ECOLOGY

Do the Largest Protected Areas Conserve Whales or Whalers?

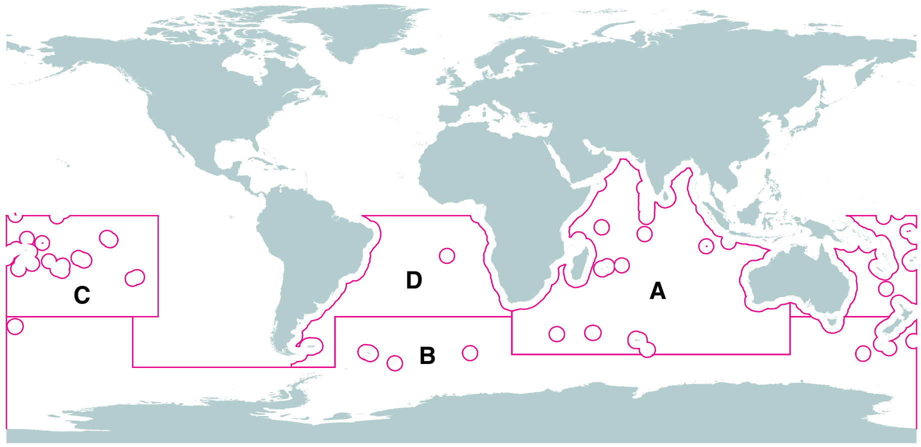
Leah R. Gerber,[1] K. David Hyrenbach,[2] Mark A. Zacharias[3]

In 1946, the International Convention on the Regulation of Whaling authorized the International Whaling Commission (IWC) to designate sanctuaries that prohibit commercial or aboriginal subsistence whaling (*1*, *2*). A sanctuary operated in the South Pacific sector of the Southern Ocean between 1938 and 1955. Since then, the Indian Ocean Sanctuary was adopted in 1979 and the Southern Ocean Sanctuary (SOS) in 1994 (*1*). These sanctuaries constitute the world's largest marine protected areas (see the figure, this page). Early IWC sanctuaries were emergency measures enacted to protect overexploited stocks while other measures were implemented. More recently, the establishment of IWC sanctuaries has been criticized as a political, rather than scientific, means to exclude commercial whaling from large areas of the ocean. Critics view the sanctuaries as a way to preempt the potential adoption of the Revised Management Procedure (RMP), a science-based harvest framework within the broader Revised Management Scheme (RMS) that is intended to replace the current global moratorium on commercial whaling (*3*).

In response to these criticisms, the IWC adopted three scientific objectives in 1998 (*4*). Sanctuaries were charged with promoting the recovery of whale stocks, including the establishment of appropriate monitoring of depleted populations. The effects of zero catch limits on whale stocks were to be assessed. Research was mandated on the effects of environmental change on whale populations. In 2003, the IWC directed the Scientific Committee to undertake a decadal (1994–2004) review of the SOS.

We were appointed by the IWC Scientific Committee to review the SOS and to evaluate how approaches in marine protected areas might be integrated into the IWC sanctuary program. On the basis of existing literature related to marine protected areas and cetacean biology (*5*–*8*), we have concluded (*9*) that the SOS in particular, and the IWC sanctuary program in general, are currently not scientifically justified. In particular, the IWC faces four main limitations:

Arbitrary boundaries. All whale species with commercial harvest potential migrate outside of the sanctuary boundaries at some point in their lives and therefore are vulnerable to commercial harvest if the global whaling moratorium is lifted (*10*).



Map of IWC sanctuaries in the Indian (A) and Southern (B) Oceans. Establishment of the South Pacific (C) and South Atlantic (D) Ocean sanctuaries has been proposed.

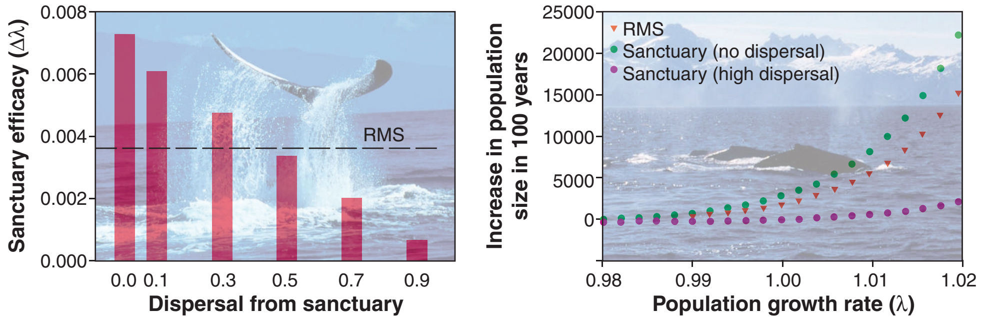
Narrow focus. Sanctuaries do not protect or mitigate other threats to Southern Ocean whale stocks and the marine ecosystems upon which these populations depend, including pollution, habitat degradation and loss, introduced species, and global climate change.

Lack of an adaptive design. Comparative studies of the population structure and trends of harvested and unharvested whale stocks are unfeasible. An objective of the IWC Sanctuary Program is to facilitate comparisons of whale populations within and outside of the boundaries of protected areas (*4*). However, the size of IWC sanctuaries means that protected whales inhabiting the Indian and Southern Oceans will have to be compared with those inhabiting the Atlantic and Pacific Oceans. Because threats to whales may be different or of unequal magnitude in different ocean basins, comparisons may not be scientifically valid.

Need for baselines. Comparisons of harvested and unharvested stocks are further confounded by unregulated takes for research (i.e., scientific permit whaling), which are not limited to specific areas or time periods, and do not require adherence to catch quotas. Thus, even those populations restricted to existing IWC sanctuaries do not provide an ecological baseline for the study of the effects of climatic variability on whale populations and Southern Ocean ecosystems (*11*–*12*).

Current debate has polarized IWC members into those who advocate widespread sanctuary use and those who believe that they are redundant under the RMP/RMS [see supporting online material (SOM)]. To determine whether the application of the RMP/RMS, in conjunction with a more ecologically oriented sanctuary program, would represent a measurable improvement for whale management and conservation, we developed a population model to assess relative efficacy. We calculated the change in population growth rate (λ) due to sanctuary establishment for different rates of dispersal across a sanctuary boundary. We assumed typical life history parameters for baleen whales (i.e., we used demographic parameters for the gray whale *Eschrichtius robustus*) (*13*–*14*). To consider the applicability of our results to other whale species, we explored the sensitivity of our results to small changes in these parameter values (*15*). We examined the degree to which changes in population growth resulting from alternative management schemes determine population size 100 years into the future.

[1]The Faculty of Ecology, Evolution and Environmental Sciences, School of Life Sciences, Arizona State University, Tempe, AZ 85287–4501, USA. E-mail: Leah.Gerber@asu.edu; [2]Duke University Marine Laboratory, Beaufort, NC 28516, USA. E-mail: khyrenba@duke.edu; [3]Department of Geography, University of Victoria, Victoria, BC, Canada V8W 3P5. E-mail: Mark.Zacharias@uvic.ca



Change in whale population growth rate and projected abundance. (**Left**) Absolute change in population growth rate (λ) resulting from a 20% reduction in adult mortality in sanctuaries with different rates of dispersal compared to the population growth rate under the RMS scenario. Take is reduced by 10% for both patches in the RMS scenario (no reserve). (**Right**) Projected abundance in 100 years for a range of underlying rates of population growth under alternative management schemes reflecting the small changes in λ portrayed in graph at left. "High dispersal" corresponds to a 0.9 movement rate from sanctuary to unprotected areas.

The increase in λ as a result of decreasing adult mortality (*16*) depended strongly on the underlying rate of dispersal (see the figure above, left). The RMP/RMS management approach was more effective than sanctuary scenarios, in cases where at least 50% of the population dispersed from the sanctuary. Furthermore, very small fluctuations in λ translated into substantial long-term changes in whale numbers (see the figure above, right). Although little is known about migratory pathways and destinations for most Southern Ocean whale populations (*10*, *17*), it is reasonable to assume that at least 50% of whales inhabiting IWC sanctuaries move out of these areas during annual migrations (*10*, *18*). Thus, our model suggests that a quota-based management regime (RMP/RMS) will be more effective than IWC sanctuaries as currently configured.

Although this result was robust to small (±0.02) changes in parameter values, our model includes dispersal as diffusion, rather than as explicit migration, and does not consider density dependence, demographic stochasticity, or environmental noise. However, given the uncertainties concerning demographic and life-history information for whales (*19*) and the large number of potential sanctuary configurations, our model provides general insights into the long-term implications of different management approaches. Our results are consistent with results from previous work on demersal and benthic species of low motility in marine protected areas, where reserves maintain unharvested populations while supporting enhanced fishery yields outside the reserve (*20*, *21*). Similar benefits could materialize for highly migratory species like cetaceans (*8*); however, this depends on how much of the species' range is encompassed by the reserve (*16*). Because most whale stocks that inhabit IWC sanctuaries are highly migratory (*10*, *17*), the current sanctuaries do little for whale conservation without additional protective measures beyond their boundaries.

IWC sanctuaries could become an important part of the IWC management approach and the broader conservation of Southern Ocean marine ecosystems. This requires better integration with other activities under the IWC mandate (e.g., RMP/RMS and scientific permit whaling) as well as with other management programs (e.g., the Convention on the Conservation of Antarctic Marine Living Resources). If IWC sanctuaries are to become a cornerstone in ecosystem management for the Southern Ocean, the IWC must work with other regional institutions and global initiatives to ensure that threats to whales, other than commercial harvest and climatic variability, are considered. However, this necessitates returning to a scientific (rather than political) approach to sanctuary designation and management. A starting point would be the establishment of IWC sanctuaries conforming to more ecologically based designation. Specifically, IWC sanctuaries must embrace the following principles of reserve design and management: (i) adoption of formally stated goals (e.g., biodiversity protection and fisheries enhancement) articulated in a management plan; (ii) development of measurable objectives with which to assess progress toward attaining these goals; (iii) establishment of ecologically based sanctuary boundaries; (iv) creation of a formal management plan, including the establishment of a monitoring framework; and (v) design of more appropriate review criteria reflecting the ecological objectives described in the management plan (*9*).

We advocate the elimination of unregulated scientific permit whaling and the application of the RMP/RMS, alongside a system of IWC sanctuaries designed to protect populations of whales during certain time periods (e.g., in breeding grounds and/or feeding areas) or throughout their entire ranges (see SOM). If whaling were to resume under the RMP/RMS, IWC sanctuaries would only fully protect whales that migrate between the Southern Ocean and the Indian Ocean, where the overlapping sanctuaries likely encompass the entire ranges of several stocks. Nevertheless, the adherence to a quota system would enhance whale conservation by limiting the times and areas of whale harvesting, and by limiting the total catch. Moreover, the cessation of scientific permit whaling would reinstate the research value of IWC sanctuaries, by facilitating the monitoring and comparative study of harvested and unharvested stocks.

References and Notes

1. International Convention for the Regulation of Whaling, Washington, DC, 2 December 1946 (U.S. Government Archives, Washington, DC).
2. In accordance with the IWC, the "whaling" refers to the take of cetaceans for commercial and subsistence uses and as part of scientific studies, and "whales" are species of baleen (mysticete) and toothed (odontocete) cetaceans targeted for harvest (*22*).
3. N. M. Young, *Understanding the Revised Management Procedure* (Center for Marine Conservation, Washington, DC, 2002).
4. IWC, *Annu. Rep. Int. Whaling Comm.* **1998**, 42 (1999).
5. P. D. Boersma, J. K. Parrish, *Ecol. Econ.* **31**, 287 (1999).
6. C. E. Mills, J. T. Carlton, *Conserv. Biol.* **12**, 244 (1998).
7. K. D. Hyrenbach, K. A. Forney, P. K. Dayton, *Aquat. Conserv.* **10**, 437 (2000).
8. S. K. Hooker, L. R. Gerber, *Bioscience* **54**, 27 (2004).
9. M. A. Zacharias, L. R. Gerber, K. D. Hyrenbach, *Int. Whaling Comm. Pap.* SC/56/SOS5 (IWC, Cambridge, 2004).
10. C. R. Davis, N. Gales, *Int. Whaling Comm. Pap.* SC/56/SOS2 (IWC, Cambridge, 2004).
11. D. G. Ainley, *Mar. Ornithol.* **30,** 55 (2002).
12. P. J. Clapham *et al.*, *Bioscience* **53**, 210 (2003).
13. Values include fecundity of 0.470, adult and juvenile survival of 0.944 and 0.893, respectively, and age at sexual maturity of 8.
14. S. Reilly, *Rep. Int. Whal. Comm., Special Issue* **6**, 389 (1984).
15. Materials and methods are available as supporting material on *Science* Online.
16. L. R. Gerber, S. S. Heppell, *Biol. Conserv.* **120**, 121 (2004).
17. K. M. Stafford *et al.*, *Deep-Sea Res.* Part I, **51,** 1337 (2004).
18. J. L. Bannister, in *Encyclopedia of Marine Mammals*, W. F. Perrin, B. Würsig, J. G. M. Thewissen, Eds. (Academic Press, San Diego, CA, 2002), pp. 62–72.
19. C. S. Baker, P. J. Clapham, *Trends Ecol. Evol.* **19**, 365 (2004).
20. S. N. Murray *et al.*, *Fisheries* **24**, 11 (1999).
21. G. R. Russ *et al.*, *Ecol. Appl.* **14**, 597 (2004).
22. P. J. Clapham, C. A. Baker, in *Encyclopedia of Marine Mammals*, W. F. Perrin, B. Würsig, J. G. M. Thewissen, Eds. (Academic Press, San Diego, CA, 2002), pp. 1328–1332.
23. We thank D. P. DeMaster and two anonymous reviewers for helpful comments, the chair (A. Zerbini) and the members of the IWC SOS Review Committee for insights into the IWC Sanctuary Program; and S. Young for mapping assistance.

Supporting Online Material
www.sciencemag.org/cgi/content/full/307/5709/525/DC1

10.1126/science.1106120

The International Whaling Commission Sanctuary Program: Do the world's largest protected areas conserve whales or whalers? (Supplement)

Leah R. Gerber
Ecology, Evolution and Environmental Sciences
School of Life Sciences
Arizona State University, Box 874501
Tempe, AZ 85287-4501
USA
phone: 480 727 3109
fax: 480 965 2519
email: Leah.Gerber@asu.edu

K. David Hyrenbach
Duke University Marine Laboratory
135 Duke Marine Lab Road
Beaufort, NC 28516
USA
phone: 252 504 7576
fax: 252 504 7648
email: khyrenba@duke.edu

Mark A. Zacharias
Department of Geography
University of Victoria
PO BOX 3050 STN CSC
Victoria, B.C., V8W 3P5
Canada
phone: 250 387 5727
fax: 250 953 3481
email: Mark.Zacharias@gems6.gov.bc.ca

I. Materials and Methods

Applying a Spatial Demographic Model to Evaluate the Efficacy of Sanctuaries

In order to evaluate the consequences of a sanctuary for whale population growth, we constructed a two-site matrix model (*1*), with two patches representing a no-take marine sanctuary and unprotected habitat. We included population movement between the sanctuary and the unprotected waters outside of the sanctuary using the same general form of simple matrix models. The inclusion of dispersal results in the following 2-patch matrix, where M represents adult dispersal out of the sanctuary.

$$G = \begin{bmatrix} 0 & 0 & \cdots & F_A & 0 & 0 & \cdots & F_B \\ p_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & p_2 & 0 & \vdots & 0 & \ddots & 0 & \vdots \\ 0 & 0 & \ddots & p_{adA}(1-M) & 0 & 0 & 0 & p_{adB}M \\ 0 & 0 & 0 & F_A & 0 & 0 & 0 & F_B \\ 0 & 0 & 0 & 0 & p_1 & 0 & 0 & 0 \\ 0 & 0 & \ddots & \vdots & 0 & p_2 & 0 & \vdots \\ 0 & 0 & 0 & p_{adA}M & 0 & 0 & \ddots & p_{adB}(1-M) \end{bmatrix}$$

Matrix G (shown in age-structured form, where each row / column represents a single age class for juveniles and adults grouped into one stage) contains two single-site matrices for A (the unprotected site), and B (the Sanctuary site). The parameters p_i represent annual survival probabilities for age class i, and p_{adA} and p_{adB} are the mean annual adult survival rates outside (site A) and inside (site B) the sanctuary, respectively. Likewise, parameters F_A and F_B represent reproduction rates outside and inside the sanctuary. The length of the juvenile stage was determined assuming an age of sexual maturity of 8 years (*2*). Thus, our 2-site matrix is an 18 by 18 matrix, with nine distinct age classes from 0 to 8 years of age.

Using this model, we evaluated the relative impact of a sanctuary and a quota-based management system (RMS) in determining the population growth rate (λ) inside and outside of an IWC Sanctuary (see *3* for an explanation of survival vs. mortality sensitivity). We made the simplifying assumption that establishing a sanctuary reduces adult mortality by 20% at site B, and then we evaluated the effect of migration of adults on λ (*3–4*). For this analysis, we compared results for sanctuaries with different dispersal rates to a quota system akin to the RMS, in which mortality is reduced by 10% for both patches (*vs*. 20% reduction at site B). Additional details about model construction and parameters for gray whales are described in (*4*).

To illustrate the ecological relevance of small changes in lambda shown in Figure 2a, we then apply a simple exponential model of population growth to estimate expected abundance in 100 years for sanctuary and RMS scenarios. Specifically, we set t = 100 and solve for $N_t = N_o\lambda^t$ for the range of underlying population growth rates calculated under each management scheme. It should be noted that our model results are dependent on the assumption that scientific whaling ceases under each of the two management scenarios (or at least scientific whaling is equally distributed between the A and B areas in each scenario).

II. Supporting Text

Developing new management options for IWC

IWC Sanctuaries can play a vital role in the effective conservation and management of whales. However, by virtue of their current spatial configuration (e.g., location and extent) and operation (e.g., providing no guidance on the legality of scientific permit whaling), they fail to protect harvested stocks throughout their ranges.

IWC Sanctuaries have been rendered largely ineffective by attempts to reach a political compromise. First, according to the Convention, a country can object to change in the Schedule within 90 days (i.e., the Japanese government has objected to the SOS Sanctuary, so if the moratorium were ended, the Japanese government could commercially whale in the Sanctuary. Second, whaling nations can still harvest whales in the Sanctuary under the auspices of scientific permit whaling, and non-whaling nations can champion for the establishment of new sanctuaries as a way to set aside large expanses of the ocean to future commercial whaling. However, as our model shows, sanctuaries are ineffective at protecting highly-mobile whale stocks in light of unregulated catches, even if takes occur exclusively outside of sanctuary waters (Fig. 2). In fact, because scientific permit whaling currently takes place both within and outside IWC Sanctuaries, it renders sanctuaries ineffective as a management tool, regardless of the degree of whale dispersal (*5*).

The approval or modification of IWC Sanctuaries requires a three-quarter majority vote by the Commissioners. However, due to nearly equal numbers of pro- and anti-sanctuary nations in the IWC, no sanctuaries are likely to be established, removed, or significantly revised in the near future. At the recent IWC meeting in Sorrento, Italy, neither pro-sanctuary nor anti-sanctuary nations garnered the three-quarters majority vote required to either designate new sanctuaries or to abolish existing ones (Table 1). The current stalemate situation in the IWC precludes a number of actions requiring an amendment to the IWC Schedule, including the modification or dissolution of Article VIII governing scientific permit whaling. Because Article VIII sets no limits on scientific catches and provides a means to circumvent any quota-based whaling, its modification should constitute an integral part of any future management approaches.

The IWC is a voluntary organization of 58 nations (*6*). Many of the political conflicts in this organization arise from complicated cultural and philosophical differences (*7- 9*), and are beyond the scope of this article. Yet, whether these disparities in opinion and attitudes between whaling and non-whaling countries are reconcilable does matter to the long-term viability and effectiveness of the IWC. In particular, the continued jousting by whaling and non-whaling voting blocks to overcome the interests of each other entails a serious risk to the integrity of the organization (*9-11*). In particular, the elimination of scientific permit whaling may drive certain nations to withdraw from the IWC altogether, and to undertake unregulated and unmonitored scientific or commercial harvesting.

Change in the IWC is inevitable, regardless of whether the global commercial whaling moratorium is lifted (*12, 13*). Spurred by the Scientific Committee, the IWC Sanctuary program has already evolved from a mere prohibition of commercial harvest into a broader conservation measure designed to consider population trends, other likely impacts (e.g., bycatch, shipping, climate change) threatening whale populations, as well as other protective measures used to mitigate those impacts outside of sanctuary waters (*14- 16*). A critical step towards the effective management of IWC Sanctuaries entails the elimination of unregulated scientific permit whaling from sanctuary waters, once their boundaries have been redefined to better reflect MPA design principles and whale ecology. This measure would fully protect certain Indian Ocean whale stocks, and would thus facilitate some of the research and monitoring objectives sought by the implementation of the SOS (*12*). The changes we propose in sanctuary design and management are essential to ensure the valid and rigorous scientific studies necessary to assess the effects of sanctuary protection on whale populations, and their broader marine ecosystems (*17*, *18*). In turn, this information is critical to monitor long-term changes in the global ocean (*19*, *20*).

3. Supporting References and Notes

1. W. F. Morris, Doak, D. F. *Quantitative conservation biology: Theory and practice of population viability analysis.* (Sinauer Associates, Sunderland, 2002).
2. S. Reilly, *Rep. Int. Whal. Commn. Special Issue* **6**, 389 (1984).
3. L. R. Gerber, Heppell, S.S. *Biol.Conserv.* **120**, 121 (2004).
4. L. R. Gerber, Heppell, S.S., Ballantyne, F., Westphal, M., Sala, E. *Can. J. Fish.Aquat. Sci.* (In Press).
5. P. J. Clapham, et al., *Bioscience* **53**, 210 (2003).
6. For a list of IWC member nations consult:
http://www.iwcoffice.org/commission/iwcmain.htm#nations
7. T. Hamazaki, Tanno, D. *Human Dimensions of Wildlife* **6**, 131 (2001)
8. G. P. Donovan. in *Encyclopedia of Marine Mammals*, W. F. Perrin, B. Würsig, J. G. M. Thewissen, Eds. (Academic Press, San Diego, CA, 2002). pp.637-641.
9. P. Bridgewater. Int. Soc. Sci. J. **55**, 555 (2003).
10. D. Cyranoski. *Nature* **417**, 476 (2002).
11. S. Holt, Mar. *Poll. Bull.* **46**, 924 (2003).
12. A. Gillespie, *Ocean Dev. Int. Law* **34**, 349 (2003).
13. S. Holt, *Mar. Poll. Bull.* **44**, 715 (2002).
14. IWC, *Annex Paper* **IWC / 44 / 19** (1993).
15. IWC, *Ann. Rep. Int. Whaling Comm.* **1998**, 42 (1999).
16. E. Morgera, *Ocean Dev. Int. Law.* **35**, 319 (2004).
17. P. J. Clapham, et al., *Bioscience* **53**, 210 (2003).
18. R. P. Hewitt, et al. *Oceanogr.* **15**, 26 (2002).
19. D. G. Ainley, *Mar. Ornithol.* **30,** 55 (2002).
20. A. Atkinson, Siegel, V., Pakhomov, E., Rothery, P. *Nature* **432**, 100 (2004).

4. Supporting Tables

Table S1. Three proposals, which failed to gain the required three-quarters majorities at the 56th annual IWC meeting, held in Sorrento (Italy) from 19-22 July 2004, illustrate the political gridlock at the IWC (http://www.iwcoffice.org/meetings/meeting2004.htm#sanctuaries).

Proposal	Votes Cast		
	For	**Against**	**Abstentions**
Establishment of an IWC Sanctuary in the South Atlantic Ocean	26	21	4
Establishment of an IWC Sanctuary in the South Pacific Ocean	26	22	4
Removal of the SOS and introduction of a 2914 Antarctic Minke Whale catch limit	19	30	2