The Antarctic and Southern Ocean Coalition

ASOC Secretariat
1630 Connecticut Ave NW
Third Floor
Washington, DC 20009 USA
Tel: 202.234.2480
Fax: 202.387.4823
www.asoc.org

Antarctic Krill Fisheries and Rapid Ecosystem Change:

The Need for Adaptive Management

ATME on Climate Change
Svolvær, Norway
April 6-9, 2010

Information Paper Submitted by ASOC

Table of Contents

Antarctic Krill FIsheries and Rapid Ecosystem Change:

The Need for Adaptive Management

Abstract

This paper calls for the need for adaptive management of Antarctic krill fisheries in the Scotia Sea/ Antarctic Peninsula region to take account of the combined impacts of recovering populations of predators, future fishing and climate change. This area holds the greatest concentration of krill, has been subject to major depletion of hunted or fished stocks in the past, and is strongly affected by climate change. Therefore, a management system based on feedback procedures (adaptive management) is needed.

CCAMLR's Ecosystem Monitoring Program (CEMP) is a valuable monitoring tool that needs to be expanded and improved in order to meet the needs of adaptive management.

1 The impacts of resource extraction on the Scotia Sea/Antarctic Peninsula region

The Scotia Sea/Antarctic Peninsula region has a long history of extraction of biotic resources, occurring in a sequential pattern (e.g. Hilborn et *al.* 2003). During the last century, the Southern Ocean saw the loss of more than one million baleen whales, the vast majority of which were taken from the SW Atlantic sector (Tonnessen & Johnson 1982), with major compensatory changes happening to other components of the region's ecosystem (Laws 1977, Estes et *al.* 2006). In large part, except for humpback whales, these stocks have failed to recover (Branch et *al*. 2007, Branch 2009). Antarctic fur seals were extracted earlier, but, following protection measures, have recovered (Laws 1977). Finally, during the 1960-80s, the demersal fish stocks of the region's shelves were decimated, a condition which has yet to show much recovery (Kock 1992, 1988; Kock & Jones 2005). Therefore, as it has been shown in other ecosystems (Österblom et *al.* 2007, Watermeyer et *al.* 2008a, b), it is likely that the severe reduction in predation pressure has increased the susceptibility of this ecosystem to climate change and further exploitation.

2 The impacts of climate change on the Antarctic krill-centric ecosystem

The Scotia Sea/Antarctic Peninsula region has been experiencing alterations due to rapid climatic change that may exceed the natural abilities of many organisms to cope, especially without the food-back loops in place brought by a naturally structured foodweb. Particularly in the marine environment, which is predicted to go through profound changes as a result of climate change, adaptation strategies need to be adopted.

In this region, the foodweb is dominated by euphausids, and in particular Antarctic krill (*Euphausia superba)*, which support the energetic demands of most of the abundant predator populations still remaining (Croxall et *al.,* 1988) and also a commercial fishery. The life history and demography of Antarctic krill are intimately tied to seasonal sea ice conditions, climate, and the physical forcing of ocean currents. Key spawning, recruitment and nursery areas of krill are located along the Western Antarctic Peninsula; these krill are then advected northward into the Scotia Sea (Constable *et al.,* 2003). The climate in this area is warming rapidly (Ducklow 2007, Montes-Hugo et *al*. 2009), and as a result, the extent and duration of winter sea ice are being reduced (Parkinson 2002; Stammerjohn et *al.* 2009).

Optimal conditions for reproductive output around the Antarctic Peninsula occur when both the timing of the spring sea ice retreat and its maximum extent are both close to the long-term mean (Quetin & Ross, 2001). As the life cycle of krill is synchronized with the timing, duration, and extent of sea ice cover, deviation in either direction will affect either reproductive output and/or larval survival (Quetin & Ross, 2003). The decrease in sea ice coverage in recent decades, seen mostly as a severe reduction in the sea ice season (Stammerjohn et *al.* 2009), is thought to have led to the observed 38-81% decrease in krill abundance in the Scotia Sea (Atkinson et *al*. 2004).

Given that the ecosystem has been simplified by previous extractions, environmental factors impacting Antarctic krill populations pose even greater risks and impacts for the ecosystem. These effects flow upward in the foodweb to affect predator populations. With few exceptions, periods of reduced predator breeding performance in this region are the result of low prey availability rather than direct local weather or oceanic effects (Croxall et *al*., 1988; Fraser and Hofmann, 2003; Forcada et *al*., 2005, 2006; Trathan et *al.,* 2006; Hinke et *al*., 2007; Murphy et *al*., 2007).

The extent of the krill decline and the underlying factors are under vigorous debate, mainly because of difficulties in unraveling the effects of industrial whaling and fishing from those of sea ice retreat (Ainley et *al*., 2007, 2009; Nicol et *al*., 2007). There are also discrepancies between the abundance of krill as measured by net and acoustic methods, and the supposed historical abundance as indicated by former predator populations (Willis 2007). One problem is the enormous intra-annual as well as spatial variability needing to be considered (Hewitt et *al*., 2003; Saunders et *al*., 2007).

Changes in predator populations concurrent to observed decreases in krill biomass have been documented (Laws 1977, Bengtson and Laws 1985, Ballance et *al*. 2006). Reid & Croxall (2001) have shown extreme variation in reproductive output for krill-dependent top predators breeding at

South Georgia (fur seals, black-browed albatrosses, macaroni and gentoo penguins) in relation to annual krill availability, although Ainley & Blight (2009) note that the loss of groundfish, and their juveniles (important top predator prey), confounds the patterns. Ducklow et *al*. (2007) showed that the decrease in winter sea ice in the western Antarctic Peninsula has significantly contributed to long-term changes in the relative abundance of krill-dependent penguin populations.

In the Western Antarctic Peninsula region, the population trends of Adélie and Chinstrap penguins appear to be affected negatively by a winter krill deficit. This deficit also affects Gentoo penguins and elephant seals in the opposite direction (Ducklow et *al*., 2007; Siniff et al., 2008). Similar results on population trends at the South Orkneys suggest the loss of buffering against the changing sea ice environment by the more abundant and ice-dependent Chinstrap and Adélie penguins, and positive population consequences through habitat improvement for the less ice-related Gentoo penguin (Forcada et *al*., 2006). The loss of sea ice is likely having negative effects on the availability of Antarctic silverfish, with corresponding effects on predators such as Adélie penguins and Weddell seals (Emslie and Patterson 2007, Siniff et *al*. 2008, Montes-Hugo et *al*. 2009).

In addition, a recent SCAR report has predicted that some whale species may not get the chance to continue to recover further from whaling if the krill population remains at a low level (SCAR, 2009). In contrast, and perhaps neutral to changes in sea ice coverage, the numbers of humpback whales are increasing steadily in this area (Branch 2009).

In short the changes occurring in the Scotia Sea/Antarctic Peninsula region are not simple. The consequences of historical harvesting reduce our ability to understand the impacts of climate change on krill, seals and whales (SCAR, 2009). While the mechanisms by which environmental variability affect sea ice cover and krill demography are being investigated, it remains unclear as to how these changes affect other ecosystem components, such as upper-level predators at all spatial and temporal scales (Fraser & Hofmann, 2003).

3 The Antarctic krill fishery and the need for adaptive management

In addition to being the main food source for most animal species, Antarctic krill also sustains the largest fishery in the Southern Ocean, under the purview of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). Most of the overall krill catch for the past decade has been taken exclusively from the Scotia Sea/Antarctic Peninsula region. Moreover, 99% of krill fishing takes place along the continental slope and thus in the regions where land-based (penguins, fur seals), as well as marine-based (cetaceans) predators forage or used to forage in the case of non-recovering whales. Therefore, combined impacts from climate change and concentrated fishing for krill deserve special attention when developing adaptation strategies for the marine ecosystem in Western Antarctica.

The potential cumulative impacts of climate change and fishing on krill and krill predators are unknown and need to be considered by CCAMLR. In 2006, the Scientific Committee requested CCAMLR Members to consider "what the potential effects of climate change on Antarctic marine ecosystems might be, and how this knowledge could be used to advise the Commission on management of the krill fishery". The CCAMLR Scientific Committee has acknowledged difficulties in differentiating the effects of fishing from those of climate change.[1]

Since the first management arrangements for krill were developed in the early 1990's, CCAMLR acknowledged that the establishment of annual catch limits based on krill biomass estimates would not be sufficient to account for the risk of localised fishing impact on predator populations, and that improved management would be needed, including the development of a "feedback management procedure". Under this feedback approach, measures are continuously adjusted in response to relevant information, representing a truly adaptive management strategy for krill fisheries.[2]

The need for developing feedback management procedures for krill becomes even more pressing today, with the increasing evidence of climate change effects in this region and the apparent start of recovery of certain baleen whale stocks. Yet despite these pressures on the ecosystem, a management

[1] SC-CCAMLR, 2006, para. 3.7.
[2] SC-CCAMLR, 1991, para. 3.66 and 3.103.

scheme for krill, which accounts for interactions between the fishery, krill predator populations and environmental factors, still remains to be developed. In its 2007 meeting, CCAMLR decided that the further development of feedback management approaches will be given priority from 2009 onwards.[3] However, CCAMLR has failed so far to make progress on this issue.

An essential element in the development of a feedback management system for krill fisheries is CCAMLR's Ecosystem Monitoring Program (CEMP), which is discussed in section 4.

4 CCAMLR's Ecosystem Monitoring Program (CEMP)

CEMP was established in 1985 to monitor the effects of fishing on both harvested species (target species) and dependent species (predators), so as to assist CCAMLR with its task of regulating the commercial harvesting of Antarctic marine living resources in accordance with the "ecosystem approach" embodied in Article II (www.ccamlr.org). Based on a feedback management approach, it was expected that such a monitoring program would enable CCAMLR to adjust management measures in response to new information as it became available.

The idea behind the establishment of the CEMP was that krill predators could be good indicators of the availability of krill. The concept of indicator species was thus developed, referring to those dependent or related species that are likely to reflect changes in the species targeted by the fishery, and indicate the state of those parts of the ecosystem that are most impacted by fishing activities.[4]

One of the challenges of the CEMP is to be able to distinguish whether a detected change in an indicator species is due to fishing or to environmental effects, including climate change. Representativeness of the monitoring sites of their respective areas and regions constitutes another challenge.[5] This is mainly because the CEMP is largely dependent on national research programs and priorities. Although management considerations influenced the initial selection of monitoring sites, this selection was also determined by practical considerations such as the presence of pre-established research stations. The continuity of contributions to the CEMP also depends on national priorities, since participation in the program is voluntary. As a result, the program is restricted to monitoring a few selected krill predators and is established in only a few areas. Predator monitoring is currently restricted to land-based species.

The CEMP assessment of the impacts of krill fishing on dependent species still remains to be integrated into long-term management procedures. These procedures enable the continuous adjustment of relevant measures in response to new information obtained, according to the feedback management approach adopted by CCAMLR. At the moment, the nature of CEMP can be described as a "surveillance monitoring" program, where basic ecological data are gathered allowing for *a posteriori* attribution of the causes of change, but there is no direct link between this monitoring program and a specific management objective, and therefore it is not a truly adaptive scheme.

Although CEMP data have provided invaluable insights in the understanding of the key ecological processes in the South Atlantic and some other areas, implementing a feedback management procedure would require moving from current surveillance monitoring to "operational monitoring". The latter is designed to respond to a specific management objective, such as detecting whether a certain trigger level has been reached. The design and implementation of an operational monitoring program require clear definition of the change to be detected. Also, the monitoring should be designed so as to deliver the statistical power required to detect such a change (Reid, 2007). As CCAMLR moves into truly adaptive management procedures, the ability to effectively manage the fishery in those areas where there is no monitoring will be very limited.

---

[3] SC-CCAMLR, 2007, para. 3.36.

[4] A list of monitored parameters was developed for the CEMP, which includes predator, environmental and prey (krill) parameters. Fieldwork and data acquisition for predator parameters (indicator species) are voluntarily carried out by CCAMLR Member countries and submitted to the CCAMLR Secretariat. The Secretariat uses fisheries data submitted by Members to calculate some of the krill-related parameters. Furthermore, some environmental parameters, such as sea ice cover or sea surface temperatures are derived from publicly available datasets (Agnew, 1997). In order to facilitate data analysis and comparison between predator monitoring studies in the context of CEMP, CCAMLR's Scientific Committee developed a set of agreed Standard Methods for monitoring predator parameters. *See CCAMLR Ecosystem Monitoring Programme: Standard Methods (2004).*

[5] SC-CCAMLR, 2003, para. 3.11 and 3.12.

CCAMLR has already recognized that in its current configuration, CEMP does not allow distinguishing the impacts of fishing from those associated with environmental change, which was its main objective at the time of its creation. In addition, some CEMP sites have been discontinued in recent years and data submitted to the CEMP has decreased. In some cases, information arising from different CEMP sites with similar geographical and oceanographic features indicate contradictory trends on predator parameters, which are difficult to explain without further investigation.

As was acknowledged by CCAMLR's Working Group on Ecosystem Monitoring and Management (WG-EMM) at its last meeting in 2009, climate change may induce rapid changes within the ecosystem, impacting the way indices generated by CEMP are being used to detect fisheries impacts. According to WG-EMM, in order to distinguish between climate change and fisheries impacts, it may be necessary to establish reference sites (i.e. where no fishing takes place) and/or additional parameters.[6]

At this critical moment in the development of the krill management regime, CCAMLR needs to make progress towards an effective feedback management system. The CEMP must be expanded accordingly to support this system. In this context, decision rules must be developed to allow adaptive management through appropriate data arising from operational monitoring (as opposed to surveillance monitoring). On the basis of these decision rules, an analysis of the CEMP should be undertaken. This analysis can include questions such as location of additional monitoring sites, the need to add new species into the program as necessary, and indices to be measured.[7] The potential use of area closures in the monitoring program in order to evaluate the combined effects of fishing and climate change, using closed (reference) areas as a control should also be considered. Furthermore, the CEMP should be periodically reviewed to allow for adjustments in the design and operation of the program as required by feedback management needs.

CEMP represents a notable example of ecosystem monitoring in the Antarctic, holding time series data for more than 20 years. An expanded CEMP could provide valuable data for other monitoring initiatives in the Antarctic, such as the Southern Ocean Sentinel.[8] In addition, CEMP needs to be significantly reformed and expanded in its coverage, so as to allow incorporation of monitoring data into the formulation of specific conservation measures, under a truly adaptive management system in the context of ecosystem change.

5 Closing Remarks

While more information is necessary to understand how long-term changes in the Scotia Sea/ Antarctic Peninsula Region will affect krill population dynamics, we do know that the breeding performance and success of krill-dependent predators is affected strongly by these changes. This knowledge underscores the necessity to account for known or forecasted changes in krill availability to predators when setting krill catch limits in areas where predators forage. This should be an important component of adaptation management strategies for the Southern Ocean, especially considering the central role that krill plays in the food web of the region. In order to take due account of the combined impacts of fishing, recovery from past fishing/hunting and climate change, an extensive and well-designed monitoring program, including both fishing and non-fishing areas, will be key to the timely detection of local or regional adverse effects on krill or krill predators from a long-term krill decline that may be augmented by a fishery (Hewitt & Low, 2000).

One of CCAMLR's key management objectives for the krill fishery is to preserve sufficient prey to sustain healthy predator populations and their recovery, including both cetaceans and finfish. CCAMLR has adopted, in principle, a feedback approach to krill fisheries management, such that management measures need to be continuously adjusted to relevant information -- as it becomes available -- on the interactions between krill fishing and krill predators. Consequently, the CEMP was

[6] SC-CCAMLR-XVIII/3, paragraph 3.110.

[7] It has been suggested that collaboration among bodies such as CCAMLR, the International Whaling Commission or the Scientific Committee for Antarctic Research (SCAR) could provide useful in this regard (Hewitt & Low, 2000).

[8] Similarly, the joint workshop between CCAMLR's Scientific Committee and the Committee for Environmental Protection recommended that CEMP data and standard methods are made available for species assessments and other tasks as needed in he context of the Environmental Protocol. See SC-CCAMLR-XXVIII/6, paragraphs 6.8 and 6.9.

established with the main goal of detecting changes in predator indicator species as a result of fishing. Therefore, integrating CEMP assessments of the combined impacts of krill fishing and climate change on dependent species into long-term management procedures should be a key element of CCAMLR's adaptive management scheme, as well as an important component of a climate change adaptation plan for Antarctic marine ecosystems. In addition, CEMP, which also monitors a few species in the Southern Indian Ocean, should be integrated into broader monitoring plans for the Southern Ocean.

6 References

Agnew, D. 1997. The CCAMLR Ecosystem Monitoring Programme. *Antarctic Science* 9 (3): 235-242.

Ainley, D.G., Ballard, G., Ackley, S., Blight, L., Eastman, J.T., Emslie, S.D., Lescroel, A., Olmastroni, S., Townsend, S.E., Tynan, C.T., Wilson, P. And Woehler, E. 2007. Paradigm lost, or is topdown forcing no longer significant in the Antarctic marine ecosystem? *Antarctic Sci*., 19, 283-290.

Ainley, D.G., G. Ballard, L.K. Blight, S. Ackley, S.D. Emslie, A. Lescroël, S. Olmastroni, S.E. Townsend, C.T. Tynan, P. Wilson, E. Woehler. 2009. Impacts of cetaceans on the structure of southern ocean food webs. *Marine Mammal Science*, DOI: 10.1111/j.1748-7692.2009.00337.

Ainley, D.G. & L.K. Blight. 2009. Ecological repercussions of historical fish extraction from the southern ocean. *Fish and Fisheries* 10, 13-38.

Atkinson, A., Siegel, V., Pakhomov, E., and Rothery, P. 2004. Long-term decline in krill stock and increase in salps within the Southern Ocean. Nature 432: 100-103.

Ballance, L., R. L. Pitman, R. P. Hewitt, D. B. Siniff, W. Z. Trivelpiece, P. J. Clapham and R. L. Brownell, Jr. 2006. The removal of large whales from the Southern Ocean: Evidence for long-term ecosystem effects? Pages 215–230 in J. A. Estes, D. P. Demaster, D. F. Doak, T. E. Williams and R. L. Brownell, Jr., eds. *Whales, whaling and ocean ecosystems*. University of California Press, Berkeley, CA.

Bengtson, J.L. and Laws, R.M. 1985. Trends in crabeater seal age at maturity: an insight into Antarctic marine interactions. In: *Antarctic Nutrient Cycles and Food Webs* (eds W.R. Siegfried, P.R. Condy and R.M. Laws). Springer-Verlag, Berlin and Heidelberg, pp. 669–675.

Branch, T.A. 2009. Humpback abundance south of 60S from three completed sets of IDCR/SOWER circumpolar surveys. *Journal of Cetacean Research and Management* (in press).

Branch, T.A., K.M. Stafford, D.M. Palacios, C. Allison, J.L. Bannister, C.L.K. Burton, E. Cabrera, C.A. Carlson, B. Galletti Vernazzani, P.C. Gill, R. Hucke-Gaete, K.C.S. Jenner, M.-N. M. Jenner, K. Matsuoka, Y.A. Mikhalev, T. Miyashita, M.G. Morrice, S. Nishiwaki, V.J. Sturrock, D. Tormosov, R.C. Anderson, A.N. Baker, P.B. Best, P. Borsa, R.L. Brownell, Jr, S. Childerhouse, K.P. Findlay, T. Gerrodette, A.D. Ilangakoon, M. Joergensen, B. Kahn, D.K. Ljungblad, B. Maughan, R.D. Mccauley, S. Mckay, T.F. Norris, Oman Whale and Dolphin Research Group, S. Rankin, F. Samaran, D. Thiele, K. Van Waerebeek, and R.M. Warneke. 2007. Past and present distribution, densities and movements of blue whales Balaenoptera musculus in the Southern Hemisphere and northern Indian Ocean. *Mammal Review* 37: 116–175.

Constable, A.J., Nicol, S. and Strutton, P.G. 2003. Southern Ocean productivity in relation to spatial and temporal variation in the physical environment. *Journal of Geophysical Research* 108 (special issue): 6 -21.

Croxall, J.P., McCann, T.S., Prince, P.A, and Rothery, P. 1988. Reproductive performance of seabirds and seals at South Georgia and Signy Island 1976-1986: implications for Southern Ocean monitoring studies. In: *Antarctic Ocean and resources variability* (ed. Sahrhage). Springer, Berlin: 261-285.

Ducklow, H.W., Baker, K., Martinson, D.G., Quentin, L.B., Ross, R.M., Smith, R.C., Stammerjohn, S.E., Vernet, M. And Fraser, W. 2007. Marine pelagic ecosystems: the West Antarctic Peninsula, *Phil. Trans. R. Soc.* B, 362, 67-94.

Emslie, S. D., and W. P. Patterson. 2007. Abrupt recent shift in δ13C and δ15N values in Adélie penguin eggshell in Antarctica. *Proceedings of the National Academy of Sciences* 104:1666–1669.

Estes, J. A., D. P. Demaster, D. F. Doak, T. E. Williams and R. L. Brownell, Jr., eds. 2006. Whales, whaling and ocean ecosystems. University of California Press, Berkeley, CA.

Forcada, J., Trathan, P.N., Reid, K. And Murphy E.J. 2005. The effects of global climate variability in pup production of Antarctic fur seals, *Ecology*, 86, 2408–2417.

Forcada, J., Trathan, P.N., Reid, K., Murphy, E.J. And Croxall, J.P. 2006. Contrasting population changes in sympatric penguin species with climate warming, *Global Change Biology,* 12, 411–423.

Fraser, W.M., Hofmann, E.E. 2003. A predator's perspective on causal links between climate change, physical forcing and ecosystem response. *Marine Ecology Progress Series* 265:1-15.

Hewitt, R. P. and Linen Low, E. H. 2000. The Fishery on Antarctic Krill: Defining an Ecosystem Approach to Management. *Reviews in Fisheries Science 8 (3): 235–298.*

Hewitt, R.P., Demer, D.A. And Emery, J.H. 2003. An 8-year cycle in krill biomass density inferred from acoustic surveys conducted in the vicinity of the South Shetland Islands during the austral summers of 1991–1992 through 2001– 2002, *Aquatic Living Resources*, 16, 205-213.

Hilborn, R., T.A. Branch, B. Ernst, A. Magnusson, C.V. Minte-Vera, M.D. Scheuerell, and J.L. Valero. 2003. State of the world's fisheries. *Annu. Rev. Environ. Resour.* 2003. 28:359–99.

Hinke, J.T., Salwicka, K., Trivelpiece, S.G., Watters, G.M. And Trivelpiece, W.Z. 2007. Divergent responses of Pygoscelis penguins reveal a common environmental driver, *Oecologia,* 153, 845-855.

Kock, K.-H. (1992) Antarctic Fish and Fisheries. Cambridge. University Press, Cambridge and New York, 359 pp.

Kock, K.-H. (1998) Changes in the fish biomass around Elephant Island (Subarea 48.1) from 1976 to 1996. *CCAMLR Science* 5, 165–189.

Kock, K.-H. and Jones, C.D. (2005) Fish Stocks in the southern Scotia Arc region – a review and prospectus for future research. *Reviews in Fisheries Science* 13, 75–108.

Laws, R.M. 1977. The significance of vertebrates in the Antarctic marine ecosystem. In: Llano, G.A. (editor), *Adaptations within Antarctic ecosystems*. Houston: Gulf Publishing Company: 411–438.

Montes-Hugo, M., S.C. Doney, H.W. Ducklow, W. Fraser, D. Martinson, S.E. Stammerjohn, O. Schofield. 2009. Recent changes in phytoplankton communities associated with rapid regional climate change along the western Antarctic Peninsula. *Science* 323: 1470-1473.

Murphy, E.J., Trathan, P.N., Watkins, J.L., Reid, K., Meredith, M.P., Forcada, J., Thorpe, S.E., Jonston, N.M. And Rothery, P. 2007. Climatically driven fluctuations in Southern Ocean ecosystems, *Proceedings of the Royal Society B*, doi:10.1098/rspb.2007.1180.

Nicol, S., Croxall, J., Trathan, P., Gales, N. And Murphy, E. 2007. Paradigm misplaced? Antarctic marine ecosystems are affected by climate change as well as biological processes and harvesting, *Antarctic Sci*., 19, 291-295.

Österblom, H., S. Hansson, U. Larsson, O. Hjerne, F. Wulff, R. Elmgren, and C. Folke. 2007. Human-induced trophic cascades and ecological regime shifts in the Baltic Sea. *Ecosystems* 10: 877–889.

Parkinson, C. L. 2002. Trends in the length of Southern Ocean sea ice seasons 1979-99. *Annals of Glaciology* 35: 435-440.

Quetin, L.B. and Ross, R.M. 2001. Environmental variability and its impact on the reproductive cycle of Antarctic krill. *American Zoologist* 41: 74-89.

Quetin, L.B. and Ross, R.M. 2003. Episodic recruitment in Antarctic krill Euphausia superba in the Palmer LTER study region. Marine Ecology Progress Series 259: 185-200

Reid, K. 2007. Monitoring and management in the Antarctic – making the link between science and policy. *Antarctic Science* 19 (2): 267-270.

Reid, K. and Croxall, J.C. 2001. Environmental responses of upper trophic-level predators reveals a system change in an Antarctic marine ecosystem. *Proceedings of the Royal Society of London* 268: 377-384.

Saunders, R.A., Brierley, A.S., Watkins, J.L., Reis, K., Murphy, E.J., Enderlein, P. And Bone, D.G. 2007. Intra-Annual variability in the density of Antarctic krill (Euphausia superba) at South Georgia, 2002-2005: within-year variation provides a new framework for interpreting previous 'annual' estimates of krill densitiy, *CCAMLR Science,* 14, 27-41.

Scientific Committee on Antarctic Research (SCAR). 2009. Antarctic Climate Change and the Environment. Cambridge, UK.

Siniff, D.B., R.A. Garrott, J.J. Rotella, W.R. Fraser & D.G. Ainley. 2008. Projecting the effects of environmental change on Antarctic seals. Antarctic Science 20: 425-435.

Stammerjohn, S. E., D. G. Martinson, R. C. Smith, X. Yuan, and D. Rind. 2008. Trends in Antarctic annual sea ice retreat and advance and their relation to El Niño–Southern Oscillation and Southern Annular Mode variability. *Journal of Geophysical Research* 113:C03S90.

Tønnessen, J.N., and A.O. Johnsen. 1982. The history of modern whaling. London: C. Hurst and Co.

Trathan, P.N., Murphy, E.J., Forcada, J., Croxall, J.P., Reid, K. And Thorpe, S.E. 2006. Physical forcing in the southwest Atlantic: ecosystem control in top predators in marine ecosystems: their role in monitoring and management (eds I L Boyd, S Wanless and C J Camphuysen), 28–45. Cambridge, UK.

Watermeyer, K.E., L.J. Shannon, and CL Griffiths. 2008a. Changes in the trophic structure of the southern Benguela before and after the onset of industrial fishing. *African Journal of Marine Science* 30(2): 351–382

Watermeyer, K.E., L.J. Shannon, J.-P. Roux and CL Griffiths. 2008b. Changes in the trophic structure of the northern Benguela before and after the onset of industrial fishing. *African Journal of Marine Science,* 30(2): 383–403.

Willis, J. 2007. Could whales have maintained a high abundance of krill? *Evolutionary Ecology Research* 9:1–12.