A review of the conservation benefits of marine protected areas for pelagic species associated with fisheries

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1 Introduction

1.1 Overview of the discussion surrounding pelagic MPAs

There is now a vast body of evidence supporting the conservation benefits of marine protected areas (MPAs; see Box 1) in coastal and nearshore ecosystems (Claudet et al., 2006, 2008; Halpern et al., 2009; Lester et al., 2009; Babcock et al., 2010). This has led to numerous proposals for expanding the use of MPAs to pelagic environments (Sumalia et al., 2007; Game et al., 2009; Koldewey et al., 2010), and interest in the use of MPAs to conserve and responsibly manage pelagic species, including tunas, has rapidly grown.

In addition to international commitments to protect significant areas of the high seas within an MPA network (Sumaila et al., 2007), there has been a highly publicised[1] drive to create vast marine reserves within national exclusive economic zones (EEZ). To date the British Indian Ocean Territory MPA is the largest of these and, at a little over half a million square kilometers, covers substantial offshore areas of pelagic ocean. Several other similar reserves have been proposed, many of which are larger still[2], and thus the percentage of pelagic ocean under formal protection is likely to continue to dramatically increase. Furthermore, spatial closures have increasingly featured in the management of offshore pelagic fisheries resources, notably tunas (e.g. Harley and Suter, 2007; Sibert et al., 2011).

Despite the apparent enthusiasm for pelagic MPAs, there remains considerable discussion over the efficacy of spatial management for the conservation of pelagic species. This discussion, neatly outlined in a recent opinion paper by Game et al. (2009) and a response to that paper (Kaplan et al., 2010), has drawn the attention of policy makers, and research is increasingly being directed towards understanding how and where pelagic MPAs can provide benefits. Nevertherless, with few established examples to learn from, the science of pelagic MPAs is still largely theoretical and largely reliant on modeling studies.

As a result, recent published literature on pelagic MPAs has focused on the *potential* benefits of pelagic MPAs and the challenges to spatial management in the open ocean. Perhaps the most commonly cited of these challenges is that pelagic ecosystems extend over huge areas and are highly dynamic, and correspondingly, many pelagic species are highly mobile. As such, the mechanisms by which MPAs are known to provide benefits in near shore ecosystems may be absent, weakened or significantly modified in pelagic ecosystems.

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1 For example, see the Global Ocean Legacy http://www.pewtrusts.org/our_work_detail.aspx?id=136

2 Coral Sea Commonwealth marine reserve http://www.environment.gov.au/coasts/mbp/coralsea/consultation/index.html

Further challenges lie in the planning and governance of pelagic MPAs. For instance, determining precisely where to place protection is complicated by the dynamic physical nature of pelagic habitats which shift in space and time and can be difficult to identify (Norse et al., 2005). Additionally, with a significant proportion of the pelagic ocean (64%) falling outside national jurisdiction, effective governance is considered to be a major challenge[3] (Miller 2007; Cullis-Suzuki & Pauly, 2010).

In this review, we bring together the most recent available evidence for conservation benefits provided by MPAs to pelagic species, taking the opportunity to provide critical discussion where it is appropriate to do so. We also provide an assessment on the impact of pelagic MPAs to fisheries, whether positive or negative. We focus here on the biological literature and do not discuss in detail the topics of governance or enforcement, except where these issues may have masked the effects of MPAs.

The remainder of this section provides a background on pelagic ecosystems, species and fisheries and the mechanics of MPAs. Section 2 contains the main review of pelagic MPA conservation benefits, with impacts to fisheries considered in section 3. In the final section we provide a concluding discussion. A table detailing current fisheries closures in place within the major Regional Fisheries Management Organisations (RFMOs) is included at the end of this document (Appendix A).

3 However, efforts are being made to address these governance concerns: http://www.un.org/depts/los/convention_agreements/convention_overview_fish_stocks.htm

Box 1: What defines a pelagic marine protected area?

The term marine protected area is frequently used as an umbrella term to describe a variety of spatial management designations. Here we use the definition of an MPA provided by the Convention on Biological Diversity:

> '*Any defined area within or adjacent to the marine environment, together with its overlying waters and associated flora, fauna and historical and cultural features, which has been reserved by legislation or other effective means, including custom, with the effect that its marine and/or coastal biodiversity enjoys a higher level of protection than its surroundings*' (DecisionVII/5, paragraph 10).

Within this we include fisheries-orientated **time/area closures**, as well as typically more conservation-orientated **marine reserves,** which generally exclude all forms of extractive use and are considered to offer the most comprehensive protection to ecosystems.

Pelagic MPAs refer to the subset of MPAs specifically situated in either nearshore or offshore pelagic environments.

1.2 The pelagic environment

The pelagic ocean is vast - approximately 14 billion cubic km - and constitutes the overwhelming majority of the marine environment, extending through the water column from the surface to the sediments. Although the term 'pelagic' is often used as a synonym for offshore waters, pelagic species are often found in both offshore and nearshore areas.

The pelagic environment can be divided into a number of descending stratifications that mark changes in physical and biological features (Figure 1) but it is within the upper 200m, the euphotic epipelagic layer, that biodiversity is concentrated (Verity et al., 2002). While many offshore MPAs are established to protect demersal species and benthic habitats, there are also a number which have been established covering the epi- and mesopelagic layers which form the focus of this report.

While vast areas of pelagic ocean are relatively unproductive, wind- and topographically-driven upwelling brings deeper nutrient-rich waters into the warm, photic surface zones, producing areas of high productivity supporting some of the most diverse and important ecological systems on the planet (Cury & Roy, 1989; Bakun & Weeks, 2008). Offshore transport and eventual descent and sedimentation of this upwelling-driven productivity are a fundamental part of the functioning of many pelagic ecosystems.

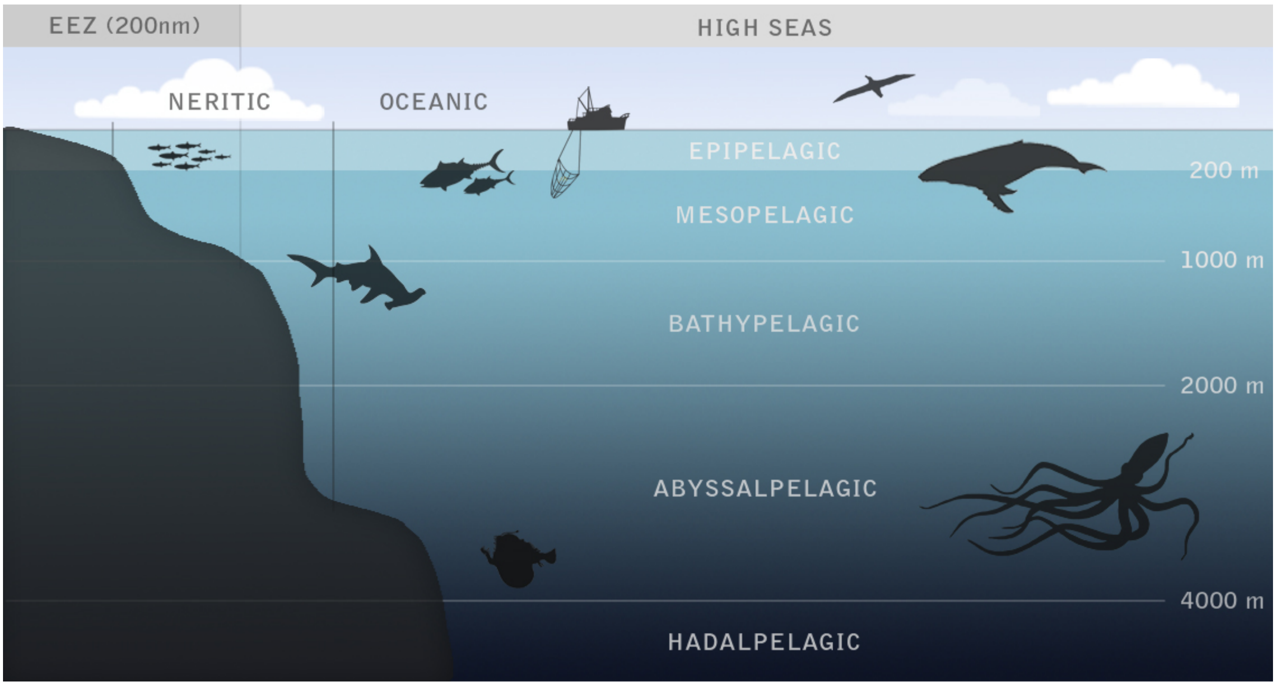

Figure 1 The pelagic realm. Descending stratifications of the pelagic ecosystem are based on biological and physical changes with the upper euphotic epipelagic layer (shown here as a light band) reaching depths of approximately 200 m. Horizontal zoning into nearshore (neritic) and oceanic waters is shown along with jurisdictional zones. Illustrations indicate typical species inhabiting the different zones.

1.3 Pelagic biodiversity

Pelagic species display a great diversity of ecological and life-history traits (Table 1). For instance, many oceanic pelagic species - those species inhabiting offshore waters - are notoriously cosmopolitan, exploiting widely distributed resources over very large spatial scales (e.g. tunas; Block et al., 2005, 2011). In contrast, the mobility of small oceanic pelagic species, while far less documented, may be relatively limited, with certain species associating with floating objects (Dagorn et al., 2007) or offshore seamounts (Klimley et al., 2003; Morato et al., 2010) for lengthy periods, potentially leading comparatively sedentary lives.

Small nearshore pelagics, while still relatively mobile, move over far smaller distances and often associate closely with upwellings in nearshore areas (Ward et al, 2006; Palomera et al., 2007). Larger nearshore pelagics, while not moving on scale of some highly mobile oceanic pelagic species, have been observed to travel considerable distances throughout nearshore areas (e.g. orca; Andrews et al., 2008).

In Table 1 we have proposed a typology of pelagic species groupings based on their capacity for movement as this is a key theme in the discussion of pelagic MPAs. It is important to bear in mind that although we frequently draw on these groupings to focus our discussion throughout the review they are intended only as an illustrative guide and individual species may span more than one grouping or differ from the typical behaviour of their nominal grouping.

Table 1 Typology of pelagic species. Species are divided into suggested groupings according to aspects of their ecology and capacity for long distance movement. Groupings are based on generalisations of species traits from available evidence.

Species grouping	Description	Example species
Very highly mobile pelagic species	Species which travel over very large distances seasonally or over the course of their life. This group mainly consists of birds and large cetaceans	Wandering albatross (Tuck et al., 1999) Baleen whale spp. (Baker et al., 1986; Mate et al., 1999)
Large oceanic pelagic	Reasonably large bodied HMS that inhabit predominantly oceanic waters and are capable of substantial movements in relatively short periods	Tuna spp. (Block et al., 2005) Oceanic shark spp. (Weng et al., 2007)
Small oceanic pelagic	Relatively small species that move only small distances within predominantly oceanic waters	Dolphinfish (Dagorn et al., 2007) Pelagic stingray (Neer, 2009)
Large nearshore pelagic	Large bodied pelagic species restricted to nearshore areas for most or all of their life and capable of modest movement	African penguin (Pichegru et al., 2010) Bottlenose dolphin (Wilson et al., 1997)
Small nearshore pelagic	Small pelagic species restricted to nearshore areas for their entire lifespan and capable of modest movement	Sardine (Palomera et al., 2007) Mackerel spp. (Uriarte & Lucio, 2001)
Diadromous pelagic species	Anadromous species that migrate between significant distances between freshwater rivers and the pelagic ocean.	Salmon (Hansen & Quinn, 1998) European eel (Aaerstrup et al., 2009)

1.3.1 Pelagic fisheries

Several large oceanic pelagics are targeted by fisheries, with upwards of 6 million tonnes landed annually over recent years. Tuna make up the majority of these landings (~75%), and up to 35% of tuna stocks are considered overexploited or depleted (FAO, 2010). Offshore fishing generally requires significant financial investment and fleets tend to be highly efficient and capital intensive, often targeting high value species for overseas markets. Large scale longline and purse seine tuna fleets epitomise offshore commercial fishing, with large vessels equipped with modern technology capable extended fishing trips.

Non-target species incidentally caught in longline, drift net or purse seine gear include small oceanic pelagics which often have no commercial value and are discarded (e.g. rainbow runner, *Elagatis bipinnulata*), as well as larger oceanic pelagics which may possess some value, such as dolphinfish or oceanic sharks, which are often retained (e.g. Amandè et al., 2011). Small-scale fisheries might also have strong and underestimated levels of bycatch but few data are available for these fisheries (Peckham et al., 2007). Such information is crucial to have a broad picture of the marine fauna associated with tuna fisheries and properly identify target MPAs.

Numerous small nearshore pelagic species inhabit accessible coastal waters and are exploited globally by artisanal and commercial nearshore fisheries. These species, many of which reproduce rapidly and in prodigious numbers, can sustain high volume industrial fisheries, such as the Peruvian anchovy fishery (Bakun & Weeks, 2008) and indeed contribute up to 50% of the total landings of marine species (FAO, 2010). By contrast, few fisheries exist for large nearshore pelagics, with the exception of some artisanal or semi-industrial fisheries that fish around anchored FADs. Some predatory species, particularly seals and small cetaceans, are known to compete with fisheries for prey (Schweigert et al., 2010) and fall victim to the indirect impacts of fishing, either through bycatch or entanglement on discarded fishing gear (Slooten & Dawson, 2010).

1.4 The mechanics of MPAs

Conservation benefits are provided by MPAs both directly through a reduction in mortality of the target species resulting from human such as fishing, shipping and mining, and indirectly through the reduction in incidental impacts associated with these activities, resulting in broader ecosystem-level recovery (Hilborn et al., 2004). The magnitude of these benefits depends on a number of factors, such as the design of the MPA, how well it is enforced and the intensity of previous human impacts (Agardy et al., 2003; Claudet, 2011).

Benefits to fisheries production are closely linked to conservation benefits and arrive through net emigration of fish across protected area boundaries ('spillover'), and export of eggs and larvae from an MPA into to fished areas outside ('recruitment subsidy') (Gell & Roberts, 2003).

A more detailed breakdown of the mechanisms by which MPAs provide conservation and fisheries benefits is given in Table 2. Here we have also briefly summarised the challenges to these MPA mechanisms in the pelagic environment.

Table 2 The key mechanisms by which MPAs provide conservation and fisheries benefits and a brief summary of the major challenges to these mechanisms in the pelagic environment

#	MPA mechanism	Challenge for pelagic MPAs
MECHANISMS FOR CONSERVATION BENEFITS		
1.	Individuals are protected within a single MPA or a network of MPAs for a significant proportion of their life span allowing populations to recover from exploitation or damaging impacts	Many pelagic species are migratory and highly mobile. Consequently MPAs would probably need to be very large to cover a significant fraction of an individual's lifespan
2.	Individuals are protected within an MPA during one or more demographically-important periods (e.g. during spawning, whilst migrating etc.) allowing populations to recover	The location of demographically-important areas is unknown and/or difficult to identify for many pelagic species, and deriving benefits from protecting these demographically-important areas requires significant differences in fishery accessibility inside and outside these areas
3.	Incidental impacts of fishing on non-target species and benthic habitats are eliminated	Incidental fisheries impacts may be displaced into other sensitive areas, particularly given the nature of offshore pelagic fisheries
MECHANISMS FOR FISHERIES BENEFITS		These fisheries mechanisms depend on pelagic species benefiting from core protection of MPAs stemming from mechanisms 1-3
4.	Increased adult biomass within MPA spills over into adjacent fishing grounds increasing fisheries yields	Modelling results suggest that excessive MPA spill over rapidly reduces or eliminates MPA benefits, particularly when combined with effort displacement
5.	Increased reproductive potential within MPA seeds surrounding fished areas with eggs and larvae aiding stock recruitment and promoting stock recovery	This will only produce benefits if the stock is recruitment-limited prior to MPA implementation
6.	MPAs act as scientific reference areas to study trends in stock dynamics in the absence of fishing	

2 Review of MPA benefits for pelagic species

We have structured our review around the three conservation MPA mechanisms in Table 2, drawing on examples from both theoretical and empirical work.

2.1 Mechanism 1: Protection of entire lifespans within a reserve

2.1.1 Differences in movement between different pelagic populations

To a large extent, resistance to the use of MPAs in the pelagic environment stems from perception that gainful spatial management of pelagic species requires the closure of vast areas. Indeed, for MPAs to effectively provide conservation benefits they must protect a sufficient number of individuals within a population for a large proportion of their life span. The results of several modeling studies support this idea, suggesting that for species with high mobility MPAs should either be very large or be part of a reserve network that covers a significant proportion of a species' range (Polacheck, 1990; Le Quesne & Codling, 2009; Moffitt et al., 2009; Grüss et al., 2011b).

However, this generalisation may not hold true for all pelagic species depending on the species' mobility. In particular nearshore and small pelagic species, while still relatively mobile, generally move across smaller spatial scales than many large oceanic pelagics (Palumbi, 2004) and thus are likely to be more responsive to appropriately managed MPAs. Despite this, spatial closures are often implemented for large pelagics, such as tunas, and only occasionally used in the management of small pelagics, usually to protect specific habitat from degradation or to prevent the catch of key development stages (Freón et al., 2005). Unfortunately formal evaluations of the closures that have been established are lacking.

Some tenuous support for MPAs benefiting small pelagics and their large pelagic predators comes from Pichegru et al. (2010) who observed a rapid shift in the spatial foraging patterns of brooding African penguins, a predator of anchovy and sardine, into a newly created fisheries closure. This spatial shift was paired with a significant decrease in foraging effort not observed in a neighbouring penguin colony situated much further from the MPA. Given the short time period between the start of the protection and observed changes in penguin behaviour (3 months), this MPA benefit for penguins cannot be due to recovery of small pelagics in the area, but would rather have to be due a localized density increase due to the absence of fishing. Nevertheless, this study does illustrate the potential benefits MPAs can provide large mobile predatory species.

A less ambiguous indication of the potential benefits of pelagic MPAs to oceanic pelagic species is provided by Jensen et al. (2010) who demonstrate significant and rapid increases in the abundance of striped marlin during two separate multi-year closures of the Mexican EEZ to longline fishing. This conservation outcome is possibly explained by the relatively limited dispersal of adult striped marlin in the Gulf of California (Domeier, 2006) resulting in individual fish and presumably recruiting age classes staying within the fisheries closure for the majority of the closure period.

Extensive tagging of large oceanic pelagic predators has revealed several important differences in movement behaviour which may predispose certain highly-mobile species (HMS) to benefit from spatial protection more than others. In a large scale tagging study by Block et al. (2011), species such as northern elephant seals, leatherback turtles, salmon sharks and white sharks showed long distance inshore-offshore movements, repeatedly using certain areas, but often showing considerable variability among individuals. In contrast, other species tagged in the study, such as yellowfin and bluefin tunas, showed more restricted alongshore movements. Nevertheless, the relatively nearshore distribution of tunas tagged in this study are not broadly representative of the distribution of tuna stocks in the wider Pacific or other regions, which can be distributed in oceanic waters including the high seas. Furthermore, the scale of movement even for these less cosmopolitan species is still very large, measured in hundreds of kilometres.

There is also some indication of variation in patterns of movement and dispersal rates of different oceanic stocks of the same species. Insight into the movement of juvenile tunas comes from classic mark-recapture studies in all three tropical oceans. In the Indian Ocean, juveniles of bigeye and yellowfin showed similar recapture patterns, with individuals reaching displacements of 900-1600 km in less than three months. These observed dispersal rates are greater than those found in the other tropical oceans, potentially due to the significant monsoon-driven climactic variability in the Indian Ocean, although spatial and temporal biases in reporting and differences in study design cannot be eliminated as explanations.

2.1.2 Differences in movement between individuals within populations

Where movement occurs across very large spatial scales at least two alternative mechanisms have been proposed that may explain how localised management in relatively small areas can produce conservation benefits. However, these mechanisms, which operate at the level of the individual, are not well represented in existing theoretical literature and are directly supported by little empirical research.

The first mechanism is based upon natural intra-species differences in movement behavior (commonly referred to as 'behavioural polymorphism'), whereby some individuals within a population are, for one reason or another, 'less mobile' than others. Differences in movement between individuals of the same species may lead to the interpretation that certain individuals with constricted movement are more to likely to remain within the boundaries of an MPA. Thus, if the proportion of these less wide-ranging individuals is large enough then populations are likely to benefit from the protection provided by MPAs.

Results from tagging studies in oceanic HMS, including tuna and billfish, have revealed considerable variation in dispersal among species, regions and individual fish (Klimley et al., 2003; Ohta & Kukuma, 2005; Domeier, 2006; Holland et al., 2009; Stevens et al., 2009; Evans et al., 2010; Meyer et al., 2010). While these results provide some indication of restricted movements for individual fish, the proportion of individuals showing movements that are significantly more restricted than other individuals in the population is generally low. It might be reasonable to assume that the proportion of 'less mobile' individuals would need to be higher in order for population-level conservation benefits to be realised. It should also be noted that pelagic MPAs targeting specific more-sedentary subsets of the population will select for such life-styles, thereby potentially modifying the genetic structure of the population (Dawson et al., 2006). Nevertheless, even relatively short residency periods within areas of habitat critical for important life history stages may produce population-level benefits (e.g. West et al., 2009). This is discussed further within 'targeted MPAs' in the following section.

A possible mechanism explaining variation in movement observed between individuals and in different regions comes from a blend of theoretical and empirical work by Humpheries et al. (2010). Observing the movements of several species of oceanic predatory fish they found differences in movement patterns to be strongly related to environmental gradients. Tagged fish showed predominantly Lévy flight movements, an efficient movement pattern characterised by long steps punctuated by short periods of localised movement, in less productive waters with sparse prey and more limited Brownian movements in productive habitats, such as shelf and convergent-front habitats.

2.1.3 Changes in movement due to habitat modification

The second suggested mechanism that may provide MPA benefits for pelagics, which also receives some theoretical endorsement from Humphries et al. (2010), is that improvement in habitat quality diminishes the dispersal of mobile species, increasing the amount of time an individual spends within the reserve.

Currently, empirical support for this mechanism comes only from reserves in coastal ecosystems. Parsons et al. (2010) found that snappers in a New Zealand marine reserve moved within a reduced home range compared to individuals outside, suggesting a response to improved habitat suitability within the reserve. Similarly, Claudet et al. (2010) reported increases in biomass for mobile bentho-pelagic species within several European MPAs, citing improved habitat quality and increased residency times within reserves as a possible explanation.

Whether this mechanism exists in the open ocean environment is unclear as the linkages between the removal of fishing pressure, improvements in habitat quality and increases in biomass of large commercially exploited HMS are poorly defined (Cox et al, 2002). The incidental impacts of fishing for offshore pelagic are instead generally related to the capture of non-target species.

Secondly, large oceanic pelagic species for which MPAs have been proposed as a management tool, such as tunas, generally forage on smaller pelagic species (e.g. *Cubiceps pauciradiatus*; Potier et al., 2008) that are subjected to only relatively weak fishing pressure. As such, significant increases in the availability of forage species within even very large pelagic MPAs are unlikely.

2.2 Mechanism 2: Protection of areas of high vulnerability

2.2.1 Theoretical basis for targeted MPAs

Given the challenges facing spatial protection of highly mobile pelagic species, such as tunas, attention is increasingly being directed towards protecting smaller areas where pelagic species spend a disproportionate amount of time, are highly vulnerable to anthropogenic pressures and/or are associated with particular life-history stages, such as spawning areas, juvenile habitats or migration routes (e.g. migrating leatherback turtles; Shillinger et al., 2008).

While many authors have identified areas that may be instrumental in the conservation of pelagic species (e.g. James et al., 2005; Louzao et al., 2006; Druon et al. 2011) real-world examples of targeted MPAs are rare and, where they do exist, appear to be incidental rather than intentional (Game et al., 2009). Consequently, support for targeted MPAs is mostly theoretical, with simple multi-patch models suggesting the greatest benefits come from protecting juvenile stages and, to a lesser extent, spawning sites and key foraging areas (Pelletier & Magal, 1996; Apostolaki et al., 2002; West et al. 2009). However, these results have yet to be fully placed in the context of general MPA models taking into account fish and fisher behavior, results of which indicate that when harvesters actively respond to spillover of adult fish across reserves boundaries, so called ‘fishing the line’, this concentration of fishing effort results in high levels of catch that can erode the core benefits of the MPA network (Grüss et al., 2011a). These results suggest that targeted MPAs for mobile species should not only protect a large number of key areas but must also be used in concert with appropriate fisheries management controls outside of MPA boundaries.

2.2.2 Identifying areas of high vulnerability

For targeted MPAs to work in practice key life stages and habitats of pelagic species must be clearly defined and identifiable. For many pelagic species, particularly cetaceans, such areas can be conspicuous and many are well documented and already under protection (e.g. Ashe et al., 2010). Long-term conservation efforts, including no-take zones, have also been directed at marine turtle and seabird nesting areas with apparent success (e.g. Taylor et al., 2000; Dutton et al., 2005; Pichegru et al., 2010).

An example of a pelagic MPA that is at least partially targeted at an area of critical habitat is the recently established South Orkneys MPA. The area, which is closed to all forms of fishing, encompasses important feeding areas for the Adélie penguin. However, while this was cited early on as an important motivation for the creation of the MPA, it was not the only objective; broader goals are to protect representative examples of benthic and pelagic habitat and provide a scientific reference site to study resource dynamics in the absence of fishing (Grant & Trathan, 2011). To date, the effectiveness of this MPA for benefiting penguins has not been measured.

Frequent association with certain habitats by oceanic pelagics has been observed in several species (Jorgensen et al., 2010; Block et al., 2011), including bluefin tuna (Royer et al. 2004; Block et al., 2005), and could flag suitable locations for targeted protection. For instance, numerous aggregations of sharks and manta rays around seamounts and nearshore coastal features have been documented (Klimley & Nelson et al., 1984; McKinnell & Seki, 1998; Litvinov, 2006; Dewar et al., 2008; Hearn et al., 2010; Oliver et al., 2011). Some vulnerable oceanic sharks are also known to associate for short periods with mobile offshore features such as fish aggregating devices (FADs) (Dagorn et al., 2007; Filmalter et al., 2011) and juvenile bluefin tuna schools have been associated with transient oceanographic features such as surface fronts and eddies (Royer et al., 2004). However, while in some instances these aggregations represent key life stages, such as in the blue shark which spends the first few years of life within nearshore and coastal habitat (Litvinov, 2006), the nature of many of these aggregations and individual residence times at aggregation sites remain unclear.

Similarly a number of studies have also observed short- to medium-term residency of tunas around certain features in the pelagic ocean, including seamounts and both drifting and anchored FADs (Fonteneau, 1991; Holland et al., 1999; Itano & Holland, 2000; Sibert et al., 2000; Klimley et al., 2003; Ohta & Kakuma, 2005), with some species showing greater vulnerability to fishing than others around these features (Itano & Holland, 2000). In general, these studies revealed transient behaviour, with residency times on the order of days to weeks. One exception is Klimley et al. (2003) that observed residency periods of up to 18 months for two (out of 23) tagged yellowfin tuna around a large seamount in the Gulf of California. These differences in measured residency times may be due to significant oceanographic differences between open ocean sites and sites within large, relatively stable embayments. Nevertheless, these results testify to the potential for residency and protection with MPAs for certain subsets of oceanic pelagic populations normally considered too highly mobile for effective conservation with MPAs.

Areas or temporal periods of high juvenile mortality can be relatively easy to identify through analysis of fisheries data. The most widely studied example of such a 'time/area closure' designed to reduce juvenile mortality of a pelagic species is that implemented by ICCAT in the eastern tropical Atlantic (Gulf of Guinea). The initial time/area closure in the early 1990s consisted of a three-month moratorium each year on FAD fishing within a known area of high juvenile catch of bigeye tuna. Although the closure resulted in an unintended response by the purse seine fleets (discussed in more detail in section 3.1), it broadly met its objectives to reduce overall juvenile mortality (Torres-Irineo, 2011).

To the best of our knowledge this ICCAT time/area closure is the only fisheries-oriented MPA that has been in place a sufficient length of time to draw conclusions on its performance (see Table 4 for a full current list of RFMO closures). Similar time/area closures in the Indian and Pacific Oceans have been established for only one or two seasons and, given the strong influence of environmental variability on catch levels in tuna fisheries, conclusions cannot yet be drawn regarding their effectiveness.

It has also been proposed that targeted pelagic MPAs need not be fixed in space and time, as are conventional protected areas, but instead could track dynamic oceanographic features or the distribution of exploited resources in real time (Hobday & Hartmann, 2006; Game et al, 2009). To date, implementation and evaluation of these 'dynamic MPA' strategies is extremely limited, possibly due to enforcement difficulties and high costs, yet Game et al (2009) reason that, with modern navigational technology and communication, it is possible to convey real-time information regarding the shifting position of an MPA to remote fishing vessels and model results suggest that this strategy may be effective for certain species with well-known and predictable patterns of habitat use (e.g., sea birds; Zydelis et al. 2011). This fairly novel use of spatial protection has already been implemented in the southern bluefin tuna (SBT) fishery off eastern Australia, where mobile fisheries restrictions based on near real-time predictions of SBT habitat are continually communicated to fishing vessels throughout the fishing season. The purpose of this arrangement is not to create no-take zones, but rather to restrict access to just those vessels that have obtained SBT quotas and reduce bycatch by vessels without quotas (Hobday & Hartmann, 2006).

2.3 Mechanism 3: Removal of incidental impacts

As mentioned previously, the greatest incidental impact of pelagic fishing is bycatch of non-target species. Discrete areas of high bycatch of pelagic species have been identified in many offshore regions (Lewison et al., 2004; Deflorio et al., 2005; Zeeburg et al., 2006; Amandè et al., 2008, 2011) as well as in nearshore areas, often associated with demersal fisheries (Murray, 2007; Warden, 2011).

However, in both offshore and nearshore systems the management of bycatch is predominantly through gear modification and other non-spatial restriction on fishing effort rather than MPAs. The use of spatial closures may do little to address the root cause of bycatch and may simply displace the problem elsewhere if there are not significant differences in bycatch rates between

MPA and non-MPA sites. For instance, Baum et al. (2003) modelled the reallocation of fishing effort from a fisheries closure in the Gulf of Mexico designed to reduce turtle bycatch, showing that the reallocated effort may result in increased total catches of certain vulnerable bycatch species even though the MPA reduces bycatch of the vulnerable species specifically targeted by the MPA (e.g., by shifting bycatch from turtles to oceanic shark species).

Nonetheless, the use of targeted MPAs to reduce bycatch of specific species or species groups may have merit in some geographical areas where distributions of vulnerable pelagic bycatch species are clearly defined (e.g. Watson et al., 2008; Slooten & Dawson, 2010). For instance, Warden et al. (2011) used statistical models to inform bycatch mitigation strategies based on the distribution of sea turtle-fisheries interactions. While these bycatch mitigation measures mostly involve the deployment of turtle excluder devices (TEDs), this approach could feasibly be used to identify candidate MPA locations. Similarly, Zydelis et al. (2011) found that dynamic habitat models were successful in explaining bycatch rates of one albatross species in the Pacific Ocean, and therefore may be appropriate for defining dynamic closures for reducing bycatch of this species, but were unsuccessful at explaining bycatch of second albatross species.

3 Pelagic MPAs and fisheries

In this section we focus on the impact of MPAs on pelagic fisheries, with emphasis on the reallocation of fishing effort by fishing fleets. We also provide a review of current fisheries closures in place throughout the major Regional Fisheries Management Organisations (RFMOs).

3.1 Impact of fisheries closures on pelagic fisheries

In many coastal systems MPAs have been shown to produce significant fisheries benefits in overexploited systems via mechanisms such as spillover or increased larval recruitment (Roberts et al., 2001; Gell & Roberts, 2003). As established in the preceding review, these same mechanisms may not exist in pelagic systems and instead MPAs may generate very different fisheries impacts.

In certain situations, where catches are deemed to be too high to be sustainable, MPAs may in fact serve as management tools to intentionally reduce fishing pressure. This was an objective in the ICCAT time/area closure in the eastern tropical Atlantic (Torres-Irineo et al., 2011).

Initially established on a voluntary basis by the European purse seine fleet the closure only affected FAD fishing for a three month window during which juvenile catches of bigeye were known to be high. However, rather than increase fishing effort on free-swimming schools within the moratorium area, which was still permitted, the response of the fleet was to continue fishing using FADs but in areas just outside the closed zone. Catches on FADs in these areas increased relative to corresponding periods in previous years (although not significantly), possibly as a response by fishers to compensate for restricted opportunities, but overall catches were lower. Consequently both the proportion and volume of juveniles in the total catch was lower as a result of the closure, thus meeting management objectives (Goujon & Labaisse-Bodilis, 2000; Torres-Irineo et al., 2011).

However, the previous example also highlights the challenge of maintaining compliance under RFMO-based management frameworks. While the FAD moratorium was largely observed by ICCAT members during the initial years, South Korean fishers working under the flag of Ghana largely ignored the closure, despite ICCAT membership and the implementation of observer programs. This lack of compliance limited the willingness of European fishers to maintain the protection plan and made scientific assessment nearly impossible, resulting in a contraction in the spatial extent of the moratorium and a shortening of its length from three months to one month per year (ICCAT, 2004).

A broadly similar example comes from the purse seine fishery in the Indian Ocean where escalating piracy activity resulted in the creation of a large *de facto* exclusion zone off the Somali coast in 2008. Although this *de facto* closure represented approximately one quarter of the total catch of the purse seine fishery between 2000 and 2005, the fleet reallocated effort to adjacent areas and maintained average catch levels and recuperated their losses, largely through an increase in FAD fishing (Chassot et al., 2010).

These two examples illustrate the importance of fisher behaviour in determining the impacts of MPAs to fisheries. In recent years, with growing recognition of the role of humans within ecological systems, there has been a proliferation of models designed to anticipate the impacts of MPAs on spatial fleet dynamics that include aspects of fisher behaviour (Pelletier & Mahévas, 2005; Fulton et al., 2011). These models vary in complexity, from those founded on simple distribution dynamics (Walters & Bonfil, 1999; Harley & Suter, 2007; Powers & Abeare, 2009; Sibert et al., 2010; Martin et al., 2011; Murua et al., 2011) to others based on detailed empirical analysis of fisher behaviour (Hutton et al., 2004; Wilcox et al., 2011).

The results of modelling exercises focused on pelagic fisheries offer varied predictions according to different assumptions of movement. Sibert et al. (2011) suggested only small changes in stock biomass and total catches of bigeye by the tuna purse seine fleet following closures in the Western Pacific. Significant conservation benefits to the stock appeared only with the complete loss of fishing effort previously in closures, and even then these benefits were quite small (less than 4 percent averaged over the simulation period).

Wilcox et al. (2011) present a more detailed model for the eastern tuna and billfish fishery off eastern Australia that allows for emergent rather than prescribed patterns of effort reallocation. Here fishing effort was redistributed from an MPA into immediately adjacent areas in such a way as to minimise operational costs and to maintain catch levels. The resulting overall profit level was marginally higher, though relative profit increased for some vessel types it decreased for others.

The examples presented above illustrate the flexibility of large-scale industrial pelagic fisheries and the mobility of vessels, which can switch from one ocean to another in a few days (e.g. Somali piracy resulted in a 30% decrease in the number of purse seiners which mainly moved toward the Atlantic Ocean; Chassot et al., 2010). As such, the impact of pelagic MPAs on fisheries, at least in terms of changes in total catch, is likely to be determined by the degree of movement by targeted species, the mobility of vessels and opportunities to exploit the stock in alternative areas, and should be evaluated on a case-by-case basis.

3.2 Existing pelagic time/area closures

The aims of pelagic area closures by RFMOs are diverse. Many of the current area closures have been established for the protection of specific benthic areas of interest such as seamounts and deep-water coral reefs (NEAFC, 2009; SEAFO, 2010) or for the protection of demersal species, including the NEAFC closures for haddock and blue ling. Several more recent closures have been established with the intention of protecting pelagic species, including both adults and juveniles (IOTC, 2010; IWC, 2011; Smith, 2011; IATTC, 2011; WCPFC, 2008). Less commonly cited reasons include the CCAMLR designated MPA as a scientific reference site (Grant & Trathan, 2011).

The aims of RFMO-established MPAs can also be fairly broad such as the protection of vulnerable marine ecosystems or the protection of biodiversity (NEAFC, 2009; Grant & Trathan, 2011), and specific intended outcomes are often unclear (IOTC SC, 2011; Murua et al., 2011, Grant & Trathan, 2011). It has been suggested that the objectives of each MPA need to be stated explicitly and where networks of MPAs are proposed, combined objectives need to be considered (CCAMLR, 2011). For instance, NEAFC have indicated that dialogue between the competent authorities on the general objectives of spatial management measures implemented by NEAFC and OSPAR would be useful (NEAFC, 2011).

The total size of RFMO closed areas is still relatively small; the area closures implemented by the WCPFC, in addition to proposed high seas expansions, are equivalent to closing 6% of total convention area (Sibert et al., 2011), and the total marine area under some form of protection within the CCAMLR Convention Area is currently 0.5% of the total Convention area (Grant & Trathan, 2011). Many of these closures apply to certain gears and during certain time periods. For instance, the IOTC time/area closure east of Somalia only prohibits purse seining and longlining for a month each year (IOTC, 2010), the WCPFC closure only applies to purse seine fishing (Sibert et al., 2011), the NEAFC closure for the protection of blue ling constitutes a ban on bottom fishing for two months of the year and the IATTC closure applies only to certain capacity classes of fleet vessels (IATTC, 2011).

Nevertheless, these closures are generally accompanied by other management arrangements including effort regulation, quotas and other protected areas. There has been an agreement by NEAFC to reduce effort in all deep-water bottom fisheries by 35% (NEAFC, 2009). The CCAMLR designated MPA is accompanied by a number of other conservation measures including Antarctic Specially Protected Areas and Antarctic Specially Managed Areas as well as areas under national jurisdictions outside the Antarctic Treaty System (Grant & Tratham, 2011). Similarly, the IOTC time/area closure is also accompanied by national closures in the British Indian Ocean Territory and Maldivian EEZs (Martin et al., 2011), and ICCAT has other management measures alongside the time/area closure including a quota system and technical modifications of longline fishing gears to reduce the catch of juveniles (ICCAT, 2011).

Currently most research appears to be focussed on appropriate area designation for MPAs, such as the research by CCAMLR into the representation of all types of geographic areas and bioregions within closures, the selection of areas of particular ecological interest for scientific research and are potentially vulnerable to human impacts (Grant & Tratham, 2011; CCAMLR, 2011), although in other regions there has been no biological rationale provided for the selection of the closed area characteristics. Areas which may have a higher degree of tuna residence, such as archipelagic waters, have the most potential for MPA success, however, they are also the most politically difficult areas to implement. Subsequently, area closures for the conservation of tropical tunas often consist of high seas areas with a general lack of geographic features that might contribute to increased residence.

There has been little evaluation of the effects of implementation of these MPAs and as information on the impacts is generally lacking, current closures are often considered to be precautionary (NEAFC, 2009). Ultimately well-defined, specific objectives by RFMOs are required so that appropriate research can be conducted to determine whether these are being realised and to provide strategic advice on the most appropriate area and time designations to enable future MPAs to achieve these specified objectives.

4 Conclusions

The science underpinning pelagic MPAs is still very much in its infancy yet there is a small but growing body of evidence supporting the use of area-based conservation in specific situations.

Differences in mobility between pelagic species appear to make some more predisposed to protection within MPAs than others. Spatial management in the pelagic environment is likely to provide the greatest benefits to less mobile species groups (small oceanic pelagics; large and small nearshore pelagics) which may gain from relatively small closures if the majority of their distribution is protected due to their limited ranges (Table 3).

Table 3 Potential mechanisms by which MPAs might provide conservation benefits for pelagic species groups

Species groups	Potential mechanism for conservation benefits	Conclusions on applicability for pelagic MPAs
Small oceanic pelagic Large nearshore pelagic Small nearshore pelagic	1, 2 & 3	More potential for less mobile species groups to be protected for a substantial proportion of their life-span, allowing mechanism 1 to work
Very highly mobile pelagic species Large oceanic pelagic (e.g. tunas) Diadromous pelagic species	2 & 3	While there is potential for benefits to be provided through targeted closures, there is still little evidence that spatial management works when fishing continues during any part of a species' life cycle.

While it has been argued that variation in patterns of dispersal between individuals might allow pelagic HMS to benefit from MPAs, this mechanism has yet to receive significant theoretical or empirical backing. Numerous observations of highly mobile oceanic species, while revealing considerable variation in the movement of individuals, consistently show movements across large spatial scales intermixed with short- or medium-term periods of apparent site fidelity.

Dispersal patterns in pelagic species are at least partially influenced by gradients in habitat quality and large scale environmental processes, with some indication that a species' mobility can vary at the regional level. While there have been few attempts to explore this facet of pelagic ecology, it is clearly an important consideration in the discussion on pelagic MPAs and should feature prominently in future research programmes.

Targeted MPAs offer perhaps the greatest potential for area-based management of very highly mobile and large oceanic pelagic species. However the success of this type of closure is dependent on whether the gains are greater than the losses generated from effort displacement outside the closure and, with few evaluations of real-world examples, it is difficult to draw definitive conclusions on their effectiveness. The impacts of such targeted closures are also highly dependent on the identification of the most appropriate areas to protect in order to provide the greatest conservation benefit. While a number of recent studies have demonstrated the potential of using species distribution models based on empirical data of behaviour and movement for the definition of areas for protection of those species where considerable data is available (e.g., some seabirds, marine mammals, turtles and sharks), additional research is necessary to determine the applicability of these results to the full diversity of pelagic species and the real-world effectiveness of these approaches in models integrating fisher response to closures.

Closely linked to this is the need for greater research into the role of human behaviour on the ability of pelagic MPAs to provide conservation benefits. Fishing fleets have demonstrated a considerable capacity to adjust fishing behaviour in response to area closures which, as well as determining the fisheries impacts of pelagic MPAs, can have bearing on the magnitude of MPA effects. Unless fish spend their entire life-cycle inside reserves, detailed observation and modelling of fishing effort displacement will be necessary to assess pelagic MPA impacts.

Undoubtedly the role of pelagic MPAs in the conservation and management of pelagic species will remain a major topic of discussion until many more documented empirical studies appear in the literature. In the meantime, whether pelagic MPAs constitute a precautionary measure in the conservation of highly mobile and large oceanic pelagic species should be explored more thoroughly by means of theoretical modelling.

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Appendix A

Table 4 Review of existing pelagic time/area fisheries closures currently set by RFMOs (with the inclusion of the OSPAR and Barcelona Conventions)

RFMO	Location/ size	Period	Stated objectives	Other	Reference
ICCAT	Eastern tropical Atlantic Northern limit: African coast Southern limit: 10 ° South western limit: meridian 5° Eastern limit: meridian 5°	Time/area closure: from 1 January to 28 February each year (effective from 2012)	To reduce catches of juvenile bigeye and yellowfin tunas and to strengthen monitoring and control measures in the fishery	Fishing or supported activities to fish for bigeye and yellowfin tunas in association with objects that could affect fish aggregation, including FADs, are prohibited: The prohibition referred to in paragraph 20 includes: - launching any floating objects, with or without buoys; - fishing around, under, or in association with artificial objects, including vessels; - fishing around, under, or in association with natural objects; - towing floating objects from inside to outside the area	ICCAT, 2011; Smith, 2011
IOTC	Indian Ocean Extending off the Somalian coast: 0 ° - 10° North and 40° - 60° East	Since 2010	Broadly for the conservation and management of tropical tunas in the IOTC are of competence	Temporal-spatial closure: IOTC Management Resolution 10/01. Closure for the month of November for purse seine fisheries and February for longline fisheries. Note: Resolution 10/01 does not explicitly define the expected objective to be achieved with the current or alternative time- area closures, and the SC and WPTT are not clear about the intended objectives of the time/area closure (particularly given recent effort reduction and likely recovery of the yellowfin tuna population).	IOTC, 2010. IOTC, 2011.
CCAMLR	The south Orkneys MPA. Large pelagic area to the south of the South Orkney Islands (2 bioregions: 6. Antarctic Shelves; 13. Weddell Gyre) CCAMLR subarea	Designated in 2009 (review due 2014)	Protection of biodiversity, facilitating maintenance of critical ecosystem processes and allowing scientists to better monitor the effects of climate change on the Southern Ocean. The area is representative of key environmental and ecosystem characteristics in the Scotia Sea	There is a CCAMLR designated MPA (Conservation Measure 91-01), designated under the General Framework for the Establishment of CCAMLR Marine Protected Areas'. The MPA contains two pelagic bioregions, an Adelie penguin foraging area, productive areas of the shelf edge, seamount ridges, important benthic shelf habitats and a range of different sea ice conditions.	WWF, 2010; Grant & Trathan, 2011.

RFMO	Location/ size	Period	Stated objectives	Other	Reference
	48.2 (Scotia Sea). pelagic bioregions 6 & 13 South Orkney Islands Southern Shelf Size: 94,000 km2		region. Protection is afforded to this area in order to provide a scientific reference site, and to conserve important predator foraging areas and representative examples of benthic and pelagic bioregions.	Fishing and discharge or refuse disposal from fishing vessels are banned.	
WCPFC	Two high seas pockets fully enclosed by EEZs bounded by 10°N and 20°S	Closed from January 2010	To curb purse seine effort to achieve a reduction in bigeye tuna fishing mortality. The overall objective of the Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean (the Convention) is to ensure through effective management, the long-term conservation and sustainable use of the highly migratory fish stocks of the Western and Central Pacific Ocean in accordance with the 1982 Convention and the Agreement.	Areas closed to purse seine fishing through conservation and management measures	WCPFC, 2008; Aranda et al., 2010. Hanich et al., 2010.
IATTC	Eastern Pacific Ocean area of 96° and 110°W and between 4°N and 3°S	29 September to 29 October	Resolution C-11-01 is for the conservation of tuna in the eastern Pacific Ocean	Closed to the purse-seine fishery for yellowfin, bigeye and skipjack tuna	IATTC, 2011.
IATTC	Eastern Pacific Ocean	From 2011 the fisheries will be closed for 62 days: either from 29 July to 28 September,	As above	Purse-seine vessels of IATTC capacity classes 4 to 6 and longline vessels >24m.	IATTC, 2011.

RFMO	Location/ size	Period	Stated objectives	Other	Reference
		or from 18 November to 18 January.			
IWC	Antarctic: south of 40°S between longitudes 70°W and 160°W Indian Ocean: extending to 55°S. Southern Ocean : 40°S parallel of latitude except around South America and into the South Pacific where the boundary is at 60°S	Antarctic since1938, Indian Ocean since 1979, Southern Ocean Sanctuary since 1994	"To provide for the proper conservation of whale stocks and thus make possible the orderly development of the whaling industry"		IWC, 2011.
Barcelona Convention (in the GFCM area)	Ligurian basin, approximately 84,000 km²	Established on 25 November 1999	To conserve amongst other things: *"the components of biological diversity in the Mediterranean, ecosystems specific to the Mediterranean area or the habitats of endangered species , are of special interest at the scientific, aesthetic, cultural or educational levels"*. Article 8(2)	The Pelagos Sanctuary for Mediterranean Marine Mammals. This is one of a list of Special Protected Areas of Mediterranean Interest (SPAMI).	http://www.cetaceanhabitat.org/pelagos.php http://www.biodiversitya-z.org/areas/31
OSPAR Convention	Six protected areas that together cover 286,200km² of the North-East Atlantic	September 2010	To "protect and conserve the biological diversity of the maritime area and its ecosystems which are, or could be, affected as a result of human activities, and to restore, where practicable, marine areas which have been adversely affected" This includes the necessity to represent all types of habitat and species and for the network to exhibit connectivity.		O'Leary et al., 2012