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Review

Potential benefits to fisheries and biodiversity of the Chagos Archipelago/British Indian Ocean Territory as a no-take marine reserve

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ABSTRACT

On 1st April 2010, the British Government announced designation of the British Indian Ocean Territory – or Chagos Archipelago – as the world's largest marine protected area (MPA). This near pristine ocean ecosystem now represents 16% of the worlds fully protected coral reef, 60% of the world's no-take protected areas and an uncontaminated reference site for ecological studies. In addition these gains for biodiversity conservation, the Chagos/BIOT MPA also offers subsidiary opportunities to act as a fisheries management tool for the western Indian Ocean, considering its size and location. While the benefits of MPAs for coral-reef dwelling species are established, there is uncertainty about their effects on pelagic migratory species. This paper reviews the increasing body of evidence to demonstrate that positive, measurable reserve effects exist for pelagic populations and that migratory species can benefit from no-take marine reserves.

1. Introduction

The main threat to biodiversity loss in the marine environment is exploitation which results in species population declines and extinctions, habitat degradation, and ecosystem changes (Essington et al., 2006; Heithaus et al., 2008; Hutchings and Baum, 2005; Jackson et al., 2001; Myers and Worm 2003; Thurstan et al., 2010). International policy commitments now aim to reduce this loss, supported by the development of threat indicators that can monitor environmental concerns related to fisheries (Dulvy et al., 2006). Overexploitation of apex predators has dramatically influenced biological communities by triggering cascading effects down food webs, leading to decreases in diversity and/or productivity, loss of ecosystem services and, in some instances, ecosystem collapse (Agardy, 2000; Jackson et al., 2001; Worm et al., 2002; Ferretti et al., 2010; Pinnegar et al., 2000; Myers et al., 2007). The majority of these studies relate to coastal ecosystems and currently there is insufficient evidence available to make an empirical assessment as to whether similar events are occurring within the pelagic realm (Worm et al., 2003). However, widespread shifts in the species targeted by some pelagic fisheries towards lower trophic-level species suggest that changes in ecosystem structure have occurred (Verity et al., 2002). An ecosystem-based approach to fisheries management is now thought necessary to understand the overall impacts of fishing (Botsford et al., 1997; Chuenpagdee et al., 2003).

The Chagos Archipelago – also known as the British Indian Ocean Territory, BIOT, and subsequently referred to as Chagos/BIOT – is one of the UK's fourteen overseas territories. The archipelago comprises of about 55 islands located in the centre of the Indian Ocean, has the greatest marine biodiversity in the UK and its territories (Sheppard, 2000a), and is of considerable importance to global biodiversity (Procter and Fleming, 1999). UK government committees have previously highlighted their concerns about the lack of attention to, and co-ordination of, environmental initiatives in the UK overseas territories, with 39 recorded terrestrial extinctions and the continued threat of extinction of around 240 other species (House of Commons Environmental Audit Committee, 2008; House of Commons Foreign Affairs Committee, 2008).

The remoteness of Chagos/BIOT combined with very low levels of anthropogenic disturbance – the only human presence is a US military base on Diego Garcia – has resulted in some of the cleanest seas and healthiest reef systems in the world (Everaarts et al., 1999). The archipelago contains about 50% of the healthy reefs remaining in the Indian Ocean, including the world's largest atoll of living coral (the Great Chagos Bank), and endemic coral and fish species that include the Chagos clownfish (*Amphiprion chagosensis*) and brain coral (*Ctenella chagius*) (Sheppard, 2000a,b). It acts as a vital stepping-stone that links the reefs of the east and western Indian Ocean (Sheppard et al., 2009) and is regionally important as a breeding ground for 17 species of seabirds, with 10 of the islands having received formal designation as Important Bird Areas (Hilton and Cuthbert, 2010; McGowan et al., 2008). The archipelago is also

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a globally significant breeding site for hawksbill (*Eretmochelys imbricata*) and green (*Chelonia mydas*) turtles (Mortimer and Day, 1999). Furthermore, the deep oceanic waters around the Chagos/BIOT, out to the 200-mile exclusive economic zone (EEZ), include an exceptional diversity of undersea geological features including submarine mountains, mid-ocean ridges, trenches deeper than 6000 m, and a broad abyssal plain (Williamson, 2009).

In November 2009, the United Kingdom Foreign and Commonwealth Office (FCO) began a four month public consultation on whether to establish a marine protected area (MPA) in Chagos/BIOT (Foreign and Commonwealth Office, 2009). Whilst specific objectives were not given, comment was requested on the anticipated benefits related to conservation, climate change, scientific research and sustainable development. Three options for a possible MPA management framework were presented: (i) a full no-take MPA to the 200 nm EEZ; (ii) a no-take marine reserve that allowed certain forms of pelagic fishery, and (iii) a no-take marine reserve for the vulnerable reef systems only. On the 1st April 2010, the British government declared their support for the first of these options; "an MPA in the British Indian Ocean Territory [which] will include a "no-take" marine reserve where commercial fishing will be banned" (http://www.fco.gov.uk/en/news/latest-news/?view=News&id=22014096). The British government recognised in this declaration that "The territory offers great scope for research in all fields of oceanography, biodiversity and many aspects of climate change, which are core research issues for UK science". To date, the management framework has yet to be defined, although there are no plans to issue any new commercial fishing licenses once the existing ones expire at the end of October 2010 (FCO, pers. comm.).

The current extent, distribution, size and spacing of MPAs globally are vastly inadequate, particularly for no-take areas, and especially in light of past, ongoing and expected future impacts on the oceans. There are only a limited number of sites around the world where establishing a large no-take MPA is practical (Nelson and Bradner, 2010) and the Chagos/BIOT MPA – which encompasses the EEZ and covers 210,000 square miles – doubles the coverage of the world's oceans that are currently strictly protected (Wood et al., 2008). This is particularly important considering currently only 0.08% of the world's oceans are no-take protected areas and international commitments have set global marine protection targets between 10% and 30% (CBD, 2009; United Nations, 2002; Wood et al., 2008).

This paper reviews the evidence that was compiled to assess the benefits of establishing a full no-take MPA during the FCO consultation, particularly closing the tuna fisheries to the 200-mile EEZ. This evidence now provides valuable guidance for the implementation of the Chagos/BIOT MPA and how pelagic MPAs can increasingly function as a marine conservation tool.

2. Fisheries in the Indian Ocean – putting Chagos/BIOT in context

The Food and Agriculture Organisation of the United Nations (FAO) has acknowledged that the maximum wild-capture fisheries potential from the world's oceans has probably been reached (FAO, 2009). In recent years, the Indian Ocean has produced approximately 10% of the almost 93 million tons of annual global fish production, with the western Indian Ocean producing about 50% of the Indian Ocean landings (FAO, 2009). Offshore fisheries operating in the western Indian Ocean (such as those that have been licensed in Chagos/BIOT) are large-scale industrial fisheries with a high level of technology and investment. Industrial fishers tend to be distant water fishing fleets from Asia and Europe that target a wide range of migratory fish, such as tuna, kingfish, bonito, and mackerel, most of which are sold in the export market (FAO, 2009). Approximately 1 million tons of oceanic tuna and tuna-like species, with a processed value of £2–3 billion, are harvested each year from the western Indian Ocean (FAO, 2009).

The western Indian Ocean is also the region where the population status of exploited fish stocks is least known or least certain (Kimani et al., 2009; van der Elst et al., 2005), however recent reports indicate that overall catches continue to dramatically increase (FAO, 2009). Landings of species especially vulnerable to population decline as a result of fisheries, such as sharks and rays, have been steadily rising in both the eastern and western Indian Ocean since the 1950s (Camhi et al., 2009; FAO, 2009). Furthermore, much of the region (not including Chagos/BIOT) suffers from pervasive illegal fishing, severe anthropogenic impacts, and lacks coordination to regulate and monitor international fishing companies (FAO, 2009).

There is general pessimism in the international community about the inability or reluctance of regional fisheries management organisations (RMFOs) to make practical management decisions (FAO, 2009). Chagos/BIOT falls under the remit of the Indian Ocean Tuna Commission (IOTC), the RMFO responsible for the management and governance of tuna fisheries in the Indian Ocean. In 2009, a panel composed of IOTC members, independent reviewers (legal and scientific) and an observer from a non-government organisation completed a review of the performance of the IOTC member states in fulfilling the mandate of the IOTC (Anonymous, 2009; Lugten, 2010). This review found numerous weaknesses in the IOTC, both legal and technical (Anonymous, 2009). The Commission was said to be outdated, and ignoring modern principles for fisheries management, notably the precautionary approach and an ecosystem-based approach to fisheries management (Anonymous, 2009). Further faults included the limited quantitative data provided for many of the stocks, low compliance, poor-quality data and a lack of co-operation (Anonymous, 2009). Recommendations were made and have since been adopted by IOTC members (Lugten, 2010). These were also made in the context of FAO recommendations for a more effective and precautionary approach to fisheries management, particularly for highly migratory and straddling species that are exploited solely or partially in the open ocean (FAO, 2009). At present, however, the western Indian Ocean remains a region with some of the most exploited poorly understood and badly enforced and managed coastal and pelagic fisheries in the world.

3. Fisheries management as operated in Chagos/BIOT

As a UK overseas territory, Chagos/BIOT is governed by the UK through the BIOT Government which is based at the FCO. The constitutional arrangements for BIOT are set out in the British Indian Ocean Territory (Constitution) Order 2004 and related instruments which give the Commissioner full power to make laws for the Territory. The Marine Resources Advisory Group (MRAG), on behalf of the UK government, has been responsible for granting fishing licenses to third parties (Mees et al., 2009a). The fisheries management strategy, developed by MRAG, stated that it would 'ensure that all fishing is undertaken with due regard and concern for the stability of fish stocks, conservation of biodiversity and appropriate management of the resources for the long-term benefit of the users' (Mees et al., 2008).

3.1. Pelagic Tuna Fisheries

The main licensed commercial fishery in Chagos/BIOT was for pelagic tuna, using both longlines and purse-seines. While within the commercial fishing industry the Chagos/BIOT fishery is considered well managed when compared to other fisheries in the western Indian Ocean, this needs to be taken in the context of the generally poor or non-existent management within the region and the weak RFMO described earlier.

Longlining is one of the dominant, commercial pelagic fishery methods globally – presently estimated at 1 billion hooks (Francis et al., 2001; Lewison et al., 2004a). The longline fishery in Chagos/BIOT waters was active year-round and mainly under Taiwanese and Japanese flagged vessels targeting large pelagic species, including yellowfin (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*), swordfish (*Xiphias gladius*), striped marlin (*Tetrapturus audax*), Indo-Pacific sailfish (*Istiophorus platypterus*), with annual catches ranging from 371 to 1366 tonnes over the last five years (Tables 1 and 2). Illegal longlining is an issue with fifty Sri Lankan flagged vessels reported in Chagos/BIOT during the years 2002–2009 (IOTC, 2010).

Purse-seine fisheries are also global in nature, operating in coastal and open waters for aggregated pelagic species, particularly tuna and sardines (FAO, 2008). In Chagos/BIOT, the purse-seine fishery targeted mainly yellowfin and skipjack tuna (*Katsuwonus pelamis*) and was highly seasonal, operating between November and March with a peak usually in December and January (Mees et al., 2009a). Catches, mainly by Spanish and French flagged vessels, were highly variable from logbook records, ranging from < 100 to ~24,000 tonnes annually over the last five years (Tables 3 and 4).

Total catch in the Indian Ocean for bigeye tuna are considered close to the maximum sustainable yield and in recent years, yellowfin tuna has also been overexploited with catches exceeding maximum sustainable yield (IOTC, 2010). Concerns regarding the level of catch of juveniles for both species have been highlighted (IOTC, 2010). Skipjack tuna is a highly productive and resilient species, however, recent indicators suggest the Indian Ocean stocks should be closely monitored (IOTC, 2010). Data from tuna fisheries indicate biases and additional information sources are necessary to fully evaluate the status of the stocks (Ahrens, 2010). Illegal, unreported and unregulated fishing is not a trivial component of the catch and adds substantial uncertainty into assessments (Ahrens, 2010). There is an increasing appreciation of the effects of uncertainty on fishery stock assessment and management, resulting in a more explicit focus on sustainability and its quantification (Ahrens, 2010; Botsford et al., 2009). As with all commercial pelagic fisheries, bycatch and discards are the greatest potential threat to non-target species. These threats are evaluated in more detail later in this paper.

Table 1
Summary of the Longline Fishery in Chagos/BIOT FCMZ between 2004/05 and 2008/09 (from Mees et al., 2009a).

Year	2004/05	2005/2006	2006/07	2007/08	2008/09
Number of vessels	33	24	26	41	22
Number of licences	48	27	34	75	26
Number of days fished	664	1207	1147	1508	571
Total catch (t)	730	916	590	1366	371
CPUE (t/day)	1.099	0.759	0.515	0.906	0.649
CPUE (t/1000 hooks)[a]	0.407	0.281	0.196	0.306	0.305

[a] Based on an average rate of 2700 hooks set per day.

Table 2
Summary of the tuna catch species composition from logbook data from the longline fishery in Chagos/BIOT FCMZ between 2004/05 and 2008/09 (from Mees et al., 2009a).

Year	2004/05	2005/2006	2006/07	2007/08	2008/09
Yellowfin tuna (%)	48	34	45	31	23
Bigeye tuna (%)	52	48	41	63	57
Other species (%)	–	28	11	6	20
Total catch (t)	730	916	590	1366	371

Table 3
Summary of the Purse-Seine Fishery in Chagos/BIOT Fisheries Conservation and Management Zone (FCMZ) between 2004/05 and 2008/09 (from Mees et al., 2009a).

Year	2004/05	2005/2006	2006/07	2007/08	2008/09
Number of vessels	52	54	55	54	43
Number of licences	56	56	56	57	45
Number of days fished	991	394	27	1294	424
Total catch (MT)	23,535	13,865	95	23,418	14,962
Catch rate (t/day)	23.75	36.19	3.52	18.10	35.28

Table 4
Summary of the tuna catch species composition from purse-seine logbook data from Chagos/BIOT FCMZ between 2004/05 and 2008/09 (from Mees et al., 2009a).

Year	2004/05	2005/2006	2006/07	2007/08	2008/09
Yellowfin tuna (%)	83.80	77.93	0.00	79.09	66.34
Skipjack tuna (%)	14.50	20.95	97.89	12.70	24.03
Bigeye tuna (%)	1.70	1.08	2.11	7.44	4.12
Albacore (%)	0.00	0.00	0.00	7.77	5.49

3.2. Recreational and Inshore Fisheries

Two smaller fisheries have also been operating in Chagos/BIOT. In 2008, a small recreational fishery on Diego Garcia caught 25.2 tonnes of tuna and tuna-like species (76% of the catch); the remainder were reef-associated species (Mees et al., 2009b). Secondly, a Mauritian inshore fishery that targeted demersal species, principally snappers, emperors and groupers, whose logbook records indicated that the catches were between 200 and 300 tonnes per year for the period 1991–1997, decreasing to between 100 and 150 tonnes from 2004 (Mees, 2008). The long distance from ports and relatively short season made this an increasingly unattractive venture and the number of licences issued declined in recent years (Mees, 2008).

Overall total catches in the inshore fishery were considered within sustainable limits, although varied considerably between atolls and banks (Mees, 2008). Despite the limited effort, such levels of exploitation were of potential concern considering the fishery targeted predatory species at the higher trophic levels e.g. groupers and the individuals retained were often at the maximum recorded total length for that species (S. Harding, pers. obs.). The biggest problem facing the inshore fish populations in Chagos/BIOT is illegal fisheries, particularly for sharks (Graham et al., 2010). Reef sharks in Chagos/BIOT have declined by over 90% in a 30 year period (1975–2006), attributed primarily to poaching by illegal vessels (Graham et al., 2010). Elasmobranchs are the predominant bycatch in the inshore fishery (Table 5) which may be a further contributing factor to the decline (Graham et al., 2010). Reef-associated shark species are likely to be resident in Chagos/BIOT, therefore the MPA offers an opportunity for their recovery. The closure and enforcement of remote locations has been advocated as a means of maintaining reef shark abundance (Robbins et al., 2006; Sandin et al., 2008).

4. Bycatch: the impact of Chagos/BIOT fisheries on other threatened species

Bycatch occurs in all fishing fleets and the management and mitigation of bycatch is one of the most pressing issues facing the global commercial fishing industry (Hall, 1996; Hall and

Table 5
Levels of discards in the past as a proportion of the landed catch each year, and an estimate of discards in 2007 based on the historical average (from Mees, 2008).

Details	1996	1997	1998	1999	2000	2001	2002	2003	2004	Avge	Discards in 2007 (mt)
Undersize				0.0%			<0.1	1.2%	0.9%	0.5%	0.62
Ciguatoxic		30.0%	8.0%	22.0%	11.3%	16.1%	12.5%	11.4%	9.9%	15.2%	17.99
Shark	0.6%	1.0%	7.6%	4.8%	2.0%	2.3%	4.0%	3.2%	2.8%	3.2%	3.74

Table 6
Fisheries Observer Coverage for Pelagic Fishing in Chagos/BIOT over Twelve fishing seasons.

Season	Longline fishery			Purse-seine fishery		
	Fishing days	Observer days	% Coverage	Fishing days	Observer days	% Coverage
1995–1996	135	0	0.00	411	61	14.84
1996–1997	280	0.5	0.18	448	73	16.29
1997–1998	1903	61	3.21	291	0	0.00
1998–1999	2307	18	0.78	482	13	2.70
1999–2000	1661	18	1.08	122	9	7.38
2000–2001	2052	35	1.71	109	37	33.94
2001–2002	901	4	0.44	379	61	16.09
2002–2003	1379	22	1.60	62	0	0.00
2003–2004	1060	26	2.45	104	0	0.00
2004–2005	656	0	0.00	991	0	0.00
2005–2006	1034	0	0.00	51	10	19.60
2007–2008	1508	0	0.00	1294	0	0.00
Mean% Observer Coverage:			1.24			5.56

Data source: MRAG Offshore Tuna Fishery Programme Observer reports between 1994 and 2006, Mees et al., (2009a).

Mainprize, 2005), regarded as being a fundamental threat to fish stock sustainability, food security and biodiversity conservation (Davies et al., 2009). Globally, bycatch from longline fisheries is a key contributor to the decline of large predators including sharks (Goodyear, 2003), as well as sea turtles (Crowder, 2000; Lewison et al., 2004b) and seabirds (Kitchell et al., 2002). Indeed, fisheries for tuna and tuna-like fish, as well as targeted shark fisheries, are the greatest threat to sharks and rays (Camhi et al., 2009; Dulvy et al., 2008). Sharks are intrinsically vulnerable to overfishing due to their slow growth, late maturity, low fecundity and, as a consequence, potential to recover from overfishing (Camhi et al., 2009; Dulvy et al., 2008). Given the large globalised market for these incidental or bycatch species, particularly sharks for the shark-fin trade, there is a strong incentive to locally over-exploit shark populations (Clarke et al., 2006). The data available from the IOTC are extremely limited or absent and stock status of sharks in the region is uncertain (IOTC, 2010).

For Chagos/BIOT fisheries, incidental, retained catch such as sharks is included in our definition of bycatch. As with most fisheries, bycatch in Chagos/BIOT has been inadequately recorded. Data are based primarily on logbooks and a limited observer programme that was completely absent in some years (e.g. 2004/05 and 2007/08). In other parts of the world, logbook information has been recognised as notoriously unreliable, usually involving significant underreporting and incorrect species identification, meaning that accurate estimates can only be achieved through programmes that use well-trained observers (Baum et al., 2003; Lewison et al., 2004b; Walsh et al., 2005). In Chagos/BIOT, observer coverage was on average only 1.24% per season for longline fishing and 5.56% mean coverage for purse-seine fishing (Table 6).

4.1. Longline Bycatch

The longline bycatch in Chagos/BIOT was substantial, particularly for sharks, rays and billfish (Pearce, 1996; Roberts, 2007), even with the aforementioned uncertainty. Between 1991 and 1995 bycatch consisted mainly of swordfish, striped marlin, Indo-Pacific sailfish and albacore (*Thunnus alalunga*) – these species are considered high value and were often retained (Pearce, 1996). Sharks e.g. bigeye thresher shark (*Alopias superciliosus*) and blue shark (*Prionace glauca*) were also caught during this period, but those discarded were not logged as catch (Pearce, 1996). Those retained on vessels since 1993 were recorded in logbooks, but data prior to 2006 may not have been accurately reported (Mees et al., 2008). A comparison of observer and logbook data for bycatch in the 1998–1999 longline fishing season showed that Taiwanese vessels were not recording bycatch of sharks at all, and Japanese vessels were underreporting shark catch by upto 50% (Marine Resources Assessment Group, 1999). While shark finning was prohibited in Chagos/BIOT waters from 2006 it is difficult to measure compliance as there has been no observer programme since then.

Shark bycatch on longlines is also a concern for global fisheries management (Hall and Mainprize, 2005); sharks are often secondary targets rather than waste, providing an important supplementary income to crews on some longline vessels (Dulvy et al., 2008). In the early 2000s, a catch per unit effort of 2.06 individuals per 1000 hooks was calculated for blue shark – a species vulnerable even at low levels of exploitation (Schindler et al., 2002). Using this estimate of the blue shark catch rate and data on the total number of hooks deployed (1.50822×10^7) over five fishing seasons in Chagos/BIOT between 2003/2004 and 2007/2008 (Mees et al., 2008), we can estimate the total number of blue sharks caught to be 31,069[1]. As blue sharks were, on average, 52% of the sharks, extrapolation results in an estimate of 59,749 sharks caught in a five-year period by longliners in Chagos/BIOT waters. The bycatch of rays was reported to be equivalent (Mees et al., 2008).

Lesser known species are also affected by bycatch in Chagos/BIOT waters. The longnose lancetfish (*Alepisaurus ferox*), a large, hermaphroditic, deep-water predatory species, can make up almost 25% of the total longline catch by number (Mees et al., 2008), though individuals are often lost or cut off the hooks before being landed, therefore unreported and not identified. Bycatch

[1] Estimated by multiplying the total number of fishing days (5586) by the average number of hooks deployed per day (2700).

Table 7
Number and weight of sharks landed, numbers of 'others' and number of sharks and total 'fish' discarded by longliners, from logbook records 1993–2007. Total discards include the sharks and some tunas (from Mees et al., 2008).

Year	Sharks retained		Others retained (no.)	Discard numbers	
	Weight (kg)	Number		Shark	All fish
1993	0	174	1064		
1994	0	54	661		
1995	0	2	113		
1996	0	4	515		
1997	0	1633	5444		
1998	0	5148	17107		
1999	0	176	28223		
2000	1138	470	7676	199	233
2001	0	693	6981		227
2002	0	1029	5035	4	51
2003	0	295	1897		5
2004	100	303	556		
2005	17506	567	4302		
2006	64433	2304	4021		
2007	79327	2772	6970		

figures for sharks and other species are presented in Table 7, though data are not available to separate these by species.

4.2. Purse-seine bycatch

Observer coverage from the purse-seine fishery documents a significant bycatch of sharks, rays, billfish and triggerfish in Chagos/BIOT. Purse-seine fisheries in Chagos/BIOT targeted free schools of tuna but in some years, fish-aggregating devices (FADs) were also used to attract and concentrate fish schools before capture and these had a greater and more diverse bycatch (Marine Resources Assessment Group, 1996; Mees et al., 2009a). According to observer reports bycatch levels were low for free-school sets, ranging from <1% to 3.6% of the total recorded catch while purse seining using FADs had bycatch levels of 10% of the total catch (Marine Resources Assessment Group, 1996, 1997, 1998, 2000, 2001, 2002). As with the longline fishery, bycatch was not recorded in logbooks during this period. The main bycatch species in the Chagos/BIOT purse-seine fishery were rainbow runner and pelagic triggerfish, silky shark, dolphinfish, black marlin and wahoo (Mees et al., 2009a). Catches of sharks by the purse-seine fishery were approximately 0.2% of the total catch in Chagos/BIOT waters during the period between 1995 and 2002 (Mees et al., 2003).

4.3. Biological effects of bycatch

Bycatch can have a considerable impact on ecosystem function (Lewison et al., 2004a), as has already been shown in the case of the loss of predatory sharks in inshore systems (Myers et al., 2007; Ferretti et al., 2010). Based on the numbers of individuals involved and the status of those species globally, the level of shark bycatch in Chagos/BIOT waters can be considered an issue. However, data are extremely limited and based primarily on logbook information. This reflects the situation for western Indian Ocean fisheries, where the total pelagic shark catch by all fisheries is thought to be considerable but underestimated, potentially resulting in a reduction in their abundance to critical levels and diminishing the biodiversity of this pelagic ecosystem (Romanov, 2001). In other oceanic regions, genetic research has shown that some migratory, pelagic sharks are made up of discrete populations that spend more time at preferred sites (Queiroz et al., 2005) and under certain circumstances shark populations are likely to benefit significantly from spatial closures of longline fisheries (Baum et al., 2003; Watson et al., 2009). To promote both fisheries management and marine species conservation, future bycatch research must continue to address these critical data limitations while developing novel approaches to address uncertainty (Lewison et al., 2004a). The high natural diversity and abundance of sharks has been shown to be vulnerable to even light fishing pressure (Ferretti et al., 2010) so given the large uncertainties and biases of management, it seems likely that closing Chagos/BIOT waters to all fishing will give these threatened species a 'safe house' that can only facilitate their recovery.

In summary, bycatch is a serious conservation issue that is complex and ecosystem-wide in its effects (Lewison et al., 2004a; Harrington et al., 2005) and the bycatch from tuna fisheries in Chagos/BIOT is significant, particularly for sharks. However, the lack of data and likely significant under- and mis-reporting of bycatch in the absence of onboard observers suggests that actual numbers could be much higher. The closure of Chagos/BIOT to all commercial fishing will eliminate bycatch and help to reduce elasmobranch bycatch in the western Indian Ocean as a whole by providing a temporal and spatial haven.

5. Potential benefits of no-take marine reserves

Global fish catches began to decline in the 1980s due to a long history of unsustainable fishing practices that have resulted in fisheries collapse and degraded ecosystems (Pauly et al., 2005). The 2002 World Summit for Sustainable Development has demanded marine reserves for fish populations to increase the sustainability of fisheries (United Nations, 2002), and while it has been recognised that some of these reserves should be inshore to protect coastal species, others need to be large and offshore to prevent losing certain species entirely (Balmforth et al., 2004; Roberts et al., 2005; Russ and Zeller, 2003). The creation of networks of marine reserves is viewed as an essential component of marine management (Lubchenco et al., 2003) because it focuses on the protection of the ecosystem rather than managing specific threats or species in isolation (Agardy, 2000). Recent guidelines have been developed for such networks to reduce or eliminate the previously assumed trade-off between achieving conservation and fisheries goals (Gaines et al., 2010). However, a long-term commitment to enforce a no-take MPA is required to achieve its full benefits, even in coral reef environments where more species show much higher site fidelity, as both size and age of the MPA are important in determining their effectiveness (Claudet et al., 2008; Jennings, 2001; Micheli et al., 2004; Molloy et al., 2009).

Fisheries protection measures are often approached from the perspective of a single economically important species. However, poor stock estimation, improved gear technology and 'cheating' by fishers often means that these management plans are intrinsically flawed (Sumaila et al., 1999). Moreover, species that are not managed will still suffer the effects of totally unmanaged fishing and be vulnerable to bycatch (Russ and Alcala, 1989; Sumaila et al., 1999). Well enforced no-take MPAs will prevent such activities from reducing both the complexity of the habitat and the associated biodiversity (Sumaila et al., 1999). Micheli et al. (2004) assert that "reserves aimed at conserving and restoring whole assemblages and ecological processes should be established as permanent no-take zones...".

5.1. Potential benefits of no-take MPAs to large pelagic and migratory species

Fisheries are the largest anthropogenic threat to pelagic ecosystems, therefore preventing fishing will potentially have the greatest beneficial effect for the ecosystem (Game et al., 2009). Indeed, it has been suggested that the simplest way to diversify the management of a given fishery resource is to exploit part of the resource while protecting the remainder as a marine reserve (Lauck et al., 1998). While undoubtedly more complex, protection measures for migratory species should not be disregarded because they potentially move through the waters of more than one nation. There are many precedents for protection of these types of species in the terrestrial world; migratory birds are vigorously protected by some countries while others actively hunt them (e.g. Fox and Madsen, 1997) and terrestrial parks do not protect the entire range of migratory mammals such a wildebeest (e.g. Thirgood et al., 2004). The Convention on the Conservation of Migratory Species of Wild Animals (CMS) is an environmental treaty within the United Nations Environmental Programme that focuses on the conservation and sustainable use of migratory animals and their habitats. CMS is currently engaged in efforts to develop a global conservation instrument for migratory sharks as well as addressing issues facing cetaceans and turtles, including bycatch.

The pelagic realm represents the largest global ecosystem and 99% of the Earth biosphere volume (Angel, 1993) and is the least protected marine habitat (Game et al., 2009). It has become increasingly apparent that the structure and function of this ecosystem has significantly changed largely due to fishing (Coleman and Williams, 2002; Hyrenbach et al., 2000; Myers and Worm, 2003; Verity et al., 2002). Based on the greater scientific understanding of the nearshore environment, the most obvious solution to this problem is a no-take MPA. However, pelagic species and habitats are generally thought to be less amenable to spatial protection measures, a view that has translated into a lack of closed area designations within this environment (Day and Roff, 2000; Game et al., 2009). Two aspects of the pelagic system have fostered the prevailing belief that the application of area closures is an inappropriate management approach; (1) the potentially highly migratory nature of many of the species that inhabit the pelagic system (Boersma and Parrish, 1999) and (2) the ephemeral nature of the physical processes that drive pelagic biological distributions (Etnoyer et al., 2004), though such models fail to adequately consider aspects of habitat heterogeneity and the effects of fishers' behaviour (Apostolaki et al., 2002; Roberts and Sargant, 2002).

Habitat heterogeneity is particularly true around oceanic islands, with the island mass effect resulting in localised increases in oceanic productivity (e.g. Doty and Oguri, 1956; Hargraves et al., 1970; Gilmartin and Revelante, 1974; Simpson et al., 1982; Le Borgne et al., 1985; Hernández-León, 1988). There are various theories (reviewed in Genin, 2004) as to why these islands are hotspots of pelagic biodiversity (Worm et al., 2003), particularly for apex predators (Stevenson et al., 2007). Seamounts can perform a similar function (Morato et al., 2008) and have been shown to host populations of bigeye (Holland et al., 1999; Itano and Holland, 2000; Morato et al., 2008), yellowfin (Holland et al., 1999; Itano and Holland, 2000) and skipjack tuna (Fonteneau, 1991; Morato et al., 2008). The presence of skipjack tuna shoals is often highly predictable due to their association with convergence zones and upwellings (Laurs et al., 1984). This heterogeneity of distribution by tuna species is exploited by the use of man-made fish aggregation devices which apply further pressure on populations by extracting immature individuals (Cayre, 1991; Itano and Holland, 2000). Shoaling behaviour is also common in other ocean predators such as pelagic sharks (Au, 1991) and assemblages of these species have been observed at seamounts and offshore islands in the eastern tropical Pacific (Hearn et al., 2010). This natural heterogeneity in distribution could potentially enhance preservation of migratory species using strategically located pelagic marine reserves.

Studies have already demonstrated that marine reserves can benefit pelagic species that exhibit highly mobile behaviours, albeit to a lesser extent than sedentary species (reviewed in Game et al., 2009). In addition, it has been shown that (1) in fisheries management, the phrase 'highly migratory' often has little biological meaning, with studies of tuna mobility demonstrating they would benefit from national-level closures (Sibert and Hampton, 2003); (2) persistence and, thus, predictability of some habitat features within the pelagic realm does occur (Alpine, 2005; Baum et al., 2003; Etnoyer et al., 2004; Hyrenbach et al., 2000; Worm et al., 2003); (3) positive, measurable reserve effects on pelagic populations exist (Baum et al., 2003; Hyrenbach et al., 2002; Jensen et al., 2010; Roberts and Sargant, 2002; Worm et al., 2003, 2005; and (4) migratory species can benefit from no-take marine reserves (Beare et al., 2010; Jensen et al., 2010; Palumbi, 2004; Polunin and Roberts, 1993). In fact, it is now believed that pelagic MPAs are an important tool in the planet's last frontier of conservation management (Game et al., 2009) and are rapidly becoming a reality (Pala, 2009), although some of the challenges relating to their implementation may be both costly and difficult (Kaplan et al., 2010). Large MPAs are considered necessary to protect migratory species such as large pelagic fish and marine mammals (Wood et al., 2008) as well as offsetting the concentration of fishing effort outside them (Walters, 2000) and maintaining ecological value (Nelson and Bradner, 2010).

Partial protection for migratory species can not be considered futile, although a more coordinated approach for protection is preferable as no-take marine reserves should be combined with areas of limited fishing effort (Pauly et al., 2002). Optimisation models have suggested that tuna fisheries could even gain some economic efficiencies by closing large areas, provided overall effort is reduced and shifted into high value geographic areas (Ahrens, 2010). In addition, the presence of pelagic MPAs has also been shown to leverage improved marine management in adjacent areas (Notarbatolo di Sciara et al., 2008).

5.2. Potential benefits of the Chagos/BIOT no-take MPA to large pelagic and migratory species

While the full benefits of pelagic MPAs are not yet understood, the newly established MPA in Chagos/BIOT has many parameters that suggest it will benefit pelagic and migratory species. Numerous geographic features, such as seamounts and convergence and upwelling zones are present in Chagos/BIOT (Charles Sheppard, unpublished data; Alex Rogers, unpublished data) and the island mass effect has been reported in neighbouring Maldives (e.g. Sasamal, 2006). As previously discussed, in other locations such features have been shown to act as natural aggregation devices for tuna and other migratory species (e.g. Holland et al., 1999; Itano and Holland, 2000; Morato et al., 2008). No-take protection that encompasses these features is therefore likely to be an effective conservation tool.

As a no-take MPA, Chagos/BIOT is of sufficient size to protect both site-attached and migratory species. Modelling of mark/recapture tagging data in both the west Indian Ocean and Pacific Ocean demonstrate median life-time displacements of around 400–500 miles in the three target tuna species in Chagos/BIOT (Fonteneau, 2008; IOTC, 2008). Although this means that these fish will be exposed to periods of exploitation at some point during their lifetime, these data demonstrate that the conservation of tuna stocks can be promoted through effective domestic management policies (Sibert and Hampton, 2003). Moreover, theoretical analyses of predator–prey models suggest that migratory pelagic species require large protected reserves to exhibit increases in population size (Micheli et al., 2004); with the Chagos/BIOT MPA being 210,000 square miles, such an expanse potentially provides an excellent area for the recovery of shark, tuna and other large predators. Scientific data (e.g. Mortimer and Broderick, 1999; Williams et al., 1999) support Chagos/BIOT playing the role of a stepping-stone for many species in the western Indian Ocean therefore Chagos/BIOT may also help some fish populations on a broad geographic scale through larval supply and recruitment.

No-take marine reserves have been widely reported to increase fish and invertebrate biomass for reef environments within their borders (reviewed in Mumby and Steneck, 2008) with many exploited species, including migratory, pelagic species (Palumbi, 2004; Polunin and Roberts, 1993) and predatory species, benefiting the most from no-take reserves (Palumbi, 2004). The absence of fishing pressure is reported as the major factor that allows both the density and individual biomass, and consequently the reproductive capacity, of exploited species to increase (McClanahan and Arthur, 2001; Palumbi, 2004). However, it is important to state that no-take MPAs cannot be a lone panacea for the protection of fish stocks or their associated habitats and appropriate management of the no-take area is essential.

It is concluded that a permanent no-take zone in the Chagos/BIOT will maintain both fish populations and the near-pristine habitat that exists in this area. One of the key issues in determining the effects of the Chagos/BIOT MPA for pelagic species is the almost complete lack of existing data, and that which exists comes entirely from fisheries. It has been proposed that MPAs can serve to hedge against inevitable uncertainties, errors, and biases in fisheries management (Lauck et al., 1998). It is certainly true that while fisheries-independent research needs to be done in Chagos/BIOT there will always be a degree of uncertainty surrounding research on pelagic organisms and their environment. The costs and logistics involved with such data collection in such a remote location reinforce the need to act now to implement a precautionary approach to achieve sustainability in marine fisheries in the context of the extreme overexploitation in the western Indian Ocean.

Modelling studies indicate that effort displacement can counteract the benefits arising from pelagic area closures (Baum et al., 2003; Worm et al., 2003). Baum et al. (2003) suggested that an effective measure to reduce the displacement effort was to avoid regions of high fishing effort in favour of areas of lower fishing effort, thus reducing the amount of effort that can be displaced. While some displacement is possible in Chagos/BIOT following implementation of the marine reserve, the reduced area of ocean available for fishing may result in a decrease in fishing effort through vessel decommissioning or a large-scale change in fishing patterns. This is particularly relevant when considering the broader regional context, particularly the *de facto* closure of the Somalia fishery due to piracy (Mangi et al., 2010). More generally, overcapacity of the global tuna fleet is an issue that needs to be addressed by all regional fisheries management organisations and fishing nations – marine reserves should be seen as a part of this broader management scheme. There may be some opportunity for monitoring activity in Chagos/BIOT that helps establish any consequences of shifting fishing effort in the region.

This paper highlights several uncertainties in the benefits and limitations of spatial closure for tuna and other pelagic species. However, the Chagos/BIOT MPA was not primarily initiated as a fisheries management tool, rather to conserve the unique and rich biodiversity of this region, both in the coastal and pelagic realm. The relatively pristine nature of the coral reefs of Chagos/BIOT is particularly important considering the 2008 Status of the World's coral reefs report reporting 19% of the original global coral reef area has already been lost through direct human impacts, with a further 15% seriously threatened within 10–20 years, and another 20% under threat in 20–40 years (Wilkinson, 2008). These predictions do not take into account the accelerating problem of climate change on the oceans (Veron et al., 2009). There remains a critically urgent need for more effective management that conserves remaining coral reefs, particularly those in areas of low anthropogenic pressure and thus likely to be most resilient to climate change impacts.

Scientific research recognises Chagos/BIOT as a globally significant, uncontaminated reference site and one of the few tropical locations where global climate change effects can be separated from those of pollution and exploitation. Research in Chagos/BIOT is already providing vital information for monitoring and managing coral reefs elsewhere, in particular the design of interventions to restore reefs to a healthier condition (Sheppard et al., 2008). Considering the paucity of empirical information on the effects of MPAs on pelagic species, there is a clear need for further work and a research agenda is under development. Delivery of this research programme will improve management and conservation actions for pelagic species both within the Chagos/BIOT MPA and in the wider context of global marine conservation planning. The implementation of a no-take marine reserve in Chagos/BIOT has therefore provided a highly unique scientific reference site of global importance for studies on both pelagic and benthic marine ecosystems and the effects of climate change upon them.

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