Review of the Southern Ocean Sanctuary: Marine Protected Areas in the context of the International Whaling Commission Sanctuary Programme

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ABSTRACT

This scientific review of the Southern Ocean Sanctuary (SOS) was commissioned by the IWC Scientific Committee and presented to the IWC Steering Committee on 27-28 June 2004. This review addresses a number of questions related to the effectiveness of the SOS and provides recommendations on how to incorporate Marine Protected Area (MPA) concepts into the SOS and the IWC Sanctuary programme. Overall, the SOS – and IWC Sanctuaries in general – are based on vague goals and objectives that are difficult to measure, lack a rigorous approach to their design and operation and do not have an effective monitoring framework for evaluation. In particular, the SOS represents a 'shotgun' approach to conservation, whereby a large area is protected with little apparent rationale for boundary selection and management prescriptions within the sanctuary. While a vast array of ecosystem-level and precautionary conservation benefits have been invoked for the establishment of the SOS, in reality this sanctuary does little more than provide a false sense of security by assuming that broad protections for whale populations are in place. The SOS was designed to restrict commercial harvests from the low latitude feeding grounds occupied by large whales during the austral summer. However, the SOS does not protect against or mitigate other threats to Southern Ocean whale stocks and the marine ecosystems upon which these populations depend, including pollution, habitat degradation and loss, introduced species and global climate change. We thus contend that sanctuary establishment and evaluation should be guided by a series of measurable and tangible goals, aimed at quantifying the status of both the 'protected' species under consideration and their role in the broader marine ecosystem. In particular, the SOS could be improved substantially to become an important part of IWC management and the larger conservation of Southern Ocean marine ecosystems, if the following steps were implemented: (a) development of formally stated goals (e.g. biodiversity protection, fisheries enhancement); (b) establishment of measurable objectives with which to assess progress towards attaining these goals; (c) creation of a formal management plan, including the establishment of a monitoring framework; and (d) development of more appropriate review criteria, reflecting the ecological objectives of the management plan.

KEYWORDS: SOUTHERN OCEAN; SANCTUARIES; CONSERVATION; MARINE PROTECTED AREA; MARINE RESERVE

INTRODUCTION

Article V of the International Convention on the Regulation of Whaling (the 'Convention' signed in 1946) permits the designation of sanctuaries (IWC, 2006a). In designating a sanctuary under the auspices of the Convention, the only regulatory measures that can be taken involve prohibiting the harvest of all whale species at any time from a specified geographic area, irrespective of their conservation status. A sanctuary in the South Pacific sector of the Southern Ocean was established in 1949. It was deregulated on the advice of the IWC Scientific Committee in 1955 in an attempt to relieve pressure on the other, overexploited areas of the Antarctic (IWC, 1955). Since then, two additional sanctuaries have been adopted: the Indian Ocean Sanctuary (IOS) in 1979 (renewed in 2002) and the Southern Ocean Sanctuary (SOS) in 1994 (Fig. 1). Additional sanctuary proposals in the South Atlantic and the South Pacific Oceans have been tabled at recent IWC annual meetings (IWC, 2004c, pp.372-4; IWC, 2001b, pp.65-7; IWC, 2001a, pp.17-9; IWC, 2000, pp.14-7; IWC, 2002, p.67).

In 2003, the IWC directed the Scientific Committee to undertake a decadal (1994-2004) review of the SOS (IWC, 2004b, pp.47-50). We were appointed by that body to review the effectiveness of the SOS in meeting its objectives and provide general advice on the value of MPA concepts to existing and proposed IWC Sanctuaries, including the establishment of sanctuary monitoring programmes. In particular, we were asked to evaluate the following:

(1) whether the SOS contributes to the recovery of whale stocks;
(2) how the SOS can advance the knowledge of whale stocks and their environment;
(3) whether the SOS boundaries were appropriately established; and
(4) how MPA concepts might be incorporated into the SOS and other IWC Sanctuaries.

ESTABLISHMENT AND HISTORY OF THE SOS

The original SOS proposal stated that the primary purpose of this sanctuary was to

> 'contribute to the rehabilitation of the Antarctic marine ecosystem by reinforcing and complementing other measures for the conservation of whales and the regulation of whaling, in particular by the protection of all Southern Hemisphere species and populations of baleen whales and the sperm whales on their feeding grounds' (IWC, 1993).

The SOS, however, was established after the 'moratorium' on global commercial whaling (Paragraph 10e of the Schedule, e.g. IWC, 2006a), which sets commercial whaling catch limits to zero for all species in all areas, irrespective of their conservation status. Thus, the moratorium, adopted in 1982 and implemented in 1985 and a *de facto* global sanctuary was in place before the establishment of the SOS.

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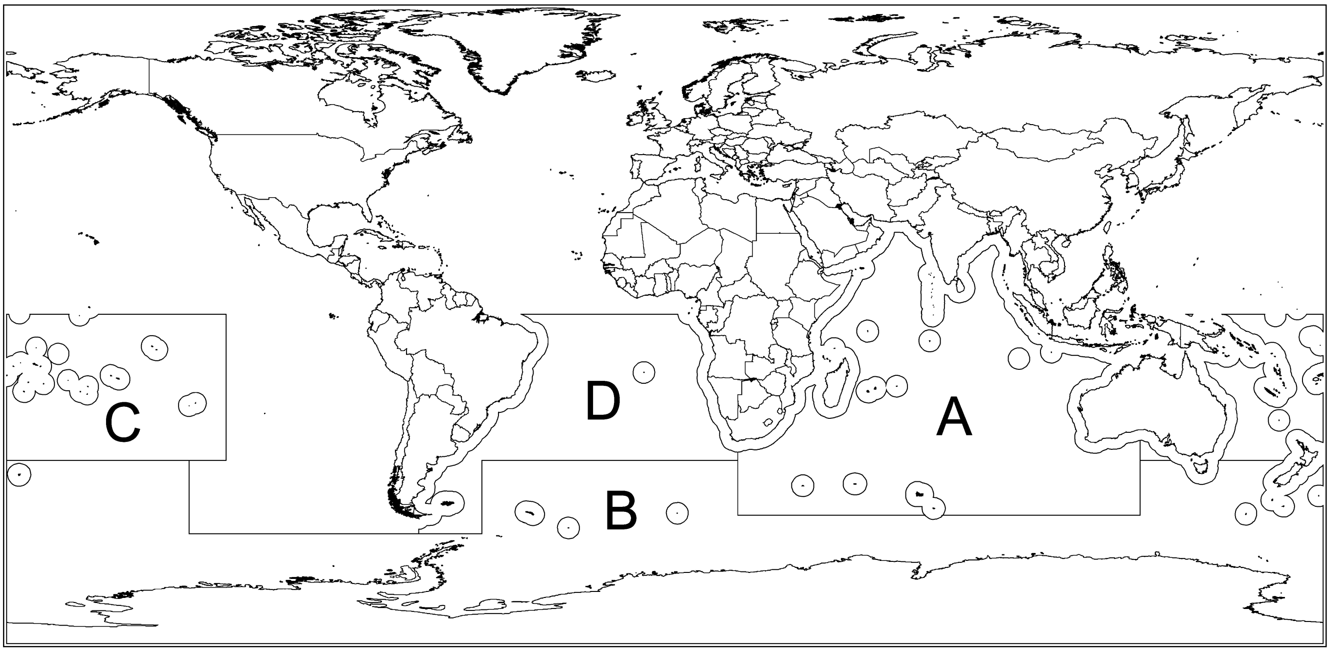

Fig. 1. Map of existing International Whaling Commission (IWC) Sanctuaries in the Indian (A) and Southern (B) Oceans. Proposals for the establishment of the South Pacific (C) and South Atlantic (D) Ocean Sanctuaries failed to gain the required three-quarters majorities at the 56th annual IWC meeting, held in Sorrento (Italy) from 19-22 July 2004.

Critics of the SOS, therefore, have alleged that its establishment reflected a desire to prevent commercial whaling for Antarctic minke whales being allowed if the Revised Management Procedure (RMP), a science-based harvest framework within the broader Revised Management Scheme (RMS) intended to replace the current moratorium. The RMP is a very conservative management approach that takes scientific uncertainty explicitly into account. It would allow limited sustainable whaling on populations meeting certain conditions. No catches would be allowed for any populations below 54% of their estimated unexploited level, with an ultimate general aim of stabilising these populations above the MSY level (e.g. Donovan, 2002; Hammond and Donovan, In press).

In response to a number of criticisms, IWC Resolution 1998-3 outlined a broader set of scientific objectives for the SOS (IWC, 1999):

(1) the recovery of whale stocks, including the undertaking of appropriate research upon and monitoring of depleted populations;
(2) the continuation of the Comprehensive Assessment of the effects of setting zero catch limits on whale stocks; and
(3) the undertaking of research on the effects of environmental change on whale stocks.

The SOS currently prevents commercial whaling being allowed on any nine migratory species/subspecies of large cetaceans in their summer feeding grounds: ‘true’ blue whale (*Balaenoptera musculus musculus*) and pygmy blue whale (*B.m. brevicauda*); fin whale (*B. physalus*); sei whale (*B. borealis*); Antarctic minke whale (*B. bonaerensis*); dwarf minke whale (*B. acutorostrata*); humpback whale (*Megaptera novaeangliae*); southern right whale (*Eualaena australis*) and sperm whale (*Physeter macrocephalus*). Had the RMP been implemented, catches would only have been allowed on one of these, the Antarctic minke whale. Whaling, however, is currently occurring in the SOS under special permit. Article VIII of the Convention permits any contracting government to authorise its nationals to kill, take, or treat whales for scientific research purposes (IWC, 2006a). Japan harvested up to 440 Antarctic minke whales annually from 1987/88-2004/05 under scientific permits within the SOS; it has since increased this under a new programme to up to 935 Antarctic minke whales and 10 fin whales with the possibility of increasing the number of fin whales to 50 and adding 50 humpback whales after 2006/2007 (IWC, 2006b, pp.48-9). The total abundance of Antarctic minke whales was estimated at 761,000 (95% CI=510,000-1,140,000) during the period 1982/83–1988/89, with more recent estimates under revision (e.g. see IWC, 1991).

REVIEW OF THE SOUTHERN OCEAN SANCTUARY

The SOS (and indeed IOS) lack formally stated goals (e.g. biodiversity protection, fisheries enhancement) and measurable objectives (e.g. recovery targets), without which it is impossible to assess the effectiveness of sanctuary establishment. Consequently, the SOS lacks a formal management plan that specifies objectives in a quantitative manner and provides clear strategies for achieving these goals (e.g. protection of feeding grounds, reducing noise pollution in critical areas, integration with the RMP). It should be noted that given the limitations of the IWC Convention to the regulation of whaling, achieving such goals would require cooperation with other bodies. Similarly, as will be discussed further below, it lacks an appropriate monitoring plan. These fundamental steps in the design and management of marine reserves will be required to incorporate MPA principles into the IWC Sanctuary programme.

The following sections of our review correspond to the questions posed to us by the IWC Scientific Committee.

Contributions of the SOS to the recovery of whale stocks

Given that the moratorium on commercial whaling was instituted prior to the establishment of the SOS, the direct contribution of this sanctuary to the recovery of whale stocks cannot easily be determined given the lack of empirical evidence. In the absence of a formal definition of 'recovery' we have chosen to base it on the concept behind the RMP[1] and consider it as achieving a population approximately 72% of its unexploited level. While it is true that whales are protected from commercial whaling within the SOS, this protection is effectively redundant as long as the moratorium remains in place. If commercial whaling were to resume under the RMP (which only applies to baleen whales and only allows catches from stocks above 54% of their unexploited size), the SOS would prevent commercial catches of stocks for which the RMP would allow catches within its boundaries – at present this would probably only apply to some stocks of Antarctic minke whales – the RMP would probably indicate catch limits of zero for the other stocks of baleen whales for the near-mid future. However, as all baleen whales species and their constituent populations migrate outside of the SOS, it can be said that this sanctuary does not *fully* protect Southern Ocean large whale species (Davies and Gales, 2004) since catches can be taken outside the SOS boundaries. Only in the Indian Ocean, where the IOS and SOS are adjacent, would the existing IWC sanctuaries protect certain baleen whale stocks during their entire latitudinal seasonal movements. In effect, the value of the SOS and IOS in terms of providing complete protection from whaling (including preventing commercial whaling on stocks for which the RMP would allow catches), will ultimately depend on the discrete nature of Indian Ocean whale stocks. In other words, due to its limited extent, the current configuration of the SOS will probably fail to fully protect large whale populations, in the absence of a well-managed fishery management programme (i.e. RMP). More study is required, however, to evaluate this statement for specific stocks and species, within a broader ecological context of predator-prey dynamics and climatic variability (Hewitt *et al.*, 2002; Mackinson *et al.*, 2003). In particular, the uncertain structure of Southern Ocean whale stocks is a critical consideration for the design of IWC sanctuaries (Davies and Gales, 2004; Hucke-Gaete *et al.*, 2004; Stafford *et al.*, 2004).

Currently, the degree of protection afforded by the SOS to different whale stocks/populations as a refuge from future commercial harvesting is dictated by their natural history (e.g. extent of seasonal migrations, location of summer-time foraging grounds) rather than by their status (e.g. whether they actually require this protection or not). Some additional level of protection in important (e.g. 'critical' or 'vulnerable') areas at key times would benefit whales within the SOS. Examples of this enhanced protection include prohibitions on activities that impact whales (e.g. vessel strikes), their prey (e.g. commercial fisheries), or their habitats (e.g. pollution). In addition, because certain areas currently within the SOS may not contribute to the IWC mandate and objectives (e.g. not used by large cetaceans for any aspect of their life history), they could be removed from the Sanctuary in exchange for more stringent and appropriate prohibitions in more important habitats located within the SOS (e.g. foraging grounds) or elsewhere (e.g. breeding grounds). Most research into habitat-based harvest management and MPAs suggests that integrated management approaches, capable of merging fishery closures with additional regulations and protections, are most effective at meeting Sanctuary goals and conservation objectives, especially for far-ranging species (Boersma and Parrish, 1999; Gilman, 2001).

[1] Given the variety of scenarios tested under the RMP, there is no formal goal – 72% represents the 'tuning' level chosen to compare candidate procedures performance after 100 years for a specific trial (Hammond and Donovan, In press)

Contributions of the SOS to the knowledge of whale stocks and their environment

One of the primary anticipated benefits of establishment of the SOS was to create an area where whales would be studied in the absence of commercial harvest. Similarly, many MPAs and sanctuaries are designed to provide baselines to gauge ecological change in areas beyond their boundaries (e.g. Murray *et al.*, 1999; Ainley, 2003). However, because the SOS was established after the moratorium, it could not provide supplemental ecological information for comparing harvested and non-harvested whale populations. Thus, a major potential scientific benefit of sanctuary establishment did not materialise.

The SOS has been credited with fostering a number of ongoing cooperative and integrative research programmes in the Southern Ocean, including multi-national photo-identification studies, international ecosystem research cruises and coordinated surveys of whale distributions and oceanographic conditions. Compared to most other MPAs, however, the number of investigations carried out as a result of the SOS has been limited and is difficult to evaluate. Sanctuary designation has not appeared to result in a significant increase in the number or size of non-lethal research programmes, compared with non-sanctuary areas. Nevertheless, we identified some ongoing research efforts within the SOS, including cooperative studies involving non-governmental organisations and university researchers (e.g. Stevick *et al.*, 2004), collaborative cruises between CCAMLR and Southern Ocean GLOBEC (Hofmann *et al.*, 2002; Thiele *et al.*, 2004), the IWC-SOWER programme in the western Antarctic Peninsula (2001-2004) (Ensor *et al.*, 2004) and studies between the IWC and CCAMLR (1999-2004) (Gillespie, 1997; Leaper and Scheidat, 1998; Leaper and Papastavrou, 1999; Thiele *et al.*, 2004).

Additionally, large-scale monitoring programmes of other upper-trophic consumers (e.g. pinnipeds and seabirds) and their prey (e.g. Antarctic krill, *Euphausia superba*) are underway, under the auspices of CCAMLR and national research programmes throughout the Southern Ocean (Boyd and Murray, 2001; Croxall *et al.*, 1999; Hewitt *et al.*, 2002; Inchausti *et al.*, 2003; Woehler, 1997). What regional cooperation that does exist appears to be directed at the continuation of the SOS and the establishment of additional sanctuaries. The presumed but unstated rationale behind these efforts appears to be to achieve the precautionary exclusion of whaling from ecologically important areas, in advance of the potential resumption of harvesting under the RMP. While a laudable social goal for some cultures, these are not scientific aims and therefore cannot be regarded as regional cooperation in the context of this review.

In contrast, the IOS does appear to have fostered some cooperative efforts among regional nations and government and non-government organisations (De Boer *et al.*, 2003), although progress towards this has been relatively slow (e.g. see Leatherwood and Donovan, 1991). This may be a function of the number of countries adjacent to the IOS, the encouragement and publicity the establishment of a sanctuary gave to local researchers, and to some extent opportunity the sanctuary afforded the research community to compare protected whale populations in the Indian Ocean with areas in which whaling continued, at least prior to the establishment of the moratorium. While similar collaborative efforts are underway for the SOS (e.g. Van Waerebeek *et al.*, 2004), it is difficult to evaluate to what extent the creation of this sanctuary motivated and facilitated these synthetic studies.

While designation of IWC Sanctuaries (such as the SOS) is not required to initiate discussions between various jurisdictions and stakeholders, such sanctuaries should provide a focal point for discussions, just as the Particularly Sensitive Sea Area programme has done (Gjerde, 2001). MPA designations in other parts of the world have resulted in significant increases in the amount of research conducted in their waters (e.g. Murray *et al.*, 1999; Halpern, 2003). This may be a temporary benefit; however, as the current interest in MPAs may wane and a lack of future funding may pose additional limitations.

A stated objective of the SOS is to compare stocks within and outside of the boundaries of the protected area. However, because the SOS encompasses the entire Southern Ocean south of 60°S and much of it south of 40°S (see Fig. 1), i.e. much of the feeding grounds of baleen whales, whale stocks within the Sanctuary must be compared to stocks in warm temperate oceans north of 40°S, where threats to whales may be entirely different or of an unequal magnitude. In addition to this logistical difficulty, this approach is fraught with a deeper conceptual limitation. This 'use' of the SOS assumes that comparisons between harvested and non-harvested populations are inherently valid. There are a number of difficulties with this assumption that inhibit comparisons across ocean basins, including:

(a) potential large-scale differences in the effects and impacts of climatic variability (e.g. magnitude and time lags between local changes in ocean productivity and the Southern Oscillation Index);
(b) changes to the rest of the food chain via anthropogenic activities (e.g. loss of the prey base due to competition with fisheries and global climate change); and
(c) additional human impacts, including incidental mortality (e.g. bycatch and ship strikes), habitat degradation and loss (e.g. plastic and acoustic pollution) and introduced species are not uniformly distributed throughout the global ocean.

In particular, the connectivity with the IOS may compromise any comparisons between the Indian Ocean sector of the SOS and other ocean basins where whaling might be permitted. Furthermore, because the SOS encompasses most areas south of 40°S, potential comparisons would likely have to be restricted to those stocks that either do (e.g. harvested outside of SOS) or do not (i.e. protected from harvest throughout life cycle) migrate outside of the Sanctuary waters. Other practical difficulties in making comparisons and detecting changes have been discussed by Butterworth and Punt (1994) and Butterworth and De Oliveira (1994). Additionally, the whaling versus non-whaling comparison does not consider the potential confounding effects of illegal harvesting, regional disparities in the competition of whale stocks with other upper-trophic predators consuming the same marine resources (e.g. penguins, pinnipeds, petrels) and the inability to detect a recovery in depleted whale populations depressed from past commercial whaling. These two artefacts may yield statistically insignificant comparisons within and between established sanctuaries. While illegal whaling, like other illegal – unreported – unregulated (IUU) fishing activities, is difficult to quantify, there is abundant evidence of the dietary overlap and the fluctuations of many Southern Ocean predator populations (Croxall, 1992; Croxall *et al.*, 1999; Woehler, 1997). Therefore, any geographic comparison across ocean basins should incorporate an understanding of potential spatial/temporal overlap and competition with fisheries and other upper-trophic consumers of whale prey.

Ecological appropriateness of the SOS boundaries

Evaluating the ecological appropriateness of the SOS boundaries is difficult in the absence of a set of formally stated goals and objectives that specifically outline the purpose of the Sanctuary. While there is some broad ecological, biogeographic and oceanographic rationale for the current boundary, the extent of the SOS does not generally conform to the established principles of reserve design (Fig. 2). These include delineating boundaries based on biological, oceanographic and physiographic criteria such as the distributions of water masses, ocean productivity domains, marine communities and 'protected' species (Hooker *et al.*, 1999; Probert, 1999; Hyrenbach *et al.*, 2000; Zacharias and Roff, 2000).

It seems clear that the SOS would benefit by drawing on lessons learned from previous case studies of reserves for wide-ranging species (summarised in Hooker and Gerber, 2004) and from other initiatives directed at identifying important migration routes and foraging grounds of other upper-trophic marine predators (e.g. seabirds, pinnipeds) throughout the Southern Ocean (e.g. Croxall and Wood, 2002; Nel and Taylor, 2003). Gerber *et al.* (2005) modelled changes in population growth rates (λ) as a result of hypothetical changes in the rate of dispersal from sanctuary to non-sanctuary areas. In the future, researchers may wish to contrast the implications of specific sanctuary boundary designs by using an expanded version of this generalised demographic model, capable of incorporating species-specific movement data.

The SOS boundary appears to have been delineated primarily through a socio-political compromise (notably with respect to EEZs between 40°S and 60°S), with some consideration given to the multiple species it is designed to protect. Given its stated multi-species objectives, the delineation of the sanctuary boundaries will have to reconcile many compromises.

From an ecological perspective, the following aspects of the SOS boundary are probably appropriately established:

(a) the boundary meets with that of the IOS to preserve a contiguous marine area, thus ensuring connectivity between the IOS and SOS (Fig. 1);
(b) the 40°S latitude boundary is roughly consistent with a zone of transition between warm-water and cold-water temperate biogeographic domains associated with the location of the Subtropical Convergence, a broad (~100km) frontal region where subtropical and sub-Antarctic waters converge as a result of the prevalent large-scale wind patterns (Sverdrup *et al.*, 1942; Rio and Hernandez, 2003) – however, the frontal boundaries between these distinct water masses vary both spatially and temporally (Belkin and Gordon, 1996; Kostianoy *et al.*, 2004; Fig. 3); and
(c) it meets a general criteria that a single, large reserve is more beneficial than several small reserves (the SLOSS

– Single Large Or Several Small debate) – although this does not particularly reflect the ecological choice of boundaries, merely that the area it covers is very large.

From an ecological perspective, the following aspects of the SOS boundary are probably not appropriately established:

(a) although the SOS encompasses a variety of large-scale oceanographic habitats, spanning from the Subtropical Convergence (~35-45°S) south to the permanent ice sheet (~65-75°S), several biogeographic domains and water masses are not represented within this sanctuary (Longhurst, 1998), thus providing a poor degree of representativity;
(b) the boundary does not contour to any particular oceanographic (e.g. water temperature) or physiographic (e.g. depth) characteristic(s) other than latitude and distance from territorial waters;
(c) there is no ecological basis for the manner in which the existing boundary excludes waters around landmasses – if the SOS must avoid large landmasses then its boundary could at least be delineated on the basis of biological (e.g. neritic vs. pelagic zooplankton communities), oceanographic (e.g. pycnocline depth), or physiographic (e.g. location of the 200m continental shelf break) which show some relationship to marine community types and ocean productivity patterns;
(d) good conservation reserve design favours 'smooth' reserve boundaries; square corners such as those around territorial waters should be avoided to minimise the impacts of detrimental edge effects;
(e) the boundary is static in space and time and does not reflect seasonal changes in the spatial configuration of current systems, ocean productivity patterns and marine communities (Figs 2 and 3); and
(f) while the SOS is large, several migratory species cross the boundary on their migration routes.

In conclusion, while the SOS boundary appears to have been based primarily on socio-political considerations, certain aspects of the SOS are ecologically justified. Overall, however, boundary adjustments to better reflect ecological processes and structures in the Southern Ocean would prove more effective in achieving the objectives of the Sanctuary. For instance, the now widespread use of GPS navigation equipment facilitates the design (and enforcement) of more complex boundaries, which could follow specific physiographic features and even be dynamic in nature to accommodate spatial and temporal variability in the underlying oceanography (Hyrenbach *et al.*, 2000). This approach would allow reserves to encompass dynamic habitats by shifting location, thus avoiding a major detrimental by-product of MPA designation. Sitting reserves in 'poor' habitats (i.e. sinks) may have the effect of increasing fishing pressure in the 'good' habitats (i.e. sources), resulting in a downward spiral of the whole network as sinks rely on source areas for propagules. In the case of Southern Ocean whales, differences in diet (krill-feeding mysticetes, squid-eating odontocetes), foraging habitats (ice leads, pack ice, open water) and biogeographic affinities (water masses, degree of association with sea ice) will likely influence community structure over time and space and therefore boundary location (Ainley *et al.*, 1986; Stahl *et al.*, 1985; Tynan, 1998). In addition to changing the extent and location of the SOS, the inherent nature of the

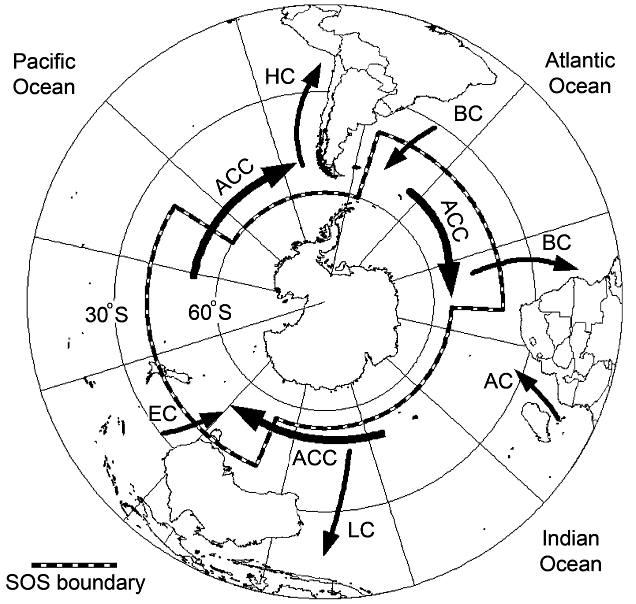

Fig. 2. Map of the Southern Ocean, showing the extent of the SOS (dashed line) and a conceptual representation of the major oceanographic fluxes influencing the distributions of water masses and prey community structure along sanctuary boundaries. The arrows show the generalised flow of the major currents in this region: the Antarctic Circumpolar Current (ACC) flowing eastwards around Antarctica; the northward-flowing eastern boundary currents in the Atlantic (Benguela Current, BC), Pacific (Humboldt Current, HC) and Indian (Leeuwin Current, LC) Oceans; and the southward-flowing western boundary currents in the Atlantic (Brazil Current, BC), Pacific (East Australia Current, EC) and Indian (Agulhas Current, AG) Oceans.

sanctuary boundaries (static vs. dynamic, core area surrounded by buffers) may change if MPA design concepts are incorporated into the IWC Sanctuary programme.

INCORPORATION OF MPA CONCEPTS INTO IWC SANCTUARIES

Applications of MPAs to marine mammals

Marine reserves are a relatively new approach to marine conservation, with the vast majority of the relevant theory published since 1992 (see Gerber *et al.*, 2003 for a review). MPAs (IWC Sanctuaries are a type of MPA that prohibits commercial exploitation of a particular taxon) can be effective tools for the conservation and management of marine resources (Duggan and Davis, 1993; Gell and Roberts, 2003; Halpern, 2003; Hooker and Gerber, 2004; Roberts and Hawkins, 2000). To date, marine reserve models have largely focused on questions concerning fishery management, with most studies concluding that reserves increase yield when populations would otherwise be overfished. However, few of these existing single-species models have considered all life stages, thereby failing to acknowledge that most marine organisms are wide-ranging and have life history stages that occur in very different habitats.

Currently, marine sanctuaries are being established worldwide on the basis of their marine mammal or bird fauna (for examples see Hooker and Gerber, 2004). However, designation of MPAs for slow growing, long-lived species such as marine mammals and seabirds has largely taken place without ecological input. There is little systematic theory for how to select, design and monitor reserves implemented to protect marine mammals. In

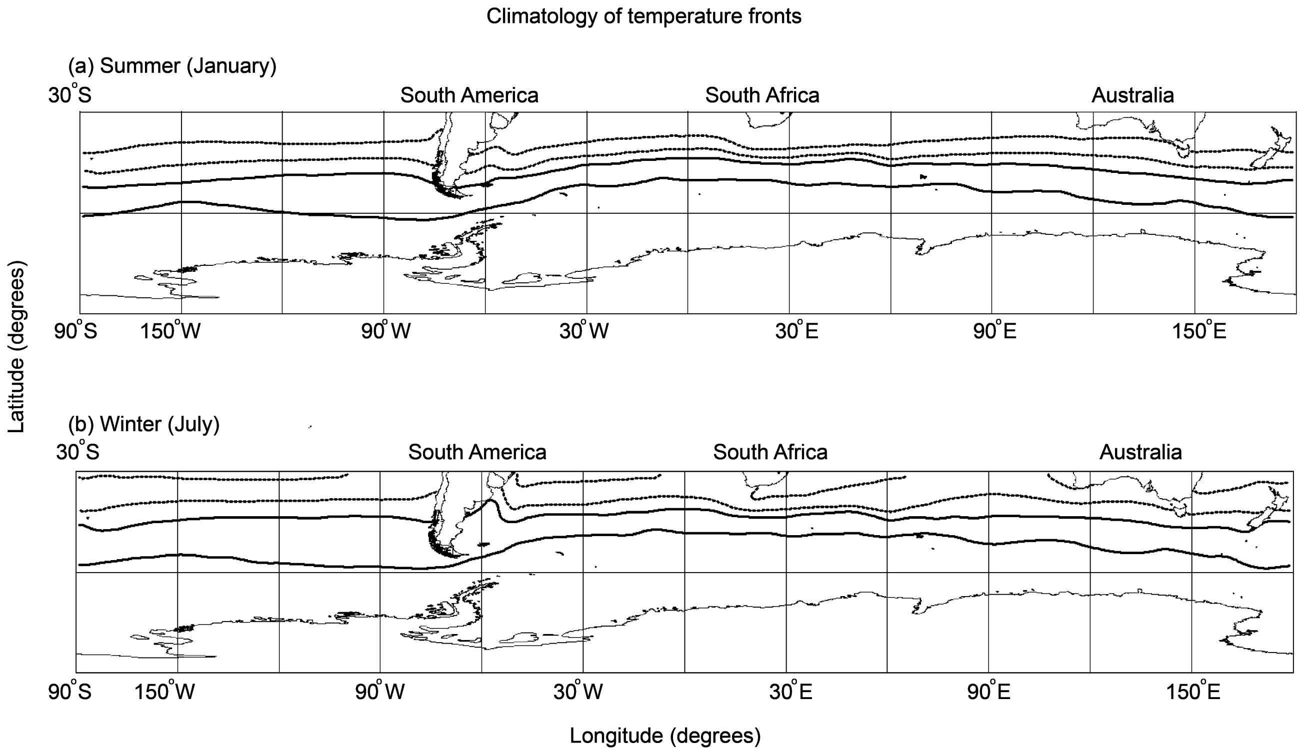

Fig. 3. Seasonal variability in the location of major oceanographic fronts throughout the Southern Ocean, as revealed by the average sea surface temperature (SST) conditions during (A) summer and (B) winter since the SOS was established (1994-2004). These monthly Reynolds Optimally Interpolated Sea Surface Temperature data, with a spatial resolution of 1°×1°, are publicly available at the Jet Propulsion Laboratory's Physical Oceanography Distributed Active Archive Center (PODAAC) server (*http://podaac.jpl.nasa.gov/*). Four frontal systems, mapped using the location of a specific surface isotherm, are plotted from south to north: the polar front (4°C), the sub-Antarctic front (10°C), the southern subtropical front (13°C) and the northern subtropical front (17°C). The extent of the Subtropical Convergence (dashed lines), separating sub-Antarctic waters to the south from sub-tropical waters to the north, is generally delineated by the location of the 13°C and 17°C surface isotherms (Belkin and Gordon, 1996; Kostianoy *et al.*, 2004).

protecting a specific population, the optimal protected area would encompass that population's year-round distribution, which is often very large. However, most migratory species have certain critical periods and/or areas in their life cycles in which they congregate for a number of reasons (e.g. staging, foraging, breeding) and are vulnerable to human activities such as capture or pollution (Roberts and Hawkins, 2000). In addition, oceanic and coastal physiography often concentrates migratory species into 'bottlenecks' (e.g. passages, lagoons) where they become more vulnerable to harvest. Since several of the threats faced by marine mammals are either incremental (e.g. pollutant exposure) or instantaneous (e.g. acoustic pollution, fishery bycatch), well-sited MPAs may protect whale populations from specific threats within areas of aggregation during critical times.

Developing a robust MPA design for wide ranging species is challenging. Comparisons of stocks/species with different life-history characteristics (e.g. diets, habitats, migrations) within sanctuary waters may be as ecologically insightful as regional comparisons of the trends and status of the same species in different geographic areas. In addition to these comparisons across whale stocks and species, broad sanctuary management plans may take advantage of ancillary data from other ecosystem constituents, including upper-trophic consumers (e.g. seabirds, pinnipeds) and lower-level prey species (e.g. Antarctic krill, *Euphasia superba*) (Agnew, 1997; Croxall, 1992). Two types of upper-trophic predator data might be especially valuable to quantify fluctuations in the food-web structure supporting Southern Ocean whale populations: (a) measures of predator dispersion and overall abundance at-sea (e.g. Hunt *et al.*, 1992; Woehler, 1997); and (b) colony-based information on predator diet composition, foraging effort and reproductive success (e.g. Boyd and Murray, 2001; Croxall *et al.*, 1999). In addition to an understanding of the life-history (e.g. recruitment) and the dispersion (e.g. patchiness) of the prey itself, information on other krill consumers will be essential to interpret the geographic comparisons of whale stocks (e.g. Hewitt *et al.*, 2002; Miller and Hampton, 1989). Furthermore, an enhanced understanding of prey availability and consumption will serve as the foundation for the establishment of a precautionary ecosystem-level management plan to protect Southern Ocean upper-trophic predators (whales, seabirds, pinnipeds) from competition with fisheries (Boyd, 2002; Hewitt *et al.*, 2002). Similar considerations have been used to gauge the trophic implications of MPAs and ecosystem-level management plans in other oceanic regions (e.g. Hunt *et al.*, 2000; Hooker *et al.*, 2002).

MPA goals

Fundamentally, MPAs can be considered to have two primary goals; the first is to preserve biodiversity and the second is to produce the highest fishery yields (Hastings and Botsford, 2003). While it may be possible to configure a single MPA to reconcile both of these goals, there has been little work on identifying how specific design concepts can advance these biodiversity and fishery reserves. Generally, MPAs designed to conserve biodiversity favour larger areas that encompass the dispersal distance for recruits. Conversely, protected areas designed to enhance production for sessile species tend to be small, to maximise larval export (Hastings and Botsford, 2003), but may have to be large when dealing with highly mobile pelagic taxa (Parrish, 1999).

A broader suite of goals has been proposed for MPAs, which generally include:

(a) scientific research;
(b) wilderness protection;
(c) preservation of species and genetic diversity;
(d) maintenance of environmental services;
(e) protection of specific natural and cultural features;
(f) tourism and recreation;
(g) education;
(h) sustainable use of natural resources;
(i) restoration or rehabilitation of communities and ecosystems; and
(j) maintenance of cultural and traditional attributes (after Airame *et al.*, 2003; Kelleher, 1999; Murray *et al.*, 1999).

Many MPA efforts utilise a variety of objectives to further articulate the goals listed above. Objectives in support of the goals outlined above, include the conservation and protection of the following:

(a) commercial and non-commercial fisheries resources, including marine mammals and their habitats;
(b) endangered or threatened marine species and their habitats;
(c) unique habitats and endemic taxa; and
(d) areas of high biodiversity or biological productivity.

Additionally, MPA objectives focused on biological attributes are often restated in terms of their degree of biogeographic representation. In terms of whale conservation and management these include:

(a) the protection of larger mobile, entirely marine and generally seasonally migrant species;
(b) the protection of mobile marine species referenced to the land environment (e.g. nesting sea birds, pinnipeds);
(c) the conservation of rare/endangered or isolated populations and communities of benthic species, including areas of high local biodiversity for specific taxa;
(d) the preservation of specific habitats and their associated communities of the wider marine environment (also known as representative habitats);
(e) the sustainable management of natural marine resources such as fisheries (and fishing/spawning areas) that may not be captured under (a) above; and
(f) areas of high productivity/predictable upwelling/ retention (after Murray *et al.*, 1999; Palumbi, 2001; Roff *et al.*, 2003).

Selection and boundary delineation of MPAs

At the highest level, MPAs can be selected on the basis of biological, oceanographic, physiographic, socio-cultural, political and economic criteria. The goals of the SOS, as currently stated, appear to balance a number of ecological criteria – management of harvested species and ecosystem-level conservation – as well as other socio-political considerations (IWC, 1993). Reserves designed to either preserve biodiversity or enhance fisheries, however, are generally based on biological criteria (e.g. aggregations of fecund individuals, larval nurseries; Botsford *et al.*, 2003). When biological information are not available, oceanographic and physiographic proxies (frequently termed 'habitat' variables) are often used when the associations between these proxies and a population, species, or community is known. Species or communities may, for example, be linked to specific habitat structures (e.g. depth + substrate + temperature) or processes (e.g. upwelling + disturbance regimes + seasonal salinity/ temperature variability). Several families of multivariate statistical methods are used for this purpose, though not all have yet been applied to marine environments (Carpenter and Gillison, 1993; Guisan and Zimmermann, 2000; Elith and Burgman, 2003).

Biological, oceanographic and physiographic variables can be used to identify a number of criteria for MPA delineation:

(a) representation;
(b) distinctiveness;
(c) sensitivity;
(d) vulnerability;
(e) critical areas and life stages;
(f) hotspots of diversity (taxonomic or genetic);
(g) rare and endemic species;
(h) areas subject to frequent or natural disturbance;
(i) species of special concern and critical life history stages;
(j) exploitable species;
(k) ecosystem functioning and linkages;
(l) ecosystem services;
(m) human threats and natural catastrophes; and
(n) size, shape and connectivity.

In particular, the number, location and design (size and shape) of MPAs are critical considerations (Boersma and Parrish, 1999; Guenette *et al.*, 2000; Halpern, 2003; Kooyman *et al.*, 1992). These considerations will determine the magnitude of potential detrimental effects from MPA implementation, including: (i) the concentration of fishing effort outside of the MPA boundaries (Walters and Bonfil, 1999); (ii) the unpredictability of MPA effectiveness in the face of oceanographic variability across space (advection) and time (climate change); (iii) the inherent time lags required for the effect(s) of MPAs on stocks/populations to become apparent; and (iv) and the impact of overall higher total bycatch of highly migratory species derived from the displacement of fishing effort to less productive areas, where lower catch rates (CPUE) require higher effort to attain constant catches.

There are a number of techniques used to identify and delineate boundaries for conservation purposes. Fundamentally these techniques can be separated into those that seek to protect the maximum (or some target) number of elements of value (as defined by the user) and those that rely on some ecological theory or concept to identify optimal areas. Most of these techniques attempt to identify and maximise values by protecting the smallest possible area.

Well-known examples of the former include Geographic Information System analyses of biogeographic representation, which attempt to identify representative (recurring at a given scale) and distinctive (unique at a given scale) areas (Roff and Taylor, 2000; Zacharias *et al.*, 1998). Given our incomplete understanding of marine communities, many of these analyses are based on identifying representative and distinctive areas defined exclusively by habitat characteristics (oceanographic and physiographic), driven by a limited understanding of the underlying ecological mechanisms. The underlying assumption being that habitat structure can be used to predict species and community composition. A practical application is given in Cañadas *et al.*, (2005).

In addition, considerable effort has been directed at developing stand-alone software that identifies potential conservation areas on the basis of biodiversity targets set by the user (McDonnell *et al.*, 2002). While several iterations of these algorithms exist (e.g. SPEXAN, Sites), the most recent version (MARXAN) has been developed for the Great Barrier Reef Marine Planning Authority (Leslie *et al.*, 2003). MARXAN is used throughout the world for identifying optimal MPA boundaries and is now considered a robust tool for reserve design. However, given the large size of the SOS and the paucity of biological data for the Southern Ocean, MARXAN may not be an appropriate tool to evaluate this and other large-scale whale sanctuaries.

There are a number of examples of reserve design based on ecological theory or concepts. Species-area relationships have been used to encompass the maximum diversity within the smallest possible area, by identifying the asymptote of the species-area curve (Arrhenius, 1921; Neigel, 2003). While the species-area approach has been widely criticised, this technique continues to be widely applied due to the lack of viable conceptual alternatives.

Focal species are a conceptual construct in conservation that may be useful for marine reserve design. Focal species are those which, for ecological or social reasons, are believed to be valuable for the understanding, management and conservation of natural environments. There are four distinct categories of focal species: indicators, keystones, umbrellas and flagships (Simberloff, 1998; Zacharias and Roff, 2001a). Each type of focal species has been operationally defined by Zacharias and Roff (2001a) in terms of their relevance to marine conservation efforts. To summarise, the keystone and umbrella concepts are probably not applicable in most marine environments and the flagship concept is a tool to garner support for conservation efforts but provides little tangible guidance for MPA design. Indicator species, though, may be valuable as they indicate community types that can be related to specific habitat types, which in turn can be mapped and protected. The ability to identify biologically and physically distinct habitat types is a fundamental prerequisite for conservation initiatives based on representation (Roff and Taylor, 2000).

Models initially developed for fisheries management have also been applied to the selection of MPAs. Perhaps the most well-known are ECOPATH and ECOSPACE, which allow the simulation of different types of anthropogenic impacts on spatially-structured populations and can simulate migratory interchange between different patches or habitat types (Christensen and Pauly, 1992; Mackinson *et al.*, 2003; Walters *et al.*, 1997). These whole-ecosystem models, however, require the input of broad, sweeping simplifications and assumptions (e.g. see IWC, 2004a) and thus may not be appropriate given our current level of knowledge of the ecological function of the Southern Ocean.

Zoning within MPAs

Within a no-take zone, additional protection should be based on the vulnerability of the features of interest (e.g. populations, habitats) to various threats. Vulnerability is defined as the probability that a feature will be exposed to a stress to which it is sensitive. In other words, vulnerability is the likelihood of exposure to a relevant external stress factor (sensu Tyler-Walters and Jackson, 1999), combined in some way with the relative exposure (duration, magnitude, rate of change) to that stress. One method that is becoming more widely applied is using the concept of identifying Vulnerable Marine Areas (VMAs) (Zacharias and Gregr, 2005). This methodology, based on the Environmental Sensitivity Index approach used for oil spill response and countermeasures (Gundlach and Hayes, 1978) identifies Valued Ecological Features (VEFs), which are defined as biological or physical features, processes, or structures deemed to have environmental, social, cultural, or economic significance. Once VEFs are identified, they are mapped and their sensitivities and vulnerabilities are determined and finally VMAs are predicted using ecological classifications (Tyler-Walters and Jackson, 1999; Zacharias and Gregr, 2005).

Designing networks or hierarchies of MPAs

This is an area of MPA research that is currently lacking a strong empirical basis. Most studies to date have been able to identify 'sets' of protected areas based on the principles of biogeographic representation, combined with the addition of 'distinctive' or unique oceanic (e.g. persistent fronts) and physiographic (e.g. seamounts) features. Many of the tools discussed previously (e.g. MARXAN) are able to identify sets of MPAs, which simultaneously maximise a number of criteria (e.g. representation, distance from human activities). Many advocate the establishment of 'networks' of MPAs, where discrete protected areas are connected through migration and larval transport. However, the function of networks is not yet clearly understood (Roff *et al.*, 2003).

Other issues that arise in MPA network discussions include the number and size of the sites required within a particular region to accommodate habitat variability over time, particularly in dynamic pelagic environments.

Steps to developing an MPA network include:

(a) classify the study area into representative and distinctive areas using biogeographic analysis methods based on biological, oceanographic and physiographic information;
(b) verify species/community relationships within these areas and predict species/community occurrence where biological inventories are unavailable;
(c) determine patterns of movement and the exchange of individuals between areas;
(d) develop inventories of conservation and management measures to determine what existing areas already contribute to the network;
(e) apply algorithms (e.g. MARXAN, S-A curves) to select the smallest areas that maximise the MPA objectives; and
(f) remove sites deemed non-viable for ecological, political, social, or economic reasons (e.g. proximity to human activities, site already disturbed), from the above analysis.

RECOMMENDATIONS

Marine habitat-based conservation (such as the SOS and other MPAs) has advanced considerably since 1994. However, there is no reason why the SOS cannot be revisited, in light of advances in marine conservation reserve science. Many of the problems highlighted in the previous sections of this review have been addressed in other MPAs and, with some additional research, should be resolvable for the SOS. The following are our recommendations for the establishment and operation of the SOS or other IWC Sanctuaries;

(1) articulate their purpose through a set of broad overarching goals (e.g. preserve biodiversity, increase fishery yields) – in particular, clearly state the

relationship between the RMP and the IWC Sanctuary programme and how sanctuaries are expected to contribute to the management of cetacean stocks and species.

(2) develop measurable objectives (e.g. increase stock *x* to size *n* by time *t*, decrease the probability of extinction of stock *x* by *y*, protect feeding areas for population *x*) that link the broader goals (discussed above) with field monitoring programmes such as the IWC IDCR/SOWER cruises (e.g. Matsuoka *et al.*, 2003) – this clarification will help identify and protect those habitats 'critical' to achieve these management objectives;

(3) establish systematic inventory and research programmes to build the required information foundation for a sanctuary management plan and subsequent monitoring programmes that *inter alia* support the following efforts:

(a) a biogeographic analysis of habitats and communities using the concepts of representativity and distinctiveness at the genetic, stock, species, community and ecosystem levels (Roff and Taylor, 2000; Roff *et al.*, 2003; Zacharias and Roff, 2001b);

(b) the identification and mapping of threats to whale populations within and outside of the SOS and the oceanographic/climatic linkages supporting ocean productivity and prey availability across sanctuary boundaries (Fig. 1; Miller and Hampton, 1989; Nel and Taylor, 2003);

(c) identification of vulnerable areas and critical habitats at different ecological scales (e.g. individual foragers and population distributions) (Block *et al.*, 2002; Croxall and Wood, 2002; Zacharias and Gregr, 2005), as well as their spatial and temporal variability (Belkin and Gordon, 1996; Hewitt *et al.*, 2002; Kostianoy *et al.*, 2004);

(d) investigation of pathways of whale stock structure and connectivity (e.g. gene flow and animal movement) (Dizon *et al.*, 1992; Torres *et al.*, 2003);

(e) development of measures of biotic integrity (e.g. standing stocks, productivity) and environmental variability (e.g. oceanography, disturbance regimes), along with appropriate physical and biological indicators of temporal variability at short (inter-annual) and long (climate change) temporal scales (Croxall, 1992; Croxall *et al.*, 1999; Inchausti *et al.*, 2003);

(4) development of a Sanctuary management plan that clearly outlines the broad strategies and specific actions needed to achieve sanctuary objectives (e.g. how to protect a given feeding area for stock *x*) and the non-IWC mechanisms required to achieve these objectives – key aspects of a sanctuary management plan should include:

(a) coordination with the objectives of other conservation and management initiatives (e.g. CCAMLR; Agnew, 1997);

(b) integration of fisheries and coastal zone management concepts within sanctuary management objectives (Boyd, 2002; Hewitt *et al.*, 2002);

(c) adherence to the tenets of adaptive management and the precautionary principle (Hewitt *et al.*, 2002);

(5) development and initiation of a monitoring strategy that measures progress towards achieving the sanctuary objectives (an essential component of this monitoring strategy is the development of practical (tested by e.g. power analyses to be achievable) indicators to monitor progress);

(6) establishment of review criteria that reflect the goals and objectives of the sanctuary, as described above; and

(7) refinement of the sanctuary management plan at periodic intervals to account for ecological, social and oceanographic changes in an adaptive fashion.

CONCLUSIONS

Even ignoring the fact that the SOS was established during the moratorium, it was based on vague goals and objectives that are difficult to measure, lacks a rigorous approach to its design and operation and does not have an effective monitoring framework to determine whether its objectives are being met. The SOS in particular – and IWC Sanctuaries in general – appear to have been established as a socio-political compromise between an area-based fisheries closure and a conservation reserve. Unfortunately, the SOS is neither an effective harvest closure, nor does it meet the generally accepted criteria for conservation reserve design and operation (Botsford *et al.*, 2003). The SOS attempts to fulfil a number of vague objectives (e.g. 'ecosystem rehabilitation', 'critical habitat' protection) without addressing the systematic application of quantitative criteria to attain tangible goals. Any 'scientific' objectives appear to have been added to lend credibility to the SOS after the sanctuary was established. Furthermore, the intent to incorporate MPA concepts into IWC Sanctuaries appears to be in response to the criticisms faced by this programme in the past.

The SOS can be said to represent a 'shotgun' approach to conservation, where a large area is protected with little apparent rationale for boundary selection and management prescriptions. Of even greater concern is the realisation that the Sanctuary was established without a proper understanding, discussion, or prediction of what contributions it is expected to make towards biodiversity protection and fisheries management in the Southern Ocean. Another critical issue is the lack of a general temporal framework for evaluation of the objectives discussed above. Even a broad conservation objective, such as improving the protection of Southern Ocean whale stocks, should include a quantifiable metric to gauge success and a time frame for this objective to be met (e.g. reduce the probability of extinction of species *s* in the next *y* years to less than *x*, determine population numbers with a confidence of *n*). These criteria are essential to provide the necessary ecological background for the development and testing of population models, to guide the collection of the necessary empirical data to support these modelling efforts and to determine the management approaches and the levels of protection required to meet these conservation goals (Doak and Mills, 1994; Fujiwara and Caswell, 2001; Gerber *et al.*, 2005; Mangel and Tier, 1994). Once these criteria and objectives have been set, they will help define the required temporal and spatial extent of the proposed sanctuary and the baseline information necessary to gauge the current status of the various ecosystem constituents (Dayton *et al.*, 1998; Jackson *et al.*, 2001; Woehler, 1997).

The existence of the moratorium and whaling under special permit has not permitted the SOS to fulfil its role of protecting whales and fostering comparative research of harvested and non-harvested whale stocks. Consequently, we conclude that the SOS has contributed little to the protection and understanding of whales in the Southern Ocean. If the moratorium were lifted and the RMP applied, the SOS may become more relevant to whale conservation and management. However, given that all baleen whales migrate outside of the SOS, it alone would not prevent RMP catches being taken outside its boundaries. Therefore, if the moratorium is lifted, careful integration between the SOS and RMP will be required.

While the SOS could be an important first step towards an ecosystem approach to management in the Southern Ocean, by itself is not an effective management construct. In particular, adequate protection from all potential threats, not simply commercial whaling, for all populations of large whales in the Southern Ocean is an important first step towards promoting the proper function of this large marine ecosystem. If the SOS is to become a cornerstone in ecosystem-based management of the Southern Ocean, the IWC must work with other regional institutions and global initiatives to ensure that threats to large whales other than commercial whaling and environmental variability (e.g. climate change) are considered.

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