Important foraging areas of seabirds from Anguilla, Caribbean: Implications for marine spatial planning

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ABSTRACT

Marine spatial planning (MSP) has become an important tool to balance the needs of commercial, economical and recreational users of the marine environment with the protection of marine biodiversity. BirdLife International advocate the designation of marine Important Bird Areas (IBAs) as a key tool to improve the protection and sustainable management of the oceans, including the designation of Marine Protected Areas, which can feed into MSP processes. This study presents the results of three years of seabird tracking from the UK Overseas Territory of Anguilla, where marine resources are currently relatively unexploited and MSP is in its infancy. The core foraging areas of 1326 foraging trips from 238 individuals, representing five species (brown booby *Sula leucogaster*, masked booby *Sula dactylatra*, sooty tern *Onychoprion fuscatus*, magnificent frigatebird *Fregata magnificens* and red-billed tropicbird *Phaethon aethereus*) breeding on three of Anguilla's offshore cays were used to calculate the hotspot foraging areas for each study species. These high activity areas were then compared with fishing activity within Anguilla's Exclusive Economic zone and to proposed coastal developments. Two marine IBAs were identified within Anguilla's waters: the first to be defined, using seabird tracking data, in the Caribbean region. Whilst the level of fishing activity and associated seabird by-catch is hard to quantify, the core foraging areas of seabirds breeding in Anguilla were observed to overlap with areas known for high fishing activity. These findings highlight the need to work both nationally and across territorial boundaries to implement appropriate marine spatial planning.

1. Introduction

The marine environment supports a range of activities such as mineral extraction, shipping and energy production, large and small-scale fisheries and aquaculture as well as providing many people with recreational opportunities [1,2]. Marine ecosystems also represent a vast biodiversity resource and their commercial exploration raises the concern of conservationists, who have been working in close collaboration with the relevant authorities to designate Marine Protected Areas (MPAs). Marine Spatial Planning (MSP) is a mechanism that brings together multiple users to make informed and coordinated decisions on how to use marine

resources in a sustainable way [3,4] and is used to reduce conflict between stakeholders. Areas where fishing and/or recreational activities are limited or excluded, such as within MPAs, have proven to be effective tools within the MSP process for the conservation management of marine species and the promotion of sustainable livelihoods [5–7].

It is, however, often a challenge to predict and define what activities should be allowed or restricted in any particular marine area. A further difficulty in the designation of marine protected areas is that much of the biodiversity that uses the marine environment is inconspicuous to humans, often requiring expensive high-tech equipment to monitor [8,9]. In addition, marine species that demand protection tend to also be highly migratory [10]. The use of seabirds to inform marine spatial planning has been tried and tested [11] with both at-sea survey data [12] and tracking data being used to map areas of high seabird species richness [13,14]. Such areas, in turn, are likely to represent key marine habitats or

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important sites where fish congregate [15]. These results have then led to recommendations in the designation of marine protected areas and in the demarcation of marine area zones [12,16,17].

Several approaches exist to predict seabird distribution around colonies from the sea-ward extension approach which defines a mean and a maximum foraging radii around a colony based upon previously recorded foraging radii of the species or closely related species [18]. Predictive modelling has also been implemented around colonies using habitat and bathymetry preferences of seabird species. If enough information is known about the foraging ecology of a species this approach can predict foraging hotspots in the absence of any tracking or at sea survey data [19]. The application, however, of actual at-sea movement through boat/aerial based transects around the colony [20] or collection of tracking data provides more accurate and reflective data to allow marine Important Bird Area (IBA) designation. A range of methods have been implemented to allow researchers to use tracking data to identify important foraging areas for central place foragers, from kernel density methods [21] to time in grid approaches [22,23].

Birdlife International has recognised that, in the face of a proliferation of analytical and modelling approaches, there are advantages in having a standardised approach to designating important at-sea areas for seabirds. Since 2004, the Birdlife Global Marine Programme has designated these areas in the form of marine IBAs. Marine IBAs sit alongside terrestrial IBAs, which Birdlife International has been advocating since 1981. Terrestrial IBAs support important breeding populations, range restricted species, or congregations of migrating/wintering birds. The IBA designation helps to set priorities and focuses action for conservation. To date, BirdLife International has identified over 12,000 terrestrial IBAs globally, of which 1600 have been identified due to their important breeding seabird populations. Seabirds, however, spend the majority of their time at sea and most rely entirely on marine resources for prey, thus whilst terrestrial IBA designation may help protect breeding sites, the important foraging grounds of colonies are often overlooked. The new marine IBA designation is an effort to combat this problem. It is anticipated that these marine IBAs will make a vital contribution to initiatives aimed at improved protection and sustainable management of the oceans, including the designation of MPAs [24]. The optimal approach for designation is through the use of colony-specific empirical data from seabird tracking and a repeatable analytical framework has recently been described [25].

The UK Overseas Territory of Anguilla is located in the north-west region of the Caribbean's Lesser Antillean chain of islands (Fig. 1). Whilst mainland Anguilla lacks any large breeding seabird colonies its offshore cays excel in this area [26,27], with four out of its seven cays designated as terrestrial IBAs due to their important seabird populations [28], and one, Dog Island, representing the most important site for seabirds in the Lesser Antilles (based on number of globally important populations and breeding numbers) [26,29]. Five seabird populations breeding in Anguilla have also been designated as globally important and 12 as regionally important due to their breeding numbers representing > 1% of the global or regional population, respectively [28].

The threats facing Anguilla's seabird populations range from negative interactions with fisheries to coastal development. Anguilla has a relatively small artisanal fishing fleet contributing 1.8% to Anguilla's GDP in 2010, composed of approximately 105 vessels with the majority being open vessels (canoe-like) ranging from 4 to 15 m in length, with 87% being 5–11 m vessels. This industry directly employs approximately 234–300 fishers, with 60% of these reporting to be part-time fishers [30]. In 2015, it was estimated that 59 vessels were using fishing methods that have previously been reported to be a cause of seabird by-catch, including use of hand lines, trolling, and vertical long-lining (Table 1) [31,32] There
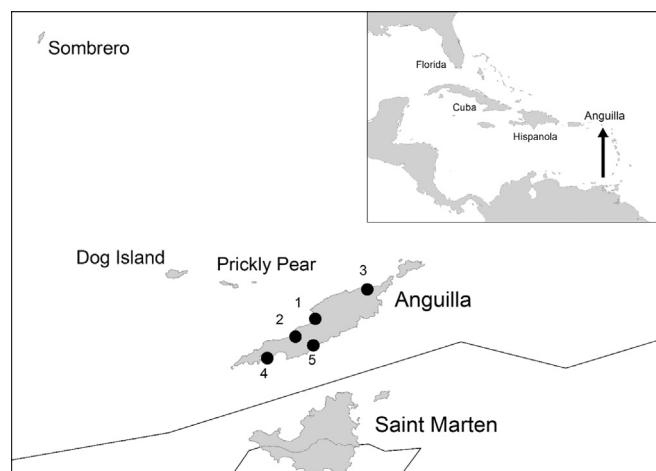

Fig. 1. Map of Anguilla mainland and offshore cays and location of fishing villages (black circles). Insert map showing location of Anguilla.

Table 1
Estimated number of fishing boats in Anguilla using fishing methods that have previously reported seabird by-catch. (Fishing village locations can be seen in Fig. 1) (Data [30]).

Fishing method	Estimated number of boats/fishing ports					
	Cove Bay (1)	Sandy Ground (2)	Island Harbour (3)	Crocus Bay (4)	Blowing Point (5)	Totals
Trolling	0	4	10	0	1	15
Handlines	4	6	15	4	8	37
Vertical longlines	0	2	5	0	0	7

is also an increasing number of charter operators in Anguilla offering angling trips for tourists. Sports-fishing is also popular in the nearby British Virgin Islands (140 km from Anguilla) and Sint Maarten/Saint Martin (13 km from Anguilla). *Ad hoc* reports to the Anguilla National Trust from charter angling boats reveal that birds are occasionally caught on hooks and lines and small amounts of fishing line have been recorded in the magnificent frigatebird colony on Dog Island. There is also a Memorandum of Understanding (MOU) currently in place between the Government of Anguilla and private investors allowing for the development of marinas suitable for mega-yachts (yachts longer than 40 m) on the southern coastlines of Anguilla and one project proposal for a further marine development on the north-west coast, thus likely increasing boat traffic to Anguilla and potentially increasing recreational fishing effort and pollution.

This study uses tracking data collected from both globally and regionally important seabird populations breeding on Anguilla's offshore cays to identify important foraging areas within and around the territory. Identified foraging areas were also related to potential threats including fishing activity and potential marina development around Anguilla's coastline. Since both MSP and marine resource exploitation are in their infancy for this territory, Anguilla provides an ideal opportunity to integrate biodiversity requirements into marine plans before catastrophic interactions occur. A new approach for defining marine Important Bird Areas was tested, these methods developed by BirdLife International use freely available R statistical software [25]. The identification of important foraging areas for Anguilla's seabird populations will allow policy makers to make informed decisions on marine protected area designation within Anguilla's Exclusive Economic Zone.

2. Materials and methods

2.1. Field methods

GPS tracking data was collected between 2012 and 2014 from five seabird species (magnificent frigatebird *Fregata magnificens*; brown booby *Sula leucogaster*; masked booby *Sula dactylatra*; sooty tern *Onychoprion fuscatus*; and red-billed tropicbird *Phaethon aethereus)* breeding on three of Anguilla's designated IBAs: Dog Island (18.27°N, 63.25°W), Sombrero (18.58°N, 63.42°W) and Prickly Pear West (18.26°N, 63.18°W). Loggers were attached to the central tail feathers of all birds using TESA tape [33]. This method of attachment was used to ensure loggers would fall off the birds within a few weeks if we failed to recapture them to retrieve the loggers. IgotU loggers (Mobile Action, Taiwan) were attached to brown booby, masked booby, magnificent frigatebirds and red-billed tropicbirds and set to record a position every 2 min; nanofix loggers (Pathtrack, UK) were attached to sooty terns and red-billed tropicbirds and set to record a position every 30 min, whilst re-mote download loggers set to record a position every 20 mins (Pathtrack, UK) were trialled on magnificent frigatebirds. GPS loggers weighed under 3% of the body weight of any bird [34]. Birds were caught at their nest with either a crooked pole or hand-held net and logger deployment and retrieval took no longer than 15 min for any bird. With the exception of 12 brown boobies that were tracked when incubating eggs, all tracking work was conducted on chick-rearing individuals to reduce the risk of predation of eggs and nest desertion. Furthermore, this meant that we targeted populations at the most crucial time of year when they are foraging for themselves and their chicks, and restricted to waters relatively close to their colonies. Depending on the capability of the GPS device, birds were tracked from 1 to 14 days. Data collected from different seasons and years have been pooled for analysis.

2.2. Analytical methods

R statistical software (R Statistical Core Team 2012) [35] was used to apply the BirdLife International's *marine IBA* package [25]. This approach uses seabird tracking data to identify geographic areas most intensively used by a certain population, using Kernel Density Estimation methods [21]. The first step is to identify core foraging areas based on a 50% utilisation distribution for each foraging trip. These core foraging areas are then overlaid to identify the proportion of overlap between the core foraging areas of all trips from each seabird population. The repeatability of an individual's foraging trips and the data's representativeness of the foraging areas of the whole population is also assessed using bootstrap resampling methods. The output value of sample re-presentativeness is then applied to highlight "high activity threshold areas" for the whole population. Birdlife International define these based on a balance of representativeness and usage rates (25). For example if the tracking sample's representativeness is calculated as 90%, an area used by more than 10% of the sampled population will be highlighted as "high activity threshold area". If this analysis identifies high activity threshold areas for globally important breeding populations, then these areas qualify as in-ternationally recognised marine IBAs (http://maps.birdlife.org/marineIBAs/). If high activity threshold areas were identified for regionally important breeding populations, then these areas can be considered regionally important foraging areas.

The core foraging areas and high activity threshold areas de-termined for each population were mapped in Arcmap 10.0 (ESRI computing, Vienna) and overlaid with maps of the Exclusive Economic Zone of Anguilla and neighbouring islands (downloaded from www.marineregions.org), along with the existing marine parks and Ramsar sites of Anguilla. High activity threshold areas were compared visually between populations of the same species breeding on different cays and populations of different species breeding on the same cay as a preliminary assessment of inter- and intra- specific competition.

In addition, the Government of Anguilla's Department of Fisheries and Marine Resources (DFMR) were asked to identify frequently visited fishing areas within Anguilla's 104,113 km^2 Exclusive Economic Zone (EEZ) where fishing is permitted. The three sites where plans for the development of yacht marinas were also identified and mapped using Arcmap,.

3. Results

3.1. Tracking data

1326 foraging tracks were successfully recorded (Table 2).

Table 2

Deployment details for the study species. Population size reported was recorded at the time of tracking. * indicates globally important breeding populations (i.e., > 1% of the world population of the species), **indicates a regionally important population (i.e., > 1% of the Caribbean population of the species).

Species	Island	Month	Population size (breeding pairs)	Year	No of loggers deployed	No of loggers retrieved	Logger used
Brown booby	Dog Island*	April	1231	2012	20	19	IGOTU
	Dog Island	Nov	1518	2013	49	42	IGOTU
	Dog Island	February		2014	10	9	IGOTU
	Dog Island	March		2014	18	11	IGOTU
	Dog Island	Nov	1482	2014	45	32	IGOTU
	Prickly Pear West**	Nov	185	2013	49	32	IGOTU
	Prickly Pear West	Oct	520	2014	28	11	IGOTU
	Sombrero	June	724	2014	25	21	IGOTU
Masked booby	Sombrero**	June	293	2014	32	19	IGOTU
	Dog Island**	October	47	2014	33	17	IGOTU
Sooty tern	Dog Island*	June	155,000	2014	20	11	Pathtrack Nanologger
Magnificent frigatebird	Dog Island**	March	518	2014	12	2	IGOTU
					1	N/A	Pathtrack remote download logger
	Dog Island	Jan		2015	11	1	IGOTU
					1	N/A	Pathtrack remote download logger
Red-billed tropicbird	Dog Island*	Feb	66	2014	9	4	IGOTU
					4	2	Pathtrack nano-logger

Table 3
Mean (± Standard error) foraging trip characteristics for each of the study species populations breeding on each of the study cays.

Species	Year	Number of foraging trips	Maximum distance from colony (km)	Total trip length (km)	Total trip duration (hh:mm)
Brown booby					
Dog Island	2012	95	48.3 (± 2.1)	129.0 (± 5.1)	05:30 (± 00:31)
	2013	240	44.8 (± 1.6)	116.8 (± 4.4)	06:40 (± 00:22)
	2014	265	39.7 (± 1.5)	100.1 (± 3.9)	05:54 (± 00:17)
Sombrero	2014	103	28.5 (± 6.1)	78.3 (± 2.4)	04:40 (± 00:18)
Prickly Pear West	2013	243	46.2 (± 1.6)	105.6 (± 3.9)	05:30 (± 00:27)
	2014	60	30.3 (± 2.9)	72.5 (± 7.1)	04:55 (± 00:26)
Masked booby					
Dog Island	2014	124	20.8 (± 1.1)	49.8 (± 2.24)	02:59 (± 00:10)
Sombrero	2014	163	27.0 (± 3.6)	72.5 (± 1.2)	03:40(± 00:10)
Sooty tern					
Dog Island	2014	8	95 (± 13)	215 (± 25)	12:35 (± 01:51)
Magnificent frigatebird					
Dog Island	2014	8	310 (± 37.5)	115.8 (± 14.4)	28:18 (± 04.12)
	2015	12	202.2 (± 48.0)	59.4 (± 12.2)	14:21 (± 03:50)
Red-billed tropicbird					
Dog Island	2014	5	179.5 (± 56.8)	68.5 (± 24.0)	21:17 (± 08:49)

Mean maximum foraging ranges ranged from 20.8 km (masked booby) to 310 km (magnificent frigatebird) (Table 3), whilst mean foraging trip duration ranged from 02:59 h (masked booby) to 28:19 h (magnificent frigatebird). Foraging trip site fidelity was only found to be significant for masked boobies breeding on Sombrero, as such for this population only one foraging trip per individual was used for further analysis to avoid pseudoreplication (Appendix). While predominately distributed within Anguilla's EEZ, the core foraging areas of all species were also distributed in the EEZ's of neighbouring islands, including Sint Maarten/Saint Martin, Saint Barthelemy, Saba, Saint Eustatius, Saint Kitts and Nevis, and both the British and US Virgin Islands (Fig. 2).

The representativeness of our tracking samples of the whole population ranged from 41 to 98% (Appendix). For red-billed tropicbirds, magnificent frigatebirds and sooty terns the data representativeness was insufficient (< 70%) to determine high activity threshold areas. For all other populations the presence of 10–20% of overlapping core foraging area polygons was used to represent high activity threshold areas (Appendix). All high activity threshold areas were located in Anguilla's EEZ (Fig. 1a, f, g and h) with the exception of the population of masked boobies breeding on Dog Island, where this area also extended into Saint Marten's EEZ (Fig. 2b). High activity threshold areas were identified for the globally important breeding populations of brown boobies breeding on Dog Island and Sombrero, thus these areas represent internationally recognised marine IBAs (Fig. 3a). In addition high activity threshold areas were identified for the regionally important breeding populations of masked boobies on Dog Island and Sombrero and brown boobies on Prickly Pear West, thus these areas represent regionally important foraging areas (Fig. 3(b)).

High activity threshold areas of brown boobies breeding on Sombrero, Dog Island, and Prickly Pear West did not overlap (Fig. 3a). Similarly, the high activity threshold areas of masked boobies breeding on Sombrero and Dog Island did not overlap (Fig. 3b). The core foraging areas and high activity threshold areas, however, of masked boobies and brown boobies breeding on Dog Island did overlap (Figs. 3 and 4).

3.2. Identification of threats

Anguilla's DFMR identified the channel between Dog Island and Prickly Pear West and the area North of Dog Island as the most reported and observed fishing area for fishermen using hand-lines, trolling and vertical long-lines, with one trawling boat frequently fishing using hook and line (and very occasionally long-line) between Dog Island and Sombrero and north of Sombrero (Fig. 3). The marine IBA candidate areas and regionally important foraging areas of all populations were found to overlap with these most frequented fishing areas. None of the high activity threshold areas overlapped with potential marina development sites or their nearby waters (Fig. 4). The high activity threshold areas for masked boobies and brown boobies breeding on Sombrero encompassed and extended beyond the Sombrero Ramsar site, whilst the high activity threshold areas for brown boobies breeding on Prickly Pear West overlapped with two existing Marine Parks (Fig. 4). There was no overlap between the identified high activity threshold areas for masked boobies on Dog Island nor the high activity threshold (and internationally recognised marine Important Bird Area) of brown boobies on Dog Island with existing marine parks (Fig. 4).

4. Discussion

4.1. Tracking data

This study tracked 238 individual seabirds representing five species and colonies breeding on three of Anguilla's offshore cays over a three year period. It is well reported that the foraging areas of seabirds change according to the year of study and stage of breeding [23]. As such, this study assessed the representativeness of sample sizes using BirdLife International's marine IBA script [25]. Whilst for some species (red-billed tropicbirds, magnificent frigatebirds, and sooty terns) our sample size was limited (less than eight birds), and due to logistical difficulties some were only tracked over one season and during chick-rearing, the representativeness of our tracking data ranged from 41 to 98%, indicating that for five of the eight tracked populations, we have
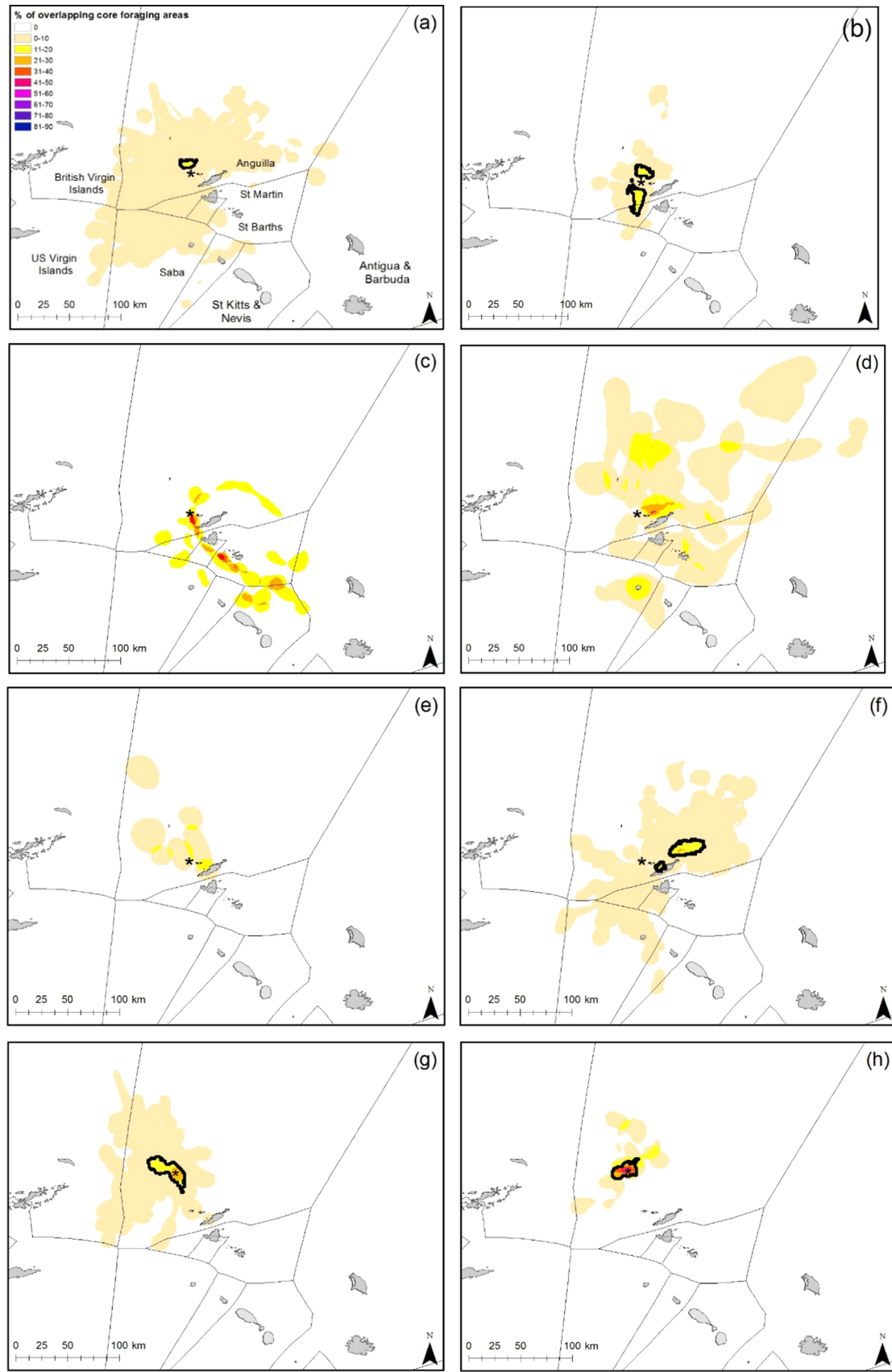
Fig. 2. Maps representing the percentage of overlapping core foraging areas for Dog Island's (a) brown booby (b) masked booby (c) sooty tern (d) magnificent frigatebird (e) red-billed tropicbird (f) brown booby from Prickly Pear West (g) brown booby from Sombrero (h) masked booby from Sombrero. Highlighted black areas represent high activity threshold areas (see Appendix). Grey lines represent the EEZ boundaries.
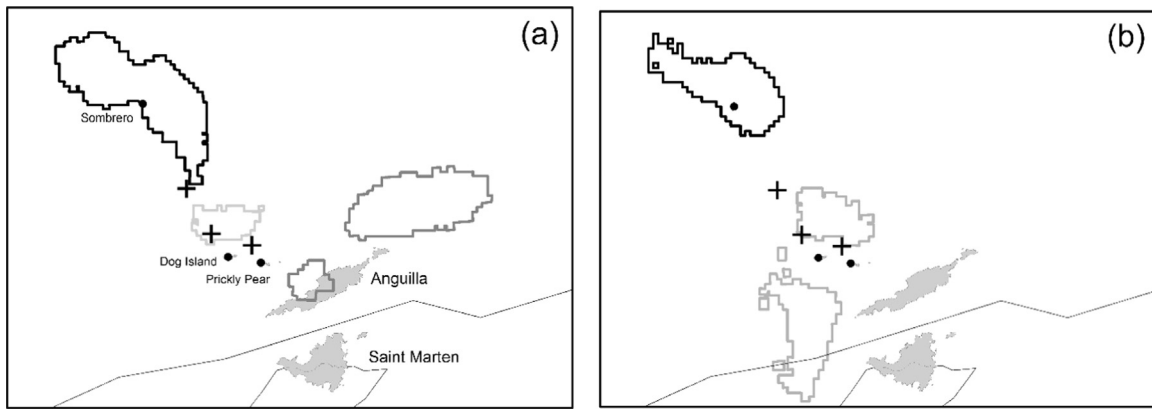
Fig. 3. (a) Map showing high activity thresholds for brown boobies breeding on Sombrero (black), Dog Island (light grey), Prickly Pear West (mid grey) (colonies represented by black circle), (b) high activity thresholds for masked boobies breeding on Sombrero (black) & Dog Island. Black crosses represent the approximate areas of high fishing effort in Anguilla.
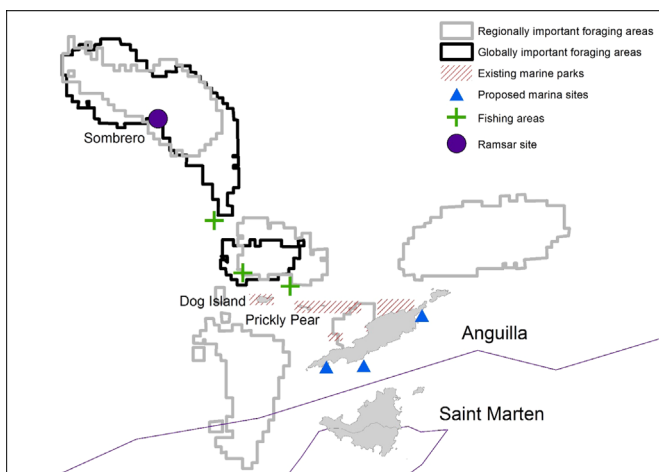
Fig. 4. High activity threshold areas for globally and regionally important seabird populations overlaid with Anguilla's existing marine parks, Ramsar site, most frequented fishing zones and Exclusive Economic Zone.

identified a good proportion of their main foraging areas.

This study identified the first marine IBAs in Anguilla for the globally important populations of brown boobies breeding on Dog Island and Sombrero. In addition, three regionally important foraging areas were identified for masked boobies breeding on Dog Island and Sombrero and brown boobies breeding on Prickly Pear West. These designations will be useful to integrate into future marine spatial planning in Anguilla and the region.

Whilst the core foraging areas of all seabird populations overlapped with the EEZ's of neighbouring islands, the identified high activity threshold areas for the populations of brown and masked boobies were predominately located within Anguilla's own EEZ. This result highlights the importance of implementing adequate protection and conservation measures in Anguilla's waters to ensure the preservation of globally and regionally important seabird populations that breed on Anguilla's offshore cays. In addition, for all species, it will be important to work with neighbouring islands to highlight important foraging areas outside of Anguilla's EEZ [2,36].

Our tracking data revealed inter-specific differences in the foraging behaviour of seabirds breeding in Anguilla with magnificent frigatebirds and red-billed tropicbirds travelling furthest from the colony (Table 3). The foraging ranges of magnificent frigatebirds are similar to those previously reported for this species in a nearby colony, located in British Virgin Islands [37] No previous reports of the GPS tracking of red-billed tropicbirds exist.

Masked boobies travelled the shortest distances and spent less time foraging than brown boobies at cays where they were both tracked. Our results revealed very little overlap between the high activity threshold areas of brown boobies tracked from three different cays and of masked boobies from two different cays. A similar pattern of foraging segregation among neighbouring populations was found in a closely related species, the northern gannet *Morus bassanus* [38] and likely reflects a strategy to decrease intraspecific competition. In contrast, different species (including the closely related brown and masked booby species) foraged in similar areas when breeding on the same cay. It is likely, however, that some niche partitioning (probably related with diet, or small-scale foraging behaviour) occurs between these species around the colony [39,40].

4.2. Threats

In 1993, the Government of Anguilla established a network of marine parks in an effort to protect fragile coral reef and seagrass beds from boat anchor damage, water skiing activities, and other destructive practices such as the discharging of pollutants from boats. The total area of marine parks in Anguilla equates to 40 km^2 of Anguilla's 104,113 km^2 EEZ (less than 0.04% of total area). Due to logistical and financial limitations, there are difficulties in enforcing the restrictions to activities in these areas or to implement any further protective measures. It is currently not known what impact the local small-scale fishery has on Anguilla's seabird populations, although other small-scale artisanal fisheries have been reported as being a significant problem elsewhere [41,42]. Fishing methods that reduce the potential risk of fisheries by-catch from hand-line, trolling and vertical long-lines should be encouraged, including faster sinking bait and bird scarers [43,44]. Since fishing activities apparently take place in the high activity threshold areas of Anguilla's seabirds (Fig. 3), implementation of these methods should be used as a precautionary measure in the absence of data on the level of the threat.

5. Conclusions

There is clearly a range of stakeholders already using or interested in Anguilla's marine environment, ranging from different types of commercial fishers, recreational users engaging in activities such as water sports and charter angling, conservationists who are interested in preserving the important biodiversity, to potential developers of mega yacht marinas. With this large number of stakeholders, there is potential for conflict in uses of

Anguilla's waters, particularly with regard to protecting the biodiversity value of Anguilla's marine environment. Policy makers in Anguilla have already recognised the importance of protecting marine habitats in the form of marine parks. The designation of Anguilla's first Ramsar site in 2015 has also highlighted Anguilla's commitment to recognising and protecting marine biodiversity. The identification of two new marine Important Bird Areas within Anguilla's waters in this study will provide a good basis for conducting further work into the potential threats to seabirds in these areas, such as assessing the level of by-catch of seabirds by fishers, and further research into the benthic habitat and presence of other biodiversity within these areas. The data presented in this study has provided valuable information that can be fed into marine spatial planning processes in Anguilla which is a useful and necessary tool for addressing the needs of the multiple users of the marine environment whilst still maintaining the rich biodiversity of Anguilla's waters.

Acknowledgements

Appendix

The representativeness of our tracking samples determined from a bootstrapping re-sampling procedure (according to BirdLife International's marine IBA script), and the resulting percentage of overlapping polygons required to identify high activity threshold areas and marine Important Bird Areas.

	Was foraging site fidelity found between trips?	% of overlapping polygons to represent core foraging area of population	Representativeness of sample (%)	Percentage area overlap of sampled population required to highlight high activity threshold area
Masked booby Sombrero	Yes	10%	97%	10%
Brown booby Sombrero	No	20%	75%	20%
Masked booby Dog Island	No	10%	93%	10%
Brown booby Dog Island	No	10%	97%	10%
Brown Booby Prickly Pear West	No	12.5%	98%	10%
Sooty tern	n/a	Too few trips	65%	n/a
Red-billed tropicbird	n/a	Too few trips	41%	n/a
Magnificent frigatebird	n/a	Data not used	57%	n/a

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