate in Pound A, month April and the fishing season of 1995 (Jan–May), in relation to which all other levels are compared to. For example, the estimate for season 2014–2015 $e^{1.119}$, means a statistically significant increase in sea turtle capture rate of 111.9% in comparison to "fishing season 1995"; or December ($e^{-0.808}$) means a significant decrease by 80.8% in capture rates in comparison with the capture rate recorded in April. Only significant terms, at $P \le 0.05$ are shown.

	Estimate	Standard error	*t*-value	*P*
Intercept	−0.377	0.461	−0.818	0.416
Main Effects				
Fishing season (2014–2015)	1.119	0.508	2.204	0.031
Fishing season (2015–2016)	1.415	0.501	2.824	0.006
Month (December)	−0.808	0.252	−3.213	0.002
Month (November)	−0.532	0.256	−2.081	0.041
Month (September)	1.516	0.377	4.025	< 0.001
Interactions				
1995–1996:December	2.177	0.664	3.280	0.002
1996–1997:December	2.350	0.664	3.539	0.001
1997–1998:December	2.302	0.664	3.467	0.001
1998–1999:December	2.262	0.664	3.408	0.001
1999–2000:December	2.337	0.664	3.520	0.001
2000–2001:December	2.039	0.664	3.072	0.003
2001–2002:December	2.096	0.664	3.157	0.002
2002–2003:December	2.208	0.664	3.326	0.001
2003–2004:December	2.136	0.664	3.217	0.002
2004–2005:December	2.086	0.664	3.143	0.002
2005–2006:December	1.019	0.308	3.313	0.001
2006–2007:December	1.207	0.334	3.615	0.001
2007–2008:December	0.864	0.350	2.471	0.016
2008–2009:December	1.329	0.308	4.323	< 0.001
2009–2010:December	1.014	0.342	2.970	0.004
2010–2011:December	0.942	0.334	2.824	0.006
2011–2012:December	0.869	0.350	2.485	0.015
2002–2003:May	1.517	0.533	2.848	0.006
1996–1997:November	1.784	0.664	2.687	0.0 09
2000–2001:November	1.532	0.664	2.308	0.024
2001–2002:November	1.684	0.664	2.537	0.013
2002–2003:November	1.615	0.664	2.432	0.018
2004–2005:November	1.356	0.664	2.043	0.045
2005–2006:November	0.654	0.308	2.128	0.037
2006–2007:November	1.157	0.363	3.190	0.002
2008–2009:November	0.751	0.337	2.226	0.029
2009–2010:November	0.824	0.384	2.149	0.035
1995–1996:October	1.024	0.474	2.161	0.034
1996–1997:October	0.959	0.474	2.024	0.047
1999–2000:October	1.097	0.474	2.313	0.024
2001–2002:October	1.115	0.474	2.351	0.022
2003–2004:October	1.102	0.474	2.325	0.023
2004–2005:October	1.809	0.474	3.816	< 0.001
2005–2006:October	1.126	0.421	2.673	0.009
2006–2007:October	1.333	0.435	3.060	0.003
2008–2009:October	1.714	0.421	4.070	< 0.001
2009–2010:October	1.572	0.436	3.606	0.001
2010–2011:October	1.902	0.378	5.032	< 0.001
1995–1996:September	−1.383	0.533	−2.596	0.012
2003–2004:September	−1.288	0.533	−2.418	0.018
2007–2008:Pound B	0.458	0.207	2.216	0.030
2009–2010:Pound B	1.553	0.301	5.159	< 0.001
2013–2014:Pound B	0.724	0.247	2.931	0.005
2004–2005:Pound D	−1.583	0.389	−4.069	0.000
2009–2010:Pound D	1.243	0.326	3.819	< 0.001
2010–2011:Pound D	−0.606	0.234	−2.586	0.012
December:Pound C	−1.300	0.500	−2.599	0.011
May:Pound D	0.841	0.351	2.399	0.019

3.4. Size variation

CCL of green turtles varied from a minimum of 27.0 cm to a maximum of 99.5 cm. Mean monthly CCLs (Fig. 5), showed that larger turtles occurred mostly in austral summer (mean of 46.0 cm in

Table 4
Summary of ANOVA results of capture rates in the Generalized Linear Model (GLM), fitted with gamma distribution and log-link function, obtained for the most parsimonious model (AIC = 139.9).% explained is calculated as deviance/residual deviance of the null model × 100, as in Ye et al. (2001). df – degrees of freedom.

Source of variation	df	Deviance	% explained	df of residuals	Residual deviance	*F*	*P*
Null				291	74.88		
Fishing season	21	25.89	34.58	270	48.99	17.38	< 0.001
Month	8	11.54	15.41	262	37.45	20.33	< 0.001
Pound	4	2.97	3.97	258	34.48	10.47	< 0.001
Fishing season:Month	147	20.56	27.46	111	13.92	1.97	< 0.001
Fishing season:Pound	20	5.90	7.88	91	8.02	4.16	< 0.001
Month:Pound	23	2.94	3.93	68	5.08	1.80	0.032
Total Explained		69.80	93.23				

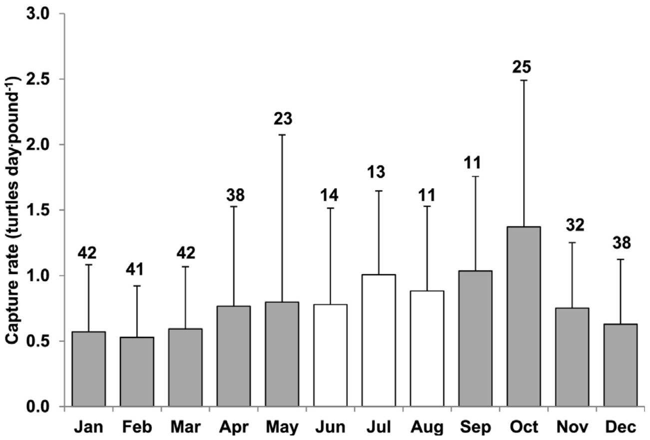

Fig. 4. Monthly variation in mean ± 1 standard deviation of captures rates (fishing days.pound^{-1}) of green sea turtles *Chelonia mydas* in pound nets in Ubatuba, southeastern Brazil, between 1995 and 2016. Values above SD bars are sample sizes (*n*), i.e. the number of months in each a pound was monitored. White bars correspond to non-fishing season (austral winter).

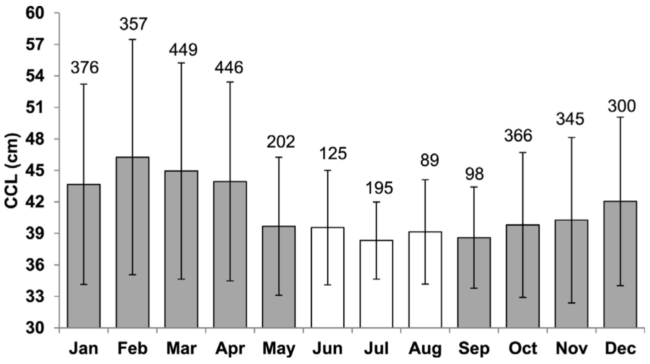

Fig. 5. Monthly variation in mean ± 1 standard deviation of Curved Carapace Length (CCL), of green sea turtles *Chelonia mydas* captured in pounds nets at Ubatuba, southeastern Brazil from 1995 to 2016. Values above SD bars are sample sizes (*n*). White bars correspond to non-fishing season (austral winter).

February) and smaller turtles in winter (May to September), with mean size in July of 38.3 cm (Fig. 5). The model, with winter months excluded, had a poor fit overall, i.e. only explained 21.0% of the variability in CCL, probably due to large variances in turtle size (Figs. 5 and 6). All three variables of the model and their interactions were significant. “Month”, “year” and the interaction “year:month” were the variables with higher explicatory power in the GLM model, with 4.9%, 6.1% and 6.1%, respectively, suggesting that turtles in different size classes recruited during different months every year. Significant lower estimates for months early in the season such as November and December (Table 6), in comparison to the reference month April (later in the fishing season), suggest recruiting occurs mainly in winter.

Overall, negative estimate values in several years (Table 6) seems to be due to a much higher value in the reference year (i.e. 1995), while the graphical analysis (Fig. 6) demonstrated that larger turtles occurred in the last four years of the temporal series with an overall upward trend in size along the 22 years period (Fig. 6 and Tables 5 and 6).

3.5. *Trends in capture rates*

A significant increasing trend in capture rates of green turtles was detected during the 22 year monitoring period at Ubatuba ($r = 0.85$, $n = 22$, $P < 0.001$; Fig. 7). The annual capture rate increased by 9.24% per year. A separate analysis excluding the effect of pound, i.e. based on data from the pound with the largest monitoring period (Pound C, from 1995 to 2006), also resulted in a similar increase in capture rates ($r = 0.80$, $n = 12$, $P = 0.008$; inset in Fig. 7).

4. Discussion

4.1. *Pound nets as a tool for monitoring sea turtle foraging aggregations*

Large numbers of green sea turtles were incidentally captured throughout every year in nearshore pound nets in southeastern Brazil (1995–2016). Roughly, one turtle was captured every other day in each pound. Despite being captured frequently, sea turtle mortality is low and the bulk of sea turtles are released with no injury. In addition, based on tagging-recapture data that pre-dated the monitoring of pound nets, the residence time of green sea turtles is of short duration, with

Table 5
Summary of ANOVA results of the GLM model for green sea turtle Curved Carapace Length (CCL). The model was fitted with Gaussian distribution and identity link function, and results are from the most parsimonious model (AIC = −5934.7).% explained is calculated as deviance/residual deviance of the null model × 100, as in Ye et al. (2001). df – degrees of freedom.

Source of variation	df	Deviance	% explained	df of residuals	Residual deviance	*F*	*P*
Null				2938	24.91		
Pound	4	0.44	1.77	2934	24.47	15.18	< 0.001
Month	8	1.51	6.06	2926	22.96	26.08	< 0.001
Year	21	1.21	4.86	2905	21.75	7.99	< 0.001
Pound:Month	25	0.29	1.16	2880	21.46	1.60	0.029
Pound:Year	21	0.28	1.12	2859	21.18	1.85	0.011
Year:Month	139	1.51	6.06	2720	19.67	1.50	< 0.001
Total Explained		5.24	21.03				

Table 6
Coefficients from the selected model with explanatory Curved Carapace Length (CCL) of green sea turtles (*Chelonia mydas*), explained by pound, month and fishing season (from September to May), excluded austral winter months and the first incomplete fishing season, as well as interactions between terms. The intercept represent the capture rate in Pound A, month April and the fishing season of 1996–1997), in relation to which all other levels are compared to. Only significant terms are shown.

	Estimate	Standard error	*t*-value	*P*
Intercept	0.582	0.057	10.292	< 0.001
Main Effects				
Pound C	−0.178	0.048	−3.720	< 0.000
December	−0.328	0.115	−2.858	0.004
November	−0.166	0.082	−2.030	0.042
2002	0.146	0.058	2.541	0.011
2006	−0.132	0.058	−2.270	0.023
2007	−0.129	0.061	−2.099	0.036
2008	−0.184	0.062	−2.993	0.003
2009	−0.162	0.062	−2.621	0.009
2010	−0.209	0.064	−3.281	0.001
2011	−0.142	0.067	−2.114	0.035
2012	−0.219	0.061	−3.585	< 0.001
2013	−0.135	0.068	−1.994	0.046
2015	−0.131	0.058	−2.248	0.025
2016	−0.127	0.058	−2.197	0.028
Interactions				
Pound C:December	0.255	0.071	3.579	< 0.001
Pound C:January	0.175	0.062	2.805	0.005
Pound C:November	0.159	0.058	2.736	0.006
Pound C:October	0.126	0.054	2.344	0.019
Pound D:2006	−0.049	0.019	−2.584	0.010
Pound D:2008	−0.086	0.038	−2.278	0.023
Pound D: 2015	−0.079	0.035	−2.274	0.023
January:2002	−0.221	0.087	−2.524	0.012
October:2002	−0.214	0.082	−2.608	0.009
December:2006	0.264	0.116	2.268	0.023
December:2007	0.302	0.118	2.550	0.011
December:2008	0.333	0.118	2.813	0.005
December:2009	0.343	0.118	2.915	0.004
December:2010	0.306	0.118	2.583	0.010
December:2011	0.315	0.123	2.563	0.010
November:2011	0.189	0.092	2.059	0.040
December:2012	0.309	0.120	2.569	0.010
December:2013	0.281	0.123	2.280	0.023
December:2014	0.268	0.123	2.183	0.029
December:2015	0.327	0.117	2.786	0.005

most individuals only captured once. However, long residence in the area could be possible, as reported for some individuals in other areas, such as northeastern Brazil in the Atlantic Ocean (Godley et al., 2003), Indian Ocean (Taquet et al., 2006) and Pacific Ocean (Senko et al., 2010). This is particularly plausible if turtles learn to avoid pounds, an issue that remains to be studied at Ubatuba through the use of remotely tracking devices attached to turtles. This scenario strongly suggests that pound net fisheries could be a suitable tool for the long term monitoring of foraging aggregations in Brazil. Pound nets are also found in other countries, such as Japan, Mexico (Seckendorff et al., 2009), USA (Epperly et al., 2007) and Albania (White et al., 2013). Pound nets along the USA's Atlantic coastline capture mainly loggerhead sea turtles, non-lethally (Epperly et al., 2007), while some pound net designs in Japan are known to kill many loggerhead turtles (Gilman et al., 2010). Despite pounds differ in capture rates, the GLM model demonstrated a minor effect of only 1.8% in the variability of data, and the analysis of a single pound shows a trend in capture rates along the years similar to the whole database. Thus, the fishery as a whole seems able to reflect reasonably well the recruitment rate of green sea turtles into the study area. Similar to any other method, using pound nets to monitor population trends has advantages and limitations. From one side it could allow the monitoring of several source populations simultaneously, by monitoring a more-easily accessible coastline instead of remote islands where green sea turtles often nest (Bowen et al., 1992); and threats to populations could be detected much earlier, because juveniles tend to recruit into coastal areas at about 2–8 years old (Reich et al., 2007; Andrade et al., 2016), whereas adult females start to lay their eggs when they are 20–25 years of age (Bjorndal et al., 2005). Thus, juvenile trends could be an earlier warning proxy, if something is causing a decline in adults. A limitation of using pound net sampling is that it depends on the schedule defined by fishermen and their willingness to cooperate with researchers. In addition, analyzing data from a mixed-stock means that problems could not be linked to an individual rookery unless proper genetic assignment of individuals to specific nesting beaches, over the years, occurs.

The southernmost monitored pound (Pound D, Fig. 1) had much higher capture rates than others, despite not being significant in models, which highlights the need to take into account these variations between pounds. On their turn, the incidence of higher mortality rates may be linked to the use of nets with larger mesh sizes, including those at the bottom of the pound, causing more frequent entanglements in some traps. However, currently, large mesh sizes are no longer allowed by legislation (Resolution SMA No. 78, 29 September 2016), thus resulting in limited mortality in the fishery as a whole. In addition, variation in capture rates between pounds could be influenced by the local characteristics at each site, such as coastal topography, water transparency, sea surface temperatures, or the abundance of algae utilized by foraging turtles; consequently a given pound is not identical to any other (Seckendorff et al., 2009).

4.2. Monthly variation in capture rates and turtle size

The deployment of pound nets decreases in winter months, due to more frequent polar fronts and rough seas, which could damage the gear. However, during winter (July–October), capture rates are higher than from the spring-summer period. It has been suggested (Gallo et al., 2006) that recruitment of individuals from southern areas occurs during the winter, as these may have migrated northward to avoid cold waters in southern Brazil, Uruguay and Argentina. However, they could also have recruited from adjacent oceanic areas. In areas south of Ubatuba, the number of green sea turtles is higher during warm months, i.e. spring to early autumn (López-Mendilaharsu et al., 2006; Carman et al., 2011; Proietti et al., 2012), which could be due to recruitment from oceanic areas, as well as from migrants from northern foraging grounds. This hypothesis of seasonal recruitment at Ubatuba from southern areas and adjacent oceanic areas is consistent with some recaptures of tagged green turtles (Gallo et al., 2006), as well as results from the current larger dataset demonstrating seasonal variation in capture rates and turtle sizes.

Furthermore, the large standard deviation in capture rates in May and October, about twice the SD of any other month, is interpreted as annual variation in the month of departure and arrival, respectively, probably influenced by oceanographic conditions such as colder waters in the south. In other words, those months could be classified as "colder" in one year, but "warm" in the following, with many or few turtles, respectively. Although seasonal latitudinal movements of green turtles have not been confirmed from the southwestern Atlantic Ocean, it is reasonable to expect that they are analogous to those occurring in the northwestern Atlantic (Epperly et al., 1995) and northwest Pacific (Fukuoka et al., 2015) Oceans, where sea turtles move to higher latitudes in summer and return to lower latitudes as temperature falls.

Torezani et al. (2010) studying green sea turtles at Espírito Santo state, about 600 km northward of Ubatuba, also found seasonality in the occurrence of green turtles in some years, but not in other years, with lower captures in winter months. They also noted short residence times, similar to Ubatuba, and referred to their site as a transient developmental habitat. The more tropical coast of Espírito Santo may explain the lack of seasonality in some years, whereas it is maintained at Ubatuba. Short migrations of green turtles between developmental or foraging grounds were reported in the southwestern Atlantic Ocean (Marcovaldi et al., 2000; Godley et al., 2003; Gallo et al., 2006; Proietti

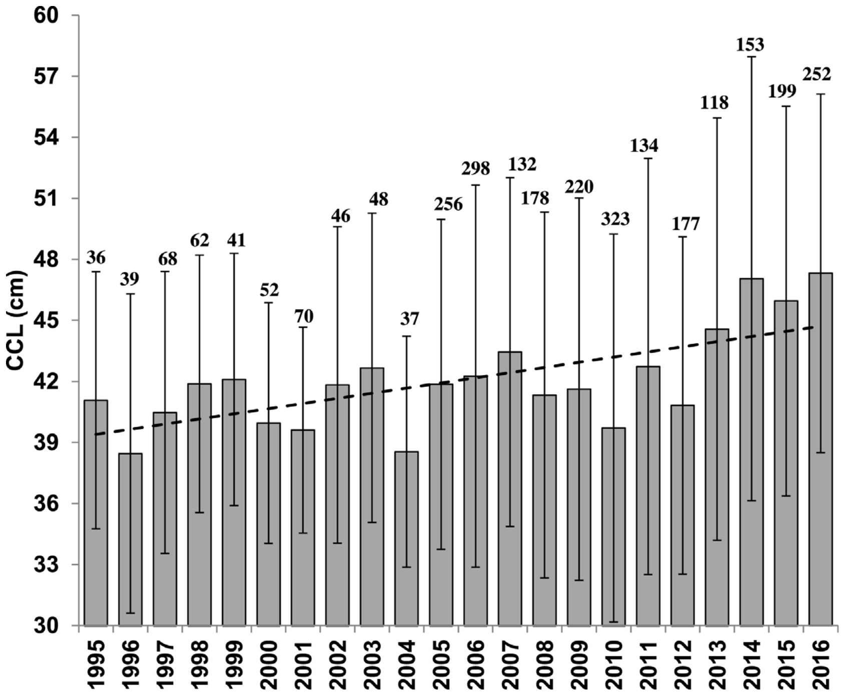

Fig. 6. Variation in mean ± 1 standard deviation of Curved Carapace Length (CCL) of green sea turtles *Chelonia mydas*, between years in pound nets at Ubatuba, southeastern Brazil. Values above SD bars are sample sizes (n) and the dashed line indicates the temporal trend.

et al., 2009). Although not well understood, these movements can help explain the short residence time in some places, including Ubatuba.

Monthly variation in CCL is additional evidence of this annual recruitment. Larger juveniles (over 40 cm CCL) occur in the area from December to April, followed by a steep (~3 cm) mean decline in CCL. If the annual growth rate recorded at Espírito Santo foraging ground of 2.21–3.60 cm year^{-1} (95% confidence interval, Torezani et al., 2010), or the rate of 1.4–3.4 cm.year^{-1} at Paraná state (Andrade et al., 2016), respectively north and south of Ubatuba, also applies to turtles at Ubatuba, then younger cohorts are arriving in May every year, perhaps from southern feeding grounds or recruiting from the oceanic phase. Furthermore, from the lowest to the highest monthly mean CCL, there is a difference of about 8 cm, i.e. double the expected growth of a green turtle in a single year. Thus, while some of the turtles seem to remain in the area during the summer, there is probably an influx of small-sized turtles around May, with turtles from different cohorts meeting at the area. The limited residence time, usually < 6 months, and the high number of untagged individuals, are also consistent with a high turnover of individuals in the area. Within- and inter-year variations in origins, and thus in genetic composition of the mixed-stock, would be an interesting refinement for a better understanding of the monitoring indicator proposed here.

4.3. Annual variation in capture rates and turtle size

Inter-annual variations in capture rates were observed and these could reflect particularly good or bad nesting seasons in any of the main rookeries that contribute to our population, or perhaps the intrinsic

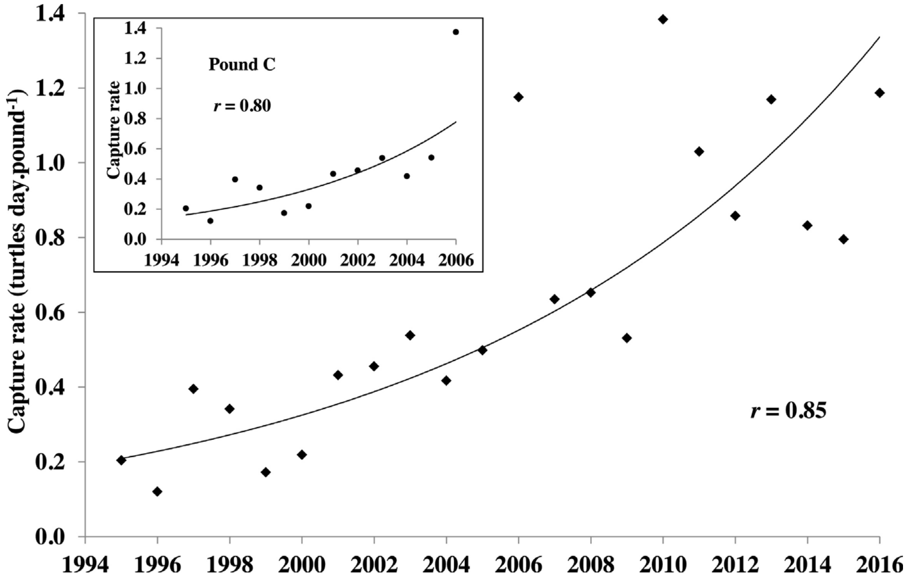

Fig. 7. Annual variation in green sea turtle *Chelonia mydas* capture rates (turtles day.pound^{-1}) in pound net fisheries in Ubatuba, southeastern Brazil, over a 22-years period. Best fit represented by the trend line obtained by exponential regression for the whole period. The inset shows the trend analysis using a single pound (C) with the longest sampling period.

variation in the number of eggs laid by green turtles (Bjorndal et al., 1999; Chaloupka et al., 2008a). In developmental foraging grounds several overlapping cohorts, including juveniles from different genetic stocks, may mask inter-annual differences in reproductive output or early-juvenile survival rates, with a low nesting season in one nesting area potentially buffered by a high nesting season in another. Alternatively, turtles could be using different foraging areas every year, despite evidence for this being lacking. Therefore, assessing sea turtle population trends in developmental habitats is even more challenging than at rookeries (Almeida et al., 2011a), and perhaps is only able to indicate population health status at a Regional Management Unit scale (sensu Wallace et al., 2010); unless foraging ground studies also identify the genetic origin of individual turtles through molecular methods. The lack of inter-annual variation in CCL supports the hypothesis of new recruits arriving at Ubatuba every austral autumn, as well as a buffering effect caused by the overlapping of several cohorts, probably from a range of nesting grounds (Naro-Maciel et al., 2007).

4.4. Trends in capture rates

Capture rates at Ubatuba showed an increase of 9.2% year^{-1} from 1995 to 2016. Juvenile green turtles found along the southwestern Atlantic Ocean coast are relatively homogeneous in terms of turtle origins, from the Equator (Fernando de Noronha Archipelago) to Argentina (Proietti et al., 2012; Prosdocimi et al., 2012), with stock composition similar to those described at Ubatuba (Naro-Maciel et al., 2007), i.e. from Ascension Island where 23,700 nests per year are counted (Weber et al., 2014), Aves Island, Venezuela, with over 1000 females per year (García-Cruz et al., 2015), and Trindade Island, Brazil, with 3600 nests (Almeida et al., 2011a). In Brazil, green turtles nest mainly on offshore islands, which makes population monitoring operationally difficult: Trindade Island is 1140 km off the mainland coast (Almeida et al., 2011a), Atol das Rocas is 267 km off the mainland coast, with an estimated 335 nests each year (Bellini et al., 2013), both are without permanent human settlements, and Fernando de Noronha, 400 km off the coast, has 55 nests each year (Almeida et al., 2011b) (Fig. 1).

The Ascension Island nesting population has shown an increase of 0.4–6% per annum, since monitoring started in 1977 (Broderick et al., 2006; Weber et al., 2014), while Trindade Island's population has remained stable (Almeida et al., 2011a). Chaloupka et al. (2008a) estimated that rates of nesting population increase ranged from *c.* 4–14% per annum over the past two to three decades in Ogasawara (Japan), Hawaii (USA), Great Barrier Reef (Australia), Florida (USA) and Tortuguero (Costa Rica). The increase of 9.2% per year in the abundance of juvenile green sea turtles at the Ubatuba foraging ground is within this range. Both analyses, of the whole dataset or of a single pound for which we had monitored for 12 years, demonstrated the consistency of using capture rate as a reliable indicator of population trends. Ascension Island is the major contributor (50%) to the Ubatuba mixed stock (Naro-Maciel et al., 2007) and nesting activity there, from the 1970's to 1998–1999, had increased 6 fold (Weber et al., 2014). Trindade Island's rookery, the second largest contributor with ~15% (Naro-Maciel et al., 2007) has remained stable (Almeida et al., 2011a). Aves Island, the third contributor to Ubatuba foraging ground also increased at 4.5% per year, from 1979 to 2009 (García-Cruz et al., 2015). So it was expected to see an increased trend in numbers at Ubatuba, and in fact there was about 6-fold increase at this study area.

The good adjustment for exponential growth model for both the Ascension Island population (Broderick et al., 2006) and the Ubatuba green turtle aggregation were similar, suggesting that in both nesting and developmental habitats, the number of individuals had not reached the point of inflection of the logistic growth, which occurs when populations reach half the environmental carrying-capacity (Broderick et al., 2006). Bjorndal et al. (2005) found that trends in abundance of juveniles on the foraging grounds did not conform to the significantly increasing trend for the major nesting population at Tortuguero, Costa Rica. The present study supports the former pattern with trends in nesting vs. foraging grounds matching closely.

The buffering effect of different cohorts and nesting grounds contributing to the composition of the mixed stock at Ubatuba results in annual variations of much lower magnitude than those verified from nesting grounds, where 10- to 20-fold fluctuations in green sea turtle nesting activities between consecutive seasons have been recorded, e.g. in Australia (Chaloupka et al., 2008a), Costa Rica, Japan and USA (Bjorndal et al., 1999; Chaloupka et al., 2008a). Likewise, nesting beaches can be used by turtles from different foraging grounds and so differences observed in trends at coastal foraging grounds and also at source rookeries must be interpreted with caution (Bjorndal et al., 2005).

5. Conclusion

The initial goal of the current initiative was to reduce incidental capture in fisheries, similar to many monitoring studies which were established with other purposes. However, such studies could provide key opportunities for in-water monitoring trends of sea turtles populations. Assessing population trends is difficult mainly because there are very few long-term studies on sea turtle population sizes, and also because there may be large variations in parameters monitored annually on nesting beaches (Hays, 2004; Chaloupka et al., 2008a). Here we show that in places where captures of sea turtles are common and fisheries are non-lethal, monitoring incidental captures to identify population/juvenile stock trends could be an important tool to assess the status of several distant rookeries that contribute to a given foraging ground. In addition, as sea turtles show delayed maturity (Balazs and Chaloupka, 2004), monitoring juvenile stocks could indicate changes in female nesting numbers or hatchling production more quickly, based on patterns of juveniles recruiting into coastal foraging areas (Bjorndal et al., 2005). Otherwise, the impacts on nesting beaches might only be identified decades afterwards. Monitoring trends at different stages of the complex life cycle of sea turtles, rather than only the nesting females, could provide additional support for the conservation and management of populations of these globally threatened reptiles. Finally, because a 22-years long dataset of oceanographic data at Ubatuba demonstrated increase in sea surface temperatures of 0.05 °C per year (Valentim et al., 2013), monitoring marine organisms could provide evidences of changes in the marine ecosystem.

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References

Ávila-da-Silva, A.O., Carneiro, M.H., Mendonça, J.T., Bastos, G.C.C., Miranda, L.V., Rosario, W.R., Santos, S., 2016. Produção pesqueira marinha e estuarina do estado de São Paulo – dezembro de 2015. Inf. Pesqueiro SP 68, 1–4.

Almeida, A.P., Moreira, L.M.P., Bruno, S.C., Thomé, J.C.A., Martins, A.S., Bolten, A.B., Bjorndal, K.A., 2011a. Green turtle nesting on Trindade Island, Brazil: abundance, trends, and biometrics. Endang. Species Res. 14, 193–201.

Almeida, A.P., Santos, A.J.B., Thomé, J.C.A., Bellini, C., Baptistotte, C., Marcovaldi, M.Â., Santos, A.S., Lopez, M., 2011b. Avaliação do estado de conservação da tartaruga marinha *Chelonia mydas* (Linnaeus, 1758) no Brasil. Biodiv. Bras. 1, 12–19.

Andrade, M.F., Domit, C., Broadhurst, M., Tolhurst, D.J., Silva-Souza, Â.T., 2016. Appropriate morphometrics for the first assessment of juvenile green turtle (*Chelonia mydas*) age and growth in the south-western Atlantic. Mar. Biol. 163, 254.

Ayres, M., Ayres-Jr, M., Ayres, D.L., Santos, A.A., 2007. BioEstat – Aplicações Estatísticas nas Áreas das Ciências Bio-médicas. Software, version 5.3. Ong Mamirauá, Belém.

Balazs, G.H., Chaloupka, M., 2004. Spatial and temporal variability in somatic growth of green sea turtles (*Chelonia mydas*) resident in the Hawaiian Archipelago. Mar. Biol. 145, 1043–1059.

Bellini, C., Santos, A.J.B., Grossman, A., Marcovaldi, M.A., Barata, P.C.R., 2013. Green turtle (*Chelonia mydas*) nesting on Atol das Rocas, north-eastern Brazil, 1990–2008. J. Mar. Biol. Assoc. UK 93, 1117–1132.

Bjorndal, K.A., Wetherall, J.A., Bolten, A.B., Mortimer, J.A., 1999. Twenty-six years of green turtle nesting at Tortuguero, Costa Rica: an encouraging trend. Conserv. Biol. 13, 126–134.

Bjorndal, K.A., Bolten, A.B., Chaloupka, M.Y., 2005. Evaluating trends in abundance of immature green turtles Chelonia mydas, in the greater Caribbean. Ecol. Appl. 15, 304–314.

Bourjea, J., Dalleau, M., Beudard, F., Marmoex, C., M'Soili, A., Roos, D., Ciccione, S., Frazier, J., 2015. Seasonality, abundance, and fifteen-year trend in green turtle nesting activity at Itsamia, Moheli, Comoros. Endang. Species Res. 27, 265–276.

Bowen, B.W., Meylan, A.B., Ross, J.P., Limpus, C.J., Balazs, G.H., Avise, J.C., 1992. Global population structure and natural history of the green turtle (*Chelonia mydas*) in terms of matriarchal phylogeny. Evolution 46, 865–881.

Broderick, A.C., Frauenstein, R., Glen, F., Hays, G.C., Jackson, A.L., Pelembe, T., Ruxton, G.D., Godley, B.J., 2006. Are green turtles globally endangered? Glob. Ecol. Biogeogr. 15, 21–26.

Brotons, J.M., Munilla, Z., Grau, A.M., Rendell, L., 2008. Do pingers reduce interactions between bottlenose dolphins and nets around the Balearic Islands? Endang. Species Res. 5, 301–308.

Bugoni, L., Krause, L., Petry, M.V., 2001. Marine debris and human impacts on sea turtles in southern Brazil. Mar. Pollut. Bull. 41, 1338–1342.

Carman, V.G., Álvarez, K.C.F., Prosdocimi, L., Inchaurraga, M.C., Dellacasa, R.F., Faiella, A., Echenique, C., González, R., Andrejuk, J., Mianzan, H.W., Campagna, C., Albareda, D.A., 2011. Argentinian coastal waters: a temperate habitat for three species of threatened sea turtles. Mar. Biol. Res. 7, 500–508.

Casale, P., Aprea, A., Deflorio, M., Metrio, G.D., 2012. Increased by-catch rates in the Gulf of Taranto, Italy, in 20 years: a clue about sea turtle population trends? Chelonian Conserv. Biol. 11, 239–243.

Castro-Filho, B.M., Miranda, L.B., Myao, S.Y., 1987. Condições hidrográficas na plataforma continental ao largo de Ubatuba: variações sazonais e em média escala. Bol. Inst. Oceanogr. Sao Paulo 35, 135–151.

Chaloupka, M., Limpus, C., 2001. Trends in the abundance of sea turtles resident in southern Great Barrier Reef waters. Biol. Conserv. 102, 235–249.

Chaloupka, M., Bjorndal, K.A., Balazs, G.H., Bolten, A.B., Ehrhart, L.M., Limpus, C.J., Suganuma, H., Troëng, S., Yamaguchi, M., 2008a. Encouraging outlook for recovery of a once severely exploited marine megaherbivore. Glob. Ecol. Biogeogr. 17, 297–304.

Chaloupka, M., Work, T.M., Balazs, G.H., Murakawa, S.K.K., Morris, R., 2008b. Cause-specific temporal and spatial trends in green sea turtle strandings in the Hawaiian Archipelago (1982–2003). Mar. Biol. 154 997–898.

Echwikhi, K., Jribi, I., Bradai, M.N., Bouain, A., 2010. Gillnet fishery – loggerhead turtle interactions in the Gulf of Gabes, Tunisia. Herpetol. J. 20, 25–30.

Epperly, S.P., Braun, J., Veishlow, A., 1995. Sea turtles in North Carolina waters. Conserv. Biol. 9, 384–394.

Epperly, S.P., Braun, J., Chester, A.J., Cross, F.A., Merriner, J.V., Tester, P.A., Churchill, J.A., 1996. Beach strandings as an indicator of at-sea mortality of sea turtles. Bull. Mar. Sci. 59, 289–297.

Epperly, S.P., Braun-McNeill, J., Richards, P.M., 2007. Trends in catch rates of sea turtles in North Carolina, USA. Endang. Species Res. 3, 283–293.

Estado de São Paulo, 1996. Macrozoneamento do Litoral Norte: Plano de Gerenciamento Costeiro Série Documentos. Secretaria do Meio Ambiente, São Paulo.

Fiedler, F.N., Sales, G., Giffoni, B.B., Monteiro-Filho, E.L.A., Secchi, E.R., Bugoni, L., 2012. Driftnet fishery threats sea turtles in the Atlantic Ocean. Biodivers. Conserv. 21, 915–931.

Fukuoka, T., Narazaki, T., Sato, K., 2015. Summer-restricted migration of green turtles *Chelonia mydas* to a temperate habitat of the northwest Pacific Ocean. Endang. Species Res. 28, 1–10.

Gallo, B.M.G., Macedo, S., Giffoni, B.B., Becker, J.H., Barata, P.C.R., 2006. Sea turtle conservation in Ubatuba, southeastern Brazil, a feeding area with incidental capture in coastal fisheries. Chelonian Conserv. Biol. 5, 93–101.

García-Cruz, M.A., Lampo, M., Peñaloza, C.L., Kendall, W.L., Solé, G., Rodríguez-Clark, K.M., 2015. Population trends and survival of nesting green sea turtles Chelonia mydas on Aves Island Venezuela. Endang. Species Res. 29, 103–116.

Gilman, E., Gearhart, J., Price, B., Eckert, S., Milliken, H., Wang, J., Swimmer, Y., Shiode, D., Abe, O., Peckham, S.H., Chaloupka, M., Hall, M., Mangel, J., Alfaro-Shigueto, J., Dalzell, P., Ishizaki, A., 2010. Mitigating sea turtle by-catch in coastal passive net fisheries. Fish Fish. 11, 57–88.

Godley, B.J., Lima, E.H.S.M., Åkesson, S., Broderick, A.C., Glen, F., Godfrey, M.H., Luschi, P., Hays, G.C., 2003. Movement patterns of green turtles in Brazilian coastal waters described by satellite tracking and flipper tagging. Mar. Ecol. Prog. Ser. 253, 279–288.

Grafen, A., Hails, R., 2002. Modern Statistics for the Life Sciences. Oxford University Press, Oxford.

Hall, M.A., 1996. On bycatches. Rev. Fish Biol. Fish. 6, 319–352.

Harms, C.A., Mallo, K.M., Ross, P.M., Segars, A., 2003. Venous blood gases and lactates of wild loggerhead sea turtles (*Caretta caretta*) following two capture techniques. J. Wildl. Dis. 39, 366–374.

Hart, K.M., Mooreside, P., Crowder, L.B., 2006. Interpreting the spatio-temporal patterns of sea turtle strandings: going with the flow. Biol. Conserv. 129, 283–290.

Hays, G.C., 2004. Good news for sea turtles. Trends Ecol. Evol. 19, 349–351.

IUCN (International Union for Conservation of Nature), 2016. *Chelonia Mmydas*. http://dx.doi.org/10.2305/IUCN.UK.2004.RLTS.T4615A11037468.en. (Accessed 20 October 2016).

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., Warner, R.R., 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 293, 629–638.

Lewison, R.L., Freeman, S.A., Crowder, L.B., 2004. Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. Ecol. Lett. 7, 221–231.

López-Mendilaharsu, M., Estrades, A., Caraccio, M.N., Calvo, V., Hernández, M., Quirici, V., 2006. Biología, ecología y etología de las tortugas marinas en la zona costera uruguaya. In: Menafra, R., Rodríguez-Gallego, L., Scarabino, F., Conde, D. (Eds.), Bases para la Conservación y el Manejo de la Costa Uruguaya. Vida Silvestre Uruguay, Montevideo, pp. 247–257.

MMA (Ministério do Meio Ambiente), 2014. Lista Nacional Oficial de Espécies da Fauna Ameaçadas de Extinção. Decree No 444, 17 December 2014, Anexo I.

Marcovaldi, M.A., Chaloupka, M., 2007. Conservation status of the loggerhead sea turtle in Brazil: an encouraging outlook. Endang. Species Res. 3, 133–143.

Marcovaldi, M.A., Silva, A.C.C.D., Gallo, B.M.G., Baptistotte, C., Lima, E.P., Bellini, C., Lima, E.H.S.M., Castilhos, J.C., Thome, J.C.A., Moreira, L.M.P., 2000. Recaptures of tagged turtles from nesting and feeding grounds protected by Projeto Tamar-Ibama, Brazil. In: 19th Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC. 443. pp. 164–166.

Monteiro, D.S., Estima, S.C., Gandra, T.B.R., Silva, A.P., Bugoni, L., Swimmer, Y., Seminoff, J.A., Secchi, E.R., 2016. Long-term spatial and temporal patterns of sea turtle strandings in southern Brazil. Mar. Biol. 163, 247.

Mussolini, G., 1980. Ensaios de Antropologia Indígena e Caiçara. Ed. Paz e Terra, Rio de Janeiro.

Naro-Maciel, E., Becker, J.H., Lima, E.H.S.M., Marcovaldi, M.Â., DeSalle, R., 2007. Testing dispersal hypotheses in foraging green sea turtles (*Chelonia mydas*) of Brazil. J. Hered. 98, 29–39.

National Research Council, 2010. Assessment of Sea-turtle Status and Trends: Integrating Demography and Abundance. National Academy Press, Washington, DC.

Nédélec, C., Prado, J., 1990. Definition and Classification of Fishing Gear Categories. FAO Fisheries Technical Paper No. 222, Revision 1. Food and Agriculture Organization of the United Nations, Rome.

Oravetz, C.A., 1999. Reducing incidental catch in fisheries. In: Eckert, K.L., Bjorndal, K.A., Abreu-Grobois, F.A., Donnelly, M. (Eds.), Research and Management Techniques for the Conservation of Sea Turtles. IUCN/SSC Marine Turtle Specialist Group Publication, No 4, Washington, DC, pp. 189–193.

Pfaller, J.B., Bjorndal, K.A., Chaloupka, M., Williams, K.L., Frick, M.G., Bolten, A.B., 2013. Accounting for imperfect detection is critical for inferring marine turtle nesting population trends. PLoS One 8, e62326.

Poiner, I.R., Buckworth, R.C., Harris, A.N.M., 1990. Incidental capture and mortality of sea turtles in Australia's northern prawn fishery. Aust. J. Mar. Freshw. Res. 41, 97–110.

Proietti, M.C., Lara-Ruiz, P., Reisser, J.W., Pinto, L.S., Dellagostin, L.A., Martins, L.F., 2009. Green turtles (*Chelonia mydas*) foraging at Arvoredo Island in southern Brazil: genetic characterization and mixed stock analysis through mtDNA control region haplotypes. Genet. Mol. Biol. 32, 613–618.

Proietti, M.C., Reisser, J.W., Kinas, P.G., Kerr, R., Monteiro, D.S., Marins, L.F., Secchi, E.R., 2012. Green turtles *Chelonia mydas* mixed stocks in the western South Atlantic, as revealed by mtDNA haplotypes and drifter trajectories. Mar. Ecol. Prog. Ser. 447, 195–209.

Prosdocimi, L., Carman, V.G., Albareda, D.A., Remis, M.I., 2012. Genetic composition of green turtle feeding grounds in coastal waters of Argentina based on mitochondrial DNA. J. Exp. Mar. Biol. Ecol. 412, 37–45.

R Core Team, 2015. R: a Language and Environment for Statistical Computing. Version 2.14.0. R Foundation for Statistical Computing, Vienna. http://www.R-project.org.

Rees, A.F., Alfaro-Shigueto, J., Barata, P.C.R., Bjorndal, K.A., Bolten, A.B., Bourjea, J., Broderick, A.C., Campbell, L.M., Cardona, L., Carreras, C., Casale, P., Ceriani, S.A., Dutton, P.H., Eguchi, T., Formia, A., Fuentes, M.M.P.B., Fuller, W.J., Girondot, M., Godfrey, M.H., Hamann, M., Hart, K.M., Hays, G.C., Hochscheid, S., Kaska, Y., Jensen, M.P., Mangel, J.C., Mortimer, J.A., Naro-Maciel, E., Ng, C.K.Y., Nichols, W.J., Phillott, A.D., Reina, R.D., Revuelta, O., Schofield, G., Seminoff, J.A., Shanker, K., Tomás, J., van de Merwe, J.P., van Houtan, K.S., Vander Zanden, H.B., Wallace, B.P., Wedemeyer-Strombel, K.R., Work, T.M., Godley, B.J., 2016. Are we working towards global research priorities for management and conservation of sea turtles? Endang. Species Res. 31, 337–382.

Reich, K.J., Bjorndal, K.A., Bolten, A.B., 2007. The 'lost years' of green turtles: using stable isotopes to study cryptic lifestages. Biol. Lett. 3, 712–714.

Sales, G., Giffoni, B.B., Barata, P.C.R., 2008. Incidental catch of sea turtles by the Brazilian pelagic longline fishery. J. Mar. Biol. Assoc. UK 88, 853–864.

Sales, G., Giffoni, B.B., Fiedler, F.N., Azevedo, V.G., Kotas, J.E., Swimmer, Y., Bugoni, L., 2010. Circle hook effectiveness for the mitigation of sea turtle bycatch and capture of target species in a Brazilian pelagic longline fishery. Aquat. Conserv. 20, 428–436.

Sasso, C.R., Braun-McNeill, J., Avens, L., Epperly, S.P., 2007. Summer abundance estimates of *Caretta caretta* (loggerhead turtles) in Core Sound, NC. Southeast. Nat. 6, 365–369.

Seckendorff, R.W., Azevedo, V.G., Martins, J.K., 2009. Sobre a técnica construtiva da arte de pesca de cerco-flutuante no litoral norte de São Paulo. Brasil. Ser. Rel. Tecn. Sao Paulo 40, 1–16.

Seminoff, J., 2002. 2002 IUCN Red List Global Status Assessment, Green Turtle *Chelonia Mmydas*. IUCN Marine Turtle Specialist Group Review.

Senko, J., López-Castro, M.C., Koch, V., Nichols, W.J., 2010. Immature east Pacific green turtles (*Chelonia mydas*) use multiple foraging areas off the Pacific coast of Baja California Sur, Mexico: first evidence from mark-recapture data. Pac. Sci. 64, 125–130.

Taquet, C., Taquet, M., Dempster, T., Soria, M., Ciccione, S., Roos, D., Dagorn, L., 2006. Foraging of the green sea turtle *Chelonia mydas* on seagrass beds at Mayotte Island (Indian Ocean), determined by acoustic transmitters. Mar. Ecol. Prog. Ser. 306, 295–302.

Torezani, E., Baptistotte, C., Mendes, S.L., Barata, P.C.R., 2010. Juvenile green turtles (*Chelonia mydas*) in the effluent discharge channel of a steel plant, Espírito Santo, Brazil, 2000–2006. J. Mar. Biol. Assoc. UK 90, 233–246.

Valentim, S.S., Bernardes, M.E.C., Dottori, M., Cortezi, M., 2013. Low-frequency physical variations in the coastal zone of Ubatuba, northern coast of São Paulo state, Brazil. Braz. J. Oceanogr. 61, 187–193.

Wallace, B.P., DiMatteo, A.D., Hurley, B.J., Finkbeiner, E.M., Bolten, A.B., Chaloupka, M.Y., Hutchinson, B.J., Abreu-Grobois, F.A., Amorocho, D., Bjorndal, K.A., Bourjea, J., Bowen, B.W., Dueñas, R.B., Casale, P., Choudhury, B.C., Costa, A., Dutton, P.H., Fallabrino, A., Girard, A., Girondot, M., Godfrey, M.H., Hamann, M., López-Mendilaharsu, M., Marcovaldi, M.A., Mortimer, J.A., Musick, J.A., Nel, R., Pilcher, N.J., Seminoff, J.A., Troëng, S., Witherington, B., Mast, R.B., 2010. Regional management units for marine turtles: a novel framework for prioritizing conservation and research across multiple scales. PLoS One 5, e15465.

Weber, S.B., Ellick, J., Avery, A., Frauenstein, R., Godley, B.J., Sim, J., Williams, N., Broderick, A.C., 2014. Recovery of the South Atlantic's largest green turtle nesting population. Biodivers. Conserv. 23, 3005–3018.

White, M., Boura, L., Venizelos, L., 2013. Population structure for sea turtles in Drini Bay: an important nearshore foraging and development habitat in Albania. Chelonian Conserv. Biol. 12, 283–292.

Yamamura, K., 1999. Transformation using (x + 0.5) to stabilize the variance of populations. Res. Popul. Ecol. 41, 229–234.

Ye, Y., Al-Husaini, M., Al-Baz, A., 2001. Use of generalized linear models to analyze catch rates having zero values: the Kuwait driftnet fishery. Fish. Res. 53, 151–168.