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First citizen-science population abundance and growth rate estimates for green sea turtles *Chelonia mydas* foraging in the northern Great Barrier Reef, Australia

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ABSTRACT: Embayments and coastal reefs of Queensland, Australia have supported some of the highest densities of green sea turtle *Chelonia mydas* foraging aggregations in the western Pacific Ocean. Since industrialization, many cumulative threats have negatively impacted these turtles with some Aboriginal communities concerned about notable reductions in local abundance and possible end to their customary hunting practice. Guided by collaborators, population trends, survivorship and somatic growth were monitored at a broadly representative inshore site in Edgecumbe Bay, Queensland, using a local citizen-science approach. The 12 yr time series of 1316 tagged turtles from 2003 to 2014 was analysed using Capture Mark Recapture (CMR) and Bayesian growth models. Models indicated the population comprised of 4392 individuals in 2014 and is rebuilding at 8.3% yr^{-1}. The data did not support more complex models with age or time-varied survivorship or recruitment. Overall survival (0.90 apparent survival yr^{-1}) and growth rate (1.20 cm yr^{-1}) were high compared to other green turtle populations globally. This study represents the first population modelling of green turtles foraging in inshore waters of the Great Barrier Reef and north-east Australia and will be an important proxy indicator for how other sites may be functioning. Although methodology and resource capacity should be carefully considered, this study demonstrates that citizen-science CMR studies can generate valid data to support replicable, robust statistical modelling and allow indigenous communities to sustainably manage and protect turtles on indigenous traditional Sea Country within Australia and worldwide.

KEY WORDS: Green sea turtles · Population abundance · Growth rate · Northern Great Barrier Reef · Citizen science · Indigenous and community groups

INTRODUCTION

Green sea turtle *Chelonia mydas* stocks are listed as vulnerable to extinction at international, national and state levels (Nature Conservation Act 1994 [Queensland], Environmental Protection and Biodiversity Conservation Act 1999 [Commonwealth], IUCN Red List 2016). The north Queensland coast of eastern Australia supports globally significant nesting and foraging habitat for the species. Green turtles in Queensland were historically harvested on nesting beaches to supply a demand for turtle soup in Europe during the 1800s. Green turtle slaughtering factories were established on several Great Barrier Reef (GBR) islands and within Moreton Bay in south-east Queensland and continued until the 1940s when insufficient numbers of nesting turtles remained to maintain a viable operation.

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Given their broad distributional range in various life history phases, coupled with high site fidelity to coastal shallow areas following recruitment to a foraging ground (Limpus 2009, Limpus et al. 2009, Hazel et al. 2013), there are many threats currently impacting the inshore populations of green turtles and their habitat along the Queensland coast, including within the GBR World Heritage Area. Two hundred years of native vegetation clearing for broadacre farming and industrialized agricultural practices have resulted in major rivers and streams carrying high sediment loads to inshore GBR waters during tropical wet-seasons (Great Barrier Reef Marine Park Authority 2014). These impacts have been exacerbated by severe cyclones, floods and storms that are predicted to increase in frequency with climate change (IPCC 2007). This in turn has led to a dramatic decline in coastal water quality and a concomitant degradation of seagrass foraging meadows, with flow-on effects to green turtle populations (Anonymous 2013, Brodie et al. 2014). Turtle health issues such as coccidiosis or fibropapillomatosis (FP) are thought to be an expression of poor water quality (George 1997, Aguirre & Lutz 2004, Van Houtan et al. 2014, Jones et al. 2016) and have been observed in some localized populations in the region (Brodie et al. 2014). There is evidence suggesting metal exposure is involved in the aetiology and development of FP, in impaired immune functions (Grillitsch & Schiesari 2010, da Silva et al. 2016) and as a contributing factor in mass strandings (Flint et al. 2014). Poor health (systemic disease, acute inflammation and liver dysfunction) from chemical exposure is an emerging issue where elevated trace element exposures in the region is thought to be adversely affecting the health of nearshore green turtles (Villa et al. 2016). Other threats include extensive urban and industrial development encroaching on nesting and foraging habitat, incidental catch in recreational and commercial fishing, egg predation by feral (e.g. foxes and pigs) and native animals (e.g. goannas) and unregulated, unsustainable harvest of adult female turtles and their eggs by coastal indigenous groups (Dobbs & Limpus 2006, 2009, Great Barrier Reef Marine Park Authority 2014). Australia is ranked as third highest in the world for the legal take of marine turtles (Humber et al. 2014). Hunting and sharing of traditional food, such as green turtles, is an important part of coastal indigenous culture, and a decline in local marine turtle populations may mean a need to change their customary hunting practice.

To better understand the effect that such threatening processes are having on green turtles and to attain reliable (and more rapid) population trends suitable for conservation management planning, it is necessary to sample the entire demographic structure of a foraging aggregation (Chaloupka & Limpus 2001, Bjorndal et al. 2003). Capture Mark Recapture (CMR) is the most reliable method of quantifying demographic parameters (such as abundance, survivorship, growth and recruitment) of wildlife (Williams et al. 2002). Obtaining robust data, however, is not always straightforward, as sampling needs to be ongoing and sufficiently intensive to ensure high capture and recapture probabilities (Pilcher & Chaloupka 2013). Sexually mature green turtles may migrate 100s or sometimes 1000s of km between feeding and nesting regions (Bolten & Balazs 1995) at irregular intervals, depending on environmental conditions, diet quality and availability (Solow et al. 2002, Rivalan et al. 2005). As multiple studies point out, the demographic composition of marine turtle populations and survival probabilities may vary greatly by sex and age class between foraging grounds (Bjorndal & Jackson 2003, Balazs & Chaloupka 2004, Chaloupka 2004, Campbell & Lagueux 2005, Chaloupka & Limpus 2005), depending on the impacts they are experiencing.

Detecting meaningful trend and demographic signals in a long-lived, slow-maturing species requires long-term sampling programs that can be difficult to sustain by the short-term funding cycles and shifting priorities that underpin academic and government research. Citizen science (or community-based monitoring) is increasingly being used worldwide as a means to engage local communities and ensure long-term data collection (Mumby et al. 1995, Pattengill-Semmens & Semmens 2003, Savan et al. 2003, Whitelaw et al. 2003 and references therein, Keough & Blahna 2006, Sultana & Abeyasekera 2008, Pilcher & Chaloupka 2013, Grech et al. 2014). Even so it is still considered underutilised in the marine environment due to logistics, safety, liabilities and expense (Cigliano et al. 2015). There is also ongoing debate over the use of citizen scientists for reasons including poor data quality, error due to the lack of familiarity with experimental design, inadequacy of training and lack of producing publishable data to inform decision-making (Mumby et al. 1995, Whitelaw et al. 2003, Conrad 2006, Conrad & Daoust 2008, Paulos 2009, Conrad & Hilchey 2011, Williams et al. 2015). Yet, citizen scientists are filling the void left by incomplete or under-resourced monitoring programs by professional scientists or government agencies (Stokes et al. 1990, Pollock & Whitelaw 2005, Conrad & Daoust 2008, Conrad & Hilchey 2011), and this approach offers a cost-effective alternative to monitoring by government employees (Whitelaw et al. 2003, Conrad & Daoust 2008). If scientists are involved in the project and are mindful of the community's ability, develop the appropriate methodology for the question posted, and assist in training and validating data collection, it can be a powerful monitoring tool. Locally based citizen science can also result in more rapid management intervention (Danielsen et al. 2009) with local support and pressure for action.

Recently within Australia, there has been a move towards the involvement and commitment of indigenous and community groups to manage local land and Sea Country (a term used by indigenous Australians and their association with in-land, coasts and the ocean). By marrying western science with indigenous knowledge, this study's aim was to build on the aspirations of Traditional Owners (Gudjuda Aboriginal Reference Group, near Bowen, and Girringun Aboriginal Corporation, near Cardwell, both in the northern GBR) to investigate the sustainable management of local green sea turtles in Edgecumbe Bay. Specifically, a long-term (12 yr) citizen-science CMR program was undertaken on a green turtle foraging aggregation within Edgecumbe Bay, north Queensland, to estimate (1) annual survival probability, (2) overall abundance and annual trend, (3) recapture probabilities and (4) somatic growth rates. Our citizen-science approach was primarily supported by local indigenous and community groups, not by profit organisations, universities and government agencies. This represents the first published analysis of the population dynamics of an inshore foraging ground of green turtles for the GBR (and within the coastal waters of north-east Australia).

MATERIALS AND METHODS

Study site

Edgecumbe Bay (20° 04′ S, 148° 21′ E), Queensland, Australia, lies within Gudjuda Reference Group Aboriginal Corporation's Sea Country, located near the township of Bowen in the central section of the GBR World Heritage Area (Fig. 1). The bay lies in a north–south orientation and is protected from the often strong prevailing south-easterly trade winds by a large offshore island, Gloucester Island. Approximately 20 km of intertidal (0–3 m deep) seagrass and algae meadows occur on a sand, rock and mud substrate. Intertidal flats extend for 800 m seaward from a predominately mangrove-fringed shoreline along the bay's western side. Fringing coral and algal reefs demark the seaward margin of the intertidal flats at which the seafloor rapidly drops to average depths of approximately 6 m throughout the bay.

Turtle capture and marking

Most of the foraging population of green turtles in Edgecumbe Bay are from the southern GBR and Coral Sea genetic stock (~85% of adults and 92% of juveniles, respectively), based on genetic assignment and recaptures of turtles tagged at nesting sites (Limpus et al. 2003, Jensen et al. 2016).

Green turtles were primarily captured on the algae and seagrass foraging meadows in the south-west area of Edgecumbe Bay (Fig. 1) between 1989 and 2014 using the standard turtle rodeo (boat or beach jumping) capture methods (Limpus & Reed 1985). Participating citizen scientists were trained in these techniques and on most trips overseen by at least 1 researcher or experienced collaborating partner. Catch effort was low whilst training and until 2003 when the CMR monitoring program was formally established, and was not undertaken in 2007 due to resource constraints. Sampling effort varied between years (Fig. 2), but the same area was searched each year during a common period (May–September) outside of the nesting season and when adults had returned to forage. After capture, tag numbers, curved carapace length (CCL, cm) and age class (CCL; 40–65 cm = juvenile, 65–85 cm = subadult, 85–120 cm = adult) were recorded, and unmarked turtles were tagged with a standard titanium turtle tag (Stockbrands) in a front flipper axillary tagging position (Limpus 1992), with 1 tag on each front flipper after subsequent recapture. Sampling was undertaken under Animal Ethics permit number SA 2015/11/531.

Estimates of population parameters and somatic growth rates

The CMR approach was used to estimate demographic parameters of population abundance, annual survival and recapture probabilities for the 12 yr period from 2003 to 2014. CMR models were fitted using RMark (Laake 2013), an interface to the program MARK (version 8, Cooch & White 2017) from the R statistical environment (R Core Team 2016).

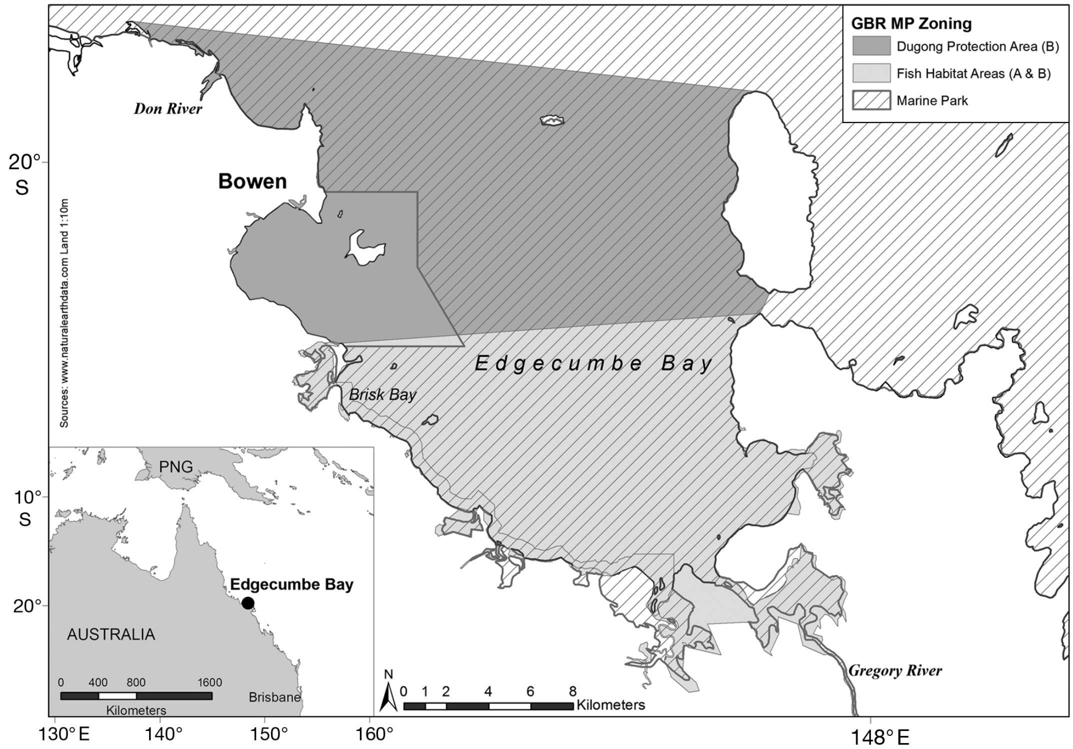

Fig. 1. Study site location of the green sea turtle foraging ground, Edgecumbe Bay, Queensland, Australia. Marine Protection (MP) zones of the northern Great Barrier Reef (GBR) are indicated. Foraging surveys were primarily concentrated in the western portion of the Bay, south of the township of Bowen to Brisk Bay, between the Don and Gregory Rivers.

There are a number of well-known assumptions inherent to this approach, which are addressed in Supplement 1 at www.int-res.com/articles/suppl/m574p181_supp.pdf. Because the number of sampling days varied between years (Fig. 2), we included the number of samplings days as a covariate for recapture probabilities.

Recapture probabilities of marked turtles were generally low within a sampling season; we therefore pooled samples within each year to give annual capture histories and analysed the data using Jolly-Seber (JS) recruitment models of population size and trend. The 'superpopulation' approach (POPAN) was used to estimate annual abundance, recapture probabilities and survival, and the temporal symmetry approach (Pradel λ) was used to estimate population trend (λ).

Even though survival and permanent emigration are confounded in JS analyses, green turtles on the GBR are known to have high fidelity to foraging grounds (Limpus 2009, Limpus et al. 2009, Hazel et al. 2013) and therefore apparent survival (Φ) is likely to be close to true survival. Similarly, estimates of the probability of entry (*b*) are likely to be close to true rates of recruitment because rates of transience are thought to be low for green turtles on GBR foraging grounds (Chaloupka & Limpus 2001).

We initially explored an initial set of 144 models addressing different effects of age and sex on survival and recapture probability (*p*) to find the best model fit. Model selection, screening and goodness-of-fit criteria are described in Supplement 2 at www.int-res.com/articles/suppl/m574p181_supp.pdf. Adult female survival was also modelled separately because it is a critical demographic measure of population viability (Caswell 2001, Chaloupka 2002). Although adult male survival is also important to the viability of green turtle populations, we did not have sufficient recapture rates to support separate models for adult males. Finally, the population trend was modelled with Pradel λ temporal symmetry models and used to estimate the per capita rate of population growth.

Growth rate on the foraging ground was modelled from longitudinal measurements of CCL using the von Bertalanffy growth curve and a hierarchical Bayesian model (Zhang et al. 2009, Eguchi et al. 2012). Growth data were first screened for unrealistic growth rates with measurements exceeding or shrinking by 5 cm yr^{-1} being discarded. Two models were compared using penalized deviance (Plummer

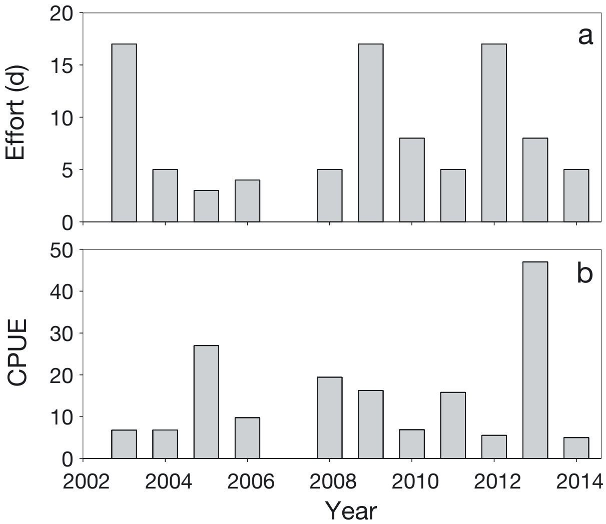

Fig. 2. (a) Number of days of sampling effort per year and (b) catch of green turtles per day of effort (catch per unit effort, CPUE)

2008). The first model treated the asymptotic length (L_∞) as fixed whereas the other model treated it as random (Zhang et al. 2009). The growth parameter (k) was treated as random in both models. We provide the median and 95% posterior intervals (PI) for the estimated parameters.

RESULTS

A total of 1316 green turtles were captured, tagged and included in the CMR analysis. Of these turtles, 11% were adult-sized females, 7% were adult-sized males, 1.7% indeterminant (adult unknown sex), 12.5% were subadult, and 68% juveniles (Fig. 3).

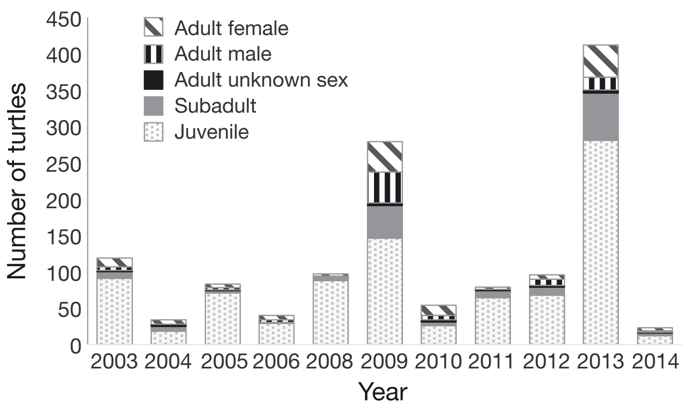

Fig. 3. Demographic composition of green sea turtles caught at Edgecumbe Bay, 2003–2014. Age classes: juvenile (40–65 cm curved carapace length, CCL), subadult (65–85 cm CCL) and adult (85–120 cm CCL)

Table 1. Real parameter estimates of apparent survival (Φ), recapture probabilities (p) and superpopulation size (N) of green sea turtles on the northern Great Barrier Reef for the POPAN model $\Phi \bullet p_{\text{effort}} b \bullet$ (where • denotes a constant parameter). LCI: 95% lower confidence interval limit, UCI: 95% upper confidence interval limit. The subscript for recapture probabilities denotes year

Parameter	Estimate	SE	LCI	UCI
$\Phi \bullet$	0.90	0.03	0.82	0.94
$b \bullet$	0.07	0.003	0.06	0.08
p_{2003}	0.06	0.01	0.04	0.08
p_{2004}	0.02	0.003	0.02	0.03
p_{2005}	0.02	0.003	0.02	0.03
p_{2006}	0.02	0.003	0.02	0.03
p_{2007}	0.02	0.002	0.01	0.02
p_{2008}	0.02	0.003	0.02	0.03
p_{2009}	0.06	0.01	0.04	0.08
p_{2010}	0.03	0.004	0.02	0.04
p_{2011}	0.06	0.01	0.04	0.08
p_{2012}	0.06	0.01	0.04	0.08
p_{2013}	0.03	0.004	0.02	0.04
p_{2014}	0.02	0.003	0.02	0.03
N	7896	706	6648	9428

The final POPAN model ($\Phi \bullet p_{\text{effort}} b \bullet$) assumed a constant apparent survival (Φ•, where • denotes a constant parameter), recapture probability that co-varied with sampling effort (p_{effort}) and a constant probability of entry (b•). This estimated an annual apparent survival of 0.90 (SE = 0.03, 95% CI = 0.82–0.94) and recapture probabilities from 0.02 to 0.06 (Table 1). The apparent survival of adult females was 0.94 (SE = 0.065, 95% CI = 0.64–0.99, n =

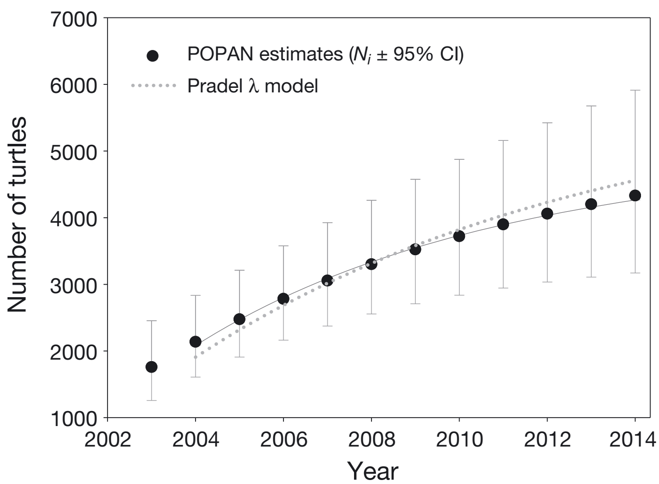

Fig. 4. Modelled population trend of green turtles in Edgecumbe Bay. Black circles are the annual estimates of abundance (N_i) for green turtles from the POPAN model (± 95% confidence intervals), and the solid line is the trend modelled by a nonlinear regression (refer to Supplement 2). The dotted line is the projected population growth from the Pradel λ model

134). The gross estimate of b was 588 turtles yr^{-1} (SE = 67.361, 95% CI = 456.781–720.839). Abundance of the foraging population was estimated to have increased from 1756 green turtles in 2003 to 4329 in 2014 (Fig. 4). The dampening of the population growth curve was caused by the combination of a high apparent survival rate and a constant probability of entry in the final POPAN model (Supplement 1).

The Pradel temporal symmetry model again assumed constant survival, constant recruitment and recapture probability that varied with sampling effort ($\Phi \bullet p_{effort}\, b \bullet \lambda$). The population growth rate from 2003 to 2014 (λ = 1.086, SE = 0.009, 95% CI = 1.068–1.103) (Fig. 4), equated to a per capita annual growth rate of 8.3% (95% CI = 6.6–9.8%).

The median positive growth rate was 1.20 cm yr^{-1}, ranging from −0.63 to 12.2 cm yr^{-1}. The model with fixed L_∞ indicated smaller penalized deviance than the other model. Therefore, we used it to make inference about the parameters. The median asymptotic length was 108.9 cm with its 95% PI of 106.2–112.2 cm. The median growth coefficient (k) was 0.039 with its 95% PI of 0.038–0.040.

DISCUSSION

The present study provides the first estimates of population dynamics of green turtles foraging in inshore waters on the northern GBR and demonstrates the potential of a citizen-science partnership to inform and develop local conservation management strategies for sea turtles. Such a monitoring program is important to provide a contemporary measure of the effect of threatening processes on inshore green turtle populations and to enable impact assessment of major coastal developments proposed along the GBR World Heritage Area.

To date, the only other peer-reviewed mark-recapture study of the demographics of green turtle foraging populations in the GBR region has been at the Heron-Wistari Reef complex in the southern GBR (Chaloupka & Limpus 2001). The population growth rate in our study (8.3% yr^{-1}, 95% CI = 6.6–9.8%, Fig. 4) was comparable to that of the previous Chaloupka & Limpus (2001) study (10.6% yr^{-1}), which was attributed to recovery from historical over-exploitation. Nesting census data from southern GBR green turtle index sites also suggest a rebuilding population, but with a slower rate of increase at ~3% yr^{-1} (Chaloupka & Limpus 2001, Chaloupka et al. 2008, Limpus et al. 2013). This discrepancy between the rate of increase at nesting sites compared to foraging populations could have a number of explanations, such as the time delay before the population growth evident at foraging sites translates into recruitment to nesting sites (green turtles first breed at 25–50 yr of age, Limpus 2009) or lower survival at other foraging grounds that contribute to the same nesting grounds. Environmental and biotic factors, as well as the localised threats connected to climatic change contributing to the selection of nesting grounds (as described in Mazaris et al. 2015), could also be a driver of recruitment variability, but would require further investigation at a regional scale.

Average apparent survival in our study was high and similar to other green turtle populations (Chaloupka & Limpus 2005), with an apparent survival of 0.94 for adult females (95% CI = 0.64–0.99). Somatic growth of green turtles in our study was also comparable to other foraging populations in tropical and temperate regions (e.g. <2.2 cm yr^{-1}, Limpus & Chaloupka 1997; <3.4 cm yr^{-1}, Seminoff et al. 2002; <3.5 cm yr^{-1}, Chaloupka et al. 2004; <3.0 cm yr^{-1}, Koch et al. 2007; <3.1 cm yr^{-1} (mean), López-Castro et al. 2010). The estimated growth coefficient parameter of the von Bertalanffy growth function was 0.039, which was within the range of those reported for other foraging areas of Bahía Magdalena, Mexico (0.04; Koch et al. 2007) and coastal waters along the southeastern USA (0.02, 95% CI = 0.01–0.03; Goshe et al. 2010).

Because of the low recapture probability and the large variation in catch per unit effort between years (Fig. 2), we were unable to fit more complex models that allowed recruitment or mortality to vary over time. Variability in foraging-ground recruitment arises from the complex life history of green turtles with multiple rookeries contributing recruits to a foraging ground (Jensen et al. 2016), high variability in the number of females nesting between years (Limpus & Nicholls 2000, Chaloupka et al. 2008) and a prolonged pelagic dispersal phase (Limpus 2009). Mortality is also likely to vary between years, as exemplified by the record numbers of green turtles that stranded in the region in summer 2010–11 (Meager & Limpus 2012). This was attributed to widespread and severe flooding in eastern Australia associated with a strong La Niña event and a very large tropical cyclone (Yasi) that crossed the coast in northern Queensland (Meager & Limpus 2012, 2014), with subsequent declines of seagrass pastures in and adjacent to Edgecumbe Bay (Rasheed et al. 2014) resulting in subsequent starvation of green turtles and loss of turtles with FP (E. Ariel et al. unpubl.).

With time-varying models, the population parameter estimates would have been more biologically realistic and possibly more informative on the response of the population to perturbations. The issues of low recapture probability are likely to be because either the sampling intensity was too low for the area and size of the population or because the sampling design somehow induced 'temporary emigration' whereby not all turtles were available to be caught on each occasion. The results may have also been influenced by the fact that tag returns from hunting were not recorded. It is recommended that such data are collected in the future and analysed appropriately (e.g. with mark-recovery models).

A further issue for estimating sex and age-specific parameters was that sex and age class was not recorded for every individual in our study. Even though there were no sex-specific differences in survival or recapture probabilities for any of the life history stages of the population modelled at the Heron-Wistari Reef complex (Chaloupka & Limpus 1997), age class-specific differences in recapture probabilities or survival can be expected (Chaloupka & Limpus 1997). Overall demographic composition (Fig. 3) of turtles foraging in a particular area can provide insight into the local and regional population dynamics and assist with assignments of status (Hamann et al. 2006) where trends are not apparent from CMR modelling. In comparison to other demographic studies (Limpus & Reed 1985, Limpus et al. 1994, Whiting 2002, Hamann et al. 2006) the Edgecumbe bay size-class distribution is similar to that reported for green turtles from Moreton Bay (Limpus et al. 1994) and Fog Bay in the Northern Territory (Whiting 2002). The higher number of immature turtles and few adults found in this study is different to the distribution found in the Heron-Wistari Reef complex (Limpus & Reed 1995) to which these CMR studies are primarily compared (Chaloupka & Limpus 2001). Size-class distribution of green turtles in foraging areas has been observed to differ between sites presumably because of a combination of ontogenetic shifts in food and/or habitat requirements as well as the level or selectivity by size of use (Limpus et al. 1994, Hamann et al. 2006). Although tools such as laparoscopy and hormone analyses are not available to citizen scientists, further training to assess sex by external measurements and the importance of complying with the search methodology (in that if a turtle was seen, it was chased until it was either captured or lost without regard to size; as per Limpus & Reed 1985, Limpus et al. 1994) is required.

Nevertheless, the present study found that, despite the extreme stranding event of 2010–11, following episodic severe weather events and a prevalence of FP, the coastal population has been increasing over the long term with high annual survivorship. As in other turtle populations globally, the FP virus recorded at Edgecumbe Bay is not considered to be impacting negatively on population viability (Alfaro-Núñez et al. 2014, Jones et al. 2016). The enduring effect of the 2010–11 stranding rates and other cumulative or climatic threats impacting on the local green turtle population in Edgecumbe Bay can only be detected with a higher probability of recapture and long-term monitoring. In order to achieve this, there is a need to further guide and build quality assurance into citizen science in survey design, data collection and data analysis.

Similar to 2 peer-reviewed citizen-science studies on marine turtles that we are aware of (Pilcher & Chaloupka 2013, Williams et al. 2015), this project incorporated non-specialist members of the public as 'citizen scientists', both as a stewardship/outreach tool and as a cost-effective monitoring strategy for specialist researchers. Although professional science may not embrace citizen-science data as usable, the potential of citizen science will not be fully realized if citizen-science data do not reach the peer-reviewed scientific literature (Theobald et al. 2015). Using models of scientific research, and accounting for the capacity and skills of the indigenous and community group data collectors (Shirk et al. 2012, van Strien et al. 2013), to the best of our knowledge, this study offers the first published citizen-science marine turtle CMR population trend and analysis in north-east Australia.

Because of the inability of the dataset to support more complex models, it is acknowledged that future methodology, training and governance structure to deliver the project could be improved and outlines the commitment required to undertake a carefully designed turtle monitoring program. Nevertheless, as a result of this project, Gudjuda and Girringun Aboriginal groups are now trained in the principles of turtle research methods and in data collection, which has built capacity and helped raise awareness about marine turtles and their habitat. As a core part of their work program, they also now engage junior rangers and promote their turtle research work through education. This project has provided the Gudjuda and Girringun Traditional Owners with an important ownership role in managing and protecting marine turtles on their traditional Sea Country.

Edgecumbe Bay is likely to be typical of other north-facing Great Barrier Reef coastal foraging habitats, and the population trend may be able to be used as a proxy indicator of how other inshore sites may be functioning. But this must be cautioned, as local green turtle foraging populations face different localised impacts. Further, the response of green turtle populations to many anthropogenic threats remains unclear, including the impacts of climate change at foraging grounds and population wide response to climatic niches (Dewald & Pike 2013, Fuentes et al. 2013, Mazaris et al. 2015, Almpanidou et al. 2016). As no other coastal mainland green turtle populations have been modelled for comparison, localised impacts and the effects to climatic niches remain a key gap in our understanding. The ideal situation would include comparable monitoring of a range of coastal populations facing varying levels of anthropogenic threats and assessing future climatic vulnerability on a stock-by-stock basis. To discern impacts (or long-term recovery) to environmental perturbations or other anthropogenic threats, future demographic studies of foraging green turtles in Edgecumbe Bay, and any other foraging population in Australia or globally, should also consider an integrated approach that includes environmental monitoring, CMR, health assessment and necropsies of stranded turtles.

CONCLUSIONS

Of the range of approaches commonly used to estimate marine turtle population abundance, such as nesting beach censuses, catch per unit effort from fisheries, transect sampling and CMR (Chaloupka 2000, Whiting et al. 2014), most are based on seasonal nesting when turtles are most accessible to researchers or citizen scientists. However, in order to assess the long-term viability of population or to diagnose demographic trends before they are realised at nesting beaches, it is also important to collect demographic data on foraging grounds (Chaloupka 2000). In our study, we show that a citizen-science approach can yield valuable demographic data for a foraging population in a timely manner crucial for understanding the long-term viability of the local marine turtle population. This study will be used to develop management strategies by Traditional Owners and government agencies including the Great Barrier Reef Marine Park Authority and Queensland Department of Environment Heritage Protection. A more detailed understanding of the marine resources in the bay will also provide benefits to all users of the Great Barrier Reef Marine Park about the conservation status of green turtle populations and local movement of individuals within this ecosystem.

The Gudjuda Aboriginal people have instituted a self-imposed moratorium on hunting dugong and a permit system to manage turtle take for traditional ceremonial purposes only. Rangers from the Gudjuda Aboriginal Reference Group are now well placed to continue the population monitoring study, and take sole responsibility for data collection and decision making contributing to the management of their Sea Country into the future. Although scientist collaboration will be required for analyses given the complexity and assumptions inherent to CMR modelling, this project provides a good example of collaboration with the use of a citizen-science approach which could be replicated and modelled in other dedicated communities both in Australia and worldwide.

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