

Gambling with Krill Fisheries in the Antarctic:
Large uncertainties equate with high risks.

Paul Johnston, David Santillo, Richard Page, Cat Dorey

Greenpeace Research Laboratories Technical Note 01/2009
12 February 2009

School of Biological Sciences
University of Exeter

Introduction

This briefing paper outlines the large uncertainties and indeterminacies attached to current scientific knowledge of krill ecology in the Antarctic. The uncertainties relate firstly to the depth of knowledge of krill standing stocks, life history and reproductive strategies and secondly to the ways in which krill ecology may be driven by ongoing climate change in the Antarctic. The Antarctic Peninsula is warming at a rate well above the global average and this will impact on seasonal sea ice which is linked to krill reproductive success.

These issues are of considerable importance since Antarctic krill is a keystone species which supports an expanding fishery sector. The management regime applied to this fishery does not adequately accommodate these uncertainties and indeterminacies. Accordingly, the pursuit of an industrial scale fishery targeting krill in the Southern Ocean is associated with high risks of unsustainability which could have major consequences for the wider ecosystem.

What are Krill?

“Krill” is a term which refers to around 85 species of euphausiid crustaceans which are mostly planktonic. They are found in all oceans of the world and their large size coupled with a tendency of some species to form dense “swarms” means that they are highly important in some marine ecosystems. In addition, some species are commercially harvested in directed fisheries which appear likely to be subject to increasing effort in coming years (Everson 2000). This is particularly true of the Antarctic region. Here, of the seven krill species commonly reported, the principal swarming species *Euphausia superba* is targeted by large scale commercial fisheries particularly in the Atlantic sector, with the Indian and Pacific Ocean sectors attracting less interest. Henceforth, the term krill is used in this document to refer to this species alone.

The distribution of krill in the waters around Antarctica is shown in Figure 1 below. It has a circumpolar distribution as far north as the Antarctic Polar Front Zone, and the distribution of the species helped define the management area defined by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) as shown in Figure 2.

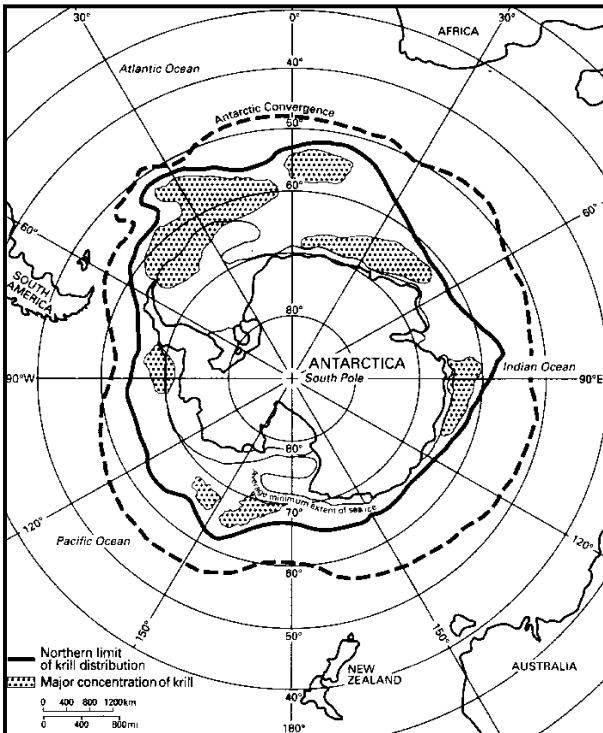


Figure 1. Map of Antarctica showing the Antarctic Convergence, major concentrations of krill and the northern-most limit of their distribution. The species is predominantly found in areas covered seasonally or permanently by sea-ice. From University of the United Nations website at: <http://www.unu.edu/unupress/unupbooks/uu15oe/uu15oe06.gif>

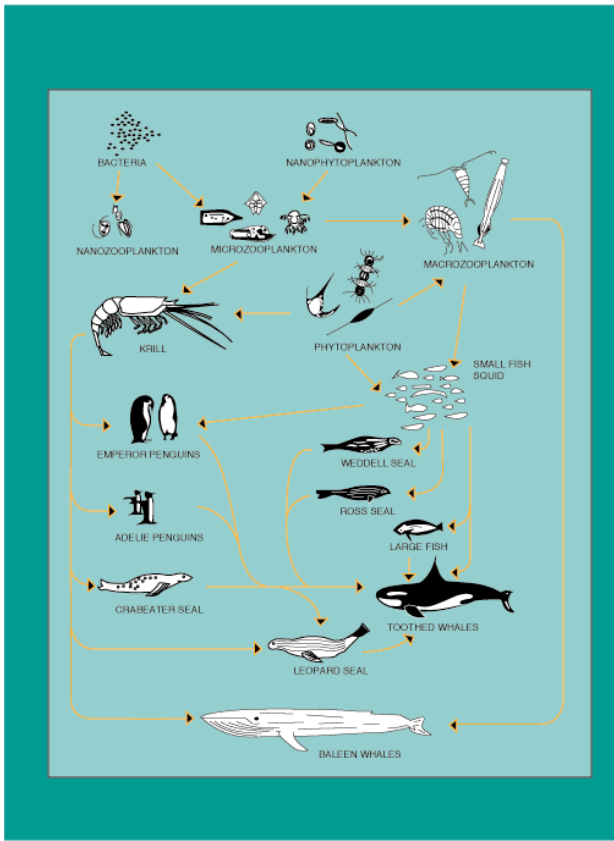


Figure 3. Diagram of the Antarctic food web showing the central role of krill. From Hader *et al.* 1991.

Water and ice movements also figure in the life history. Sea ice movements are complex and larvae associated with ice also move with it, though this is not the complete story. The Antarctic Circumpolar Current may, for example, explain the high abundance of krill in the waters around South Georgia which are free of sea-ice. Population densities have been linked to gyral circulation patterns. However, overall, this is another area where substantial uncertainties exist. The scientific literature acknowledges the fact that there is an incomplete understanding of the forces which determine the distribution of krill at all scales, local, regional or continental. Significantly, the elucidation of the population dynamics at a single location is held hostage to the fact that key processes relevant to the population (growth and recruitment) are happening in areas remote from these populations (Nicol 2006).

Recently, it has been suggested that the huge numbers of krill present in the Southern Ocean coupled with behavioural patterns which see them undertake significant daily migrations through the water column may play an important role on global carbon cycling. On this basis, it has been further suggested that krill waste products introduced below the mixed layer would effectively move carbon into deep waters where it would be retained over long time periods (Tarlign & Johnson 2006; Swadling 2006).

A thorough knowledge of the population dynamics of krill and the factors driving these dynamics is essential to understanding the way in which the populations of these organisms are likely to respond to pressures of human activities. Two major impacts with the potential to interact significantly in driving overall population impacts are currently of relevance: (a) impacts of anthropogenically-forced climate change and (b) impacts of fishing activities directed at krill. The effects of these pressures working individually and in combination are at the present time a completely unknown quantity.

Climate Change and the Antarctic

The recent IPCC Assessment Report (see: Anisimov *et al.* 2007; Lemke *et al.* 2007) documents what appear to be somewhat contradictory trends in impacts of climate change over the Antarctic as a whole with some areas warming and others apparently cooling. A recent evaluation, however, has shown that despite these apparent inconsistencies, the continent as a whole appears to be warming at a rate comparable to the entire Southern Hemisphere (Steig *et al.* 2009).

The Antarctic Peninsula, where major krill spawning and nursery areas are located, has been undergoing a dramatic warming in recent decades and is considered to be one of the most rapidly warming areas on the planet with rates several times the global mean. The temperature rise has exceeded 2.5°C over the last 50 years and although the rate is seasonally variable, the number of days when temperatures reach above 0°C has risen by 74%.

The drivers of this rapid temperature rise are not understood with complete certainty but it is thought that they are linked with anthropogenically driven changes in atmospheric circulation patterns. The climate models do not seem to simulate this warming and so it is not known to what extent it may continue into the future. The temperature changes have driven changes both in biological systems and in the physical environment in the region as a whole. Despite the complexity and the difficulty in establishing causal relationships, the British Antarctic Survey (BAS 2007) outlines observed impacts, many of which relate to the Antarctic Peninsula and the sub-Antarctic islands. While temperature is a primary driver of Antarctic ecology, moisture and nutrient availability may also be changed (Walther *et al.* 2002). Hence, a study of the ecology of lakes on Signy Island which has a maritime Antarctic climate and on which permanent ice cover has receded by some 45% since the early 1950s, has shown some profound changes. The lake open water period increased by around 63 days in 1993 as compared to 1980, reflecting a 0.5°C rise in summer air temperatures (Quayle *et al.* 2002).

In the terrestrial environment striking changes have been observed in the populations and distributions of Antarctica's only two species of flowering plants: Antarctic hair grass (*Deschampsia antarctica*) and Antarctic pearlwort (*Colobanthus quitensis*). At sites along the Antarctic Peninsula these changes have been linked to warming and to local snow recession. Larger areas are now surviving winter and reproducing in the summer months. The ranges of these plants, however, have remained largely unchanged, these being defined by the lack of suitable ice-free ground south of the Terra Firma Islands. Rapid increases in bryophytes and micro-organisms have also been observed at sites in the maritime Antarctic. Although less visible, it is expected that this change in flora will be accompanied by increases in the associated invertebrate fauna (Convey 2003).

A trend towards warmer conditions also raises the possibility that alien species of plants and animals could become established in the Antarctic and sub-Antarctic, while those already present could expand their range and numbers. Many species have the potential to establish themselves in the region, and humans are likely to be the pivotal vector (Frenot *et al.* (2005).

The general warming trend in the Antarctic has recently been powerfully confirmed by conducting a retrospective review of glaciers in the peninsula. This has convincingly shown that over the last 61 years 87% of glaciers have retreated and that the demarcation between those retreating and those advancing has moved progressively southwards (Cook *et al.* 2005). These trends seem set to continue through the rest of the 21st century. Recent modelling exercises (Bracegirdle *et al.* 2008) suggest that the intensity of near surface winds is likely to increase by some 20%. Averaged surface warming over the continent as a whole is projected to be 0.34°C per decade while sea ice area will continue to decline by around 3% (250,000 sq kilometres) per decade. Paradoxically, snowfall in the interior may increase by 20%.

A reduction in sea ice is likely to have important biological impacts. There has been a reduction in duration and extent of winter sea ice formation to the west of the Peninsula (although increases have been observed in other parts of the Antarctic). The reduction in sea ice has potentially severe implications for the distribution of *inter alia* various penguin species dependent upon sea-ice and already it appears that ice-adapted Adélie penguins are being replaced by open-water species such as chinstrap penguins. Recent work based on IPCC climate projections suggests that emperor penguins which depend on sea ice for breeding, foraging and moulting have a 36% chance of losing 95% of their population by 2100, a loss which equates with virtual extinction of the island population studied (Jenouvrier *et al.* 2009).

The most spectacular physical changes in the Antarctic environment relate to the ice shelves of the Antarctic Peninsula. These are floating extensions of a grounded ice-sheet and globally most of them are located in embayments around the Antarctic continent (including the Antarctic Peninsula.) The size of ice shelves is essentially determined by the amount of snow falling on their surface and the amount of glacial ice delivered to them. These inputs are counterbalanced by ice lost through melting and the formation (calving) of icebergs. Changes in these parameters will be reflected in changes in the size of the ice shelves. According to work cited by Anasimov *et al.* (2007) some 14,000 square kilometres have been lost from ten floating ice shelves over the last 50 years. Marine sediment core data suggest that these ice shelves have probably not been at such a minimum for 10,000 years and definitely have not been as reduced in extent at any time in the last 1000 years.

The British Antarctic Survey lists seven ice shelves which have been seriously impacted by warming on the Antarctic Peninsula (BAS 2008). With some of these, the loss of ice has been progressive, lasting several decades, while in other cases dramatic collapses have taken place. The various mechanisms of ice loss are an area of active research. The best known example of collapse was the Larsen A ice shelf collapse in 1995. This occurred in a matter of weeks. The Prince Gustav ice shelf also finally collapsed in 1995 having retreated progressively during the late 20th century. A similar retreat, followed by collapse in 2002, took place with the Larsen B ice shelf. After these collapses, links were made with climate change (BAS 2008). If the current rate of warming on the Peninsula is maintained, then further retreats and collapses can be anticipated.

The Wilkins ice shelf is likely to be next. Its collapse has been predicted since it lost around 1000 square kilometres in 1998. Ten years later, in March 2008, a further 400 square kilometres was lost. Although the ice shelves are floating and therefore will not contribute to sea level rise as they retreat or collapse, their loss may well lead to an increase in the "flow" rates of glaciers and increases in meltwater. These will both add to sea level rise.

In late November 2008, new rifts developed on the ice shelf. Currently, a small strip of ice connects the main body of the ice shelf with the adjacent Charcot Island. Much speculation exists as to when this ice bridge will disintegrate. This could, in turn, put the entire ice shelf at further risk of disintegration. It is not clear when the ice bridge will disintegrate, but the 2008 event continued to progress even after the onset of the austral winter. (Daily images from the area are being uploaded by the European Space Agency at: www.esa.int/esaEO/SEMWZS5DHN/index_0.html).

Climate Change Impacts on Krill and the Wider Antarctic Ecosystem

One serious potential impact of reduced sea ice (though not of ice shelf loss *per se*) is failure of krill populations to reproduce and a subsequent failure to recruit into the population over a much wider area. Recruitment failure of krill has already been linked to reproductive failure in a range of seal, and bird species (Convey *et al.* 2003). In the Southwest Atlantic sector which is thought to support >50% of krill stocks, there has been a decline of around 80% in krill numbers since the mid 1970s (Atkinson *et al.* 2004). At the same time, another group of filter feeders, the salps, which prefer warmer and nutrient poorer water, have increased in number. The krill which are generated along the ice edge provide a food resource over a wide area. Analysis of four species dependent on krill at South Georgia showed that all four declined during the 1990s after a period of stability or increase during the 1980s. This was attributed to reduced prey availability and corresponded with changes in krill population structure. Effectively there was a move to a situation where predation on a very large population of krill was superseded by predation on a population less able to support predator demand (Reid & Croxall 2001). Similar impacts have been observed in Adélie penguin populations near Palmer Station in the Western Antarctic peninsula implying that these impacts are already detectable over a very wide area (Fraser & Hofmann 2003). In the South Atlantic, failure of Antarctic krill recruitment and population decline will inevitably foreshadow recruitment failures in a range of higher trophic level marine organisms (Trathan *et al.* (2007).

The krill issue is also seen as of concern in relation to the potential recovery of whale populations from commercial whaling operations. It is not known whether the fast rate of warming in the Peninsula region and West Antarctic will continue. The potential, however, for far reaching changes in krill ecology seems to be high, if also relatively poorly characterised. At present, it is not known if changes in krill populations as reflected in changes in key predator populations represent an element of high inter-annual variability or the beginning of a systematic downward trend. Resolution of this conundrum is hampered by lack of a long-term data series (Kock *et al.* 2007).

Antarctic Krill Fisheries

The krill fishery began in the 1970s and reached a peak in the early 1980s when around 500,000 tonnes were taken. It stabilized at around 400,000 tonnes from 1986/87 through to 1990/91 and then declined further to 87,000 tonnes in the 1992/93 season rising again to around 100,000 tonnes in 1999. Catches reached around 126,000 tonnes in 2001/2002, falling slightly to 104,000 tonnes in the 2006/2007 season (CCAMLR 2008). However, the industry looks set to expand rapidly in the coming years with totalled report notifications for the 2007/2008 season of over 750,000 tonnes with 620,000 tonnes projected for area 48 and the balance for Area 58.4 (South Indian Ocean) (ASOC 2007 a & b). Another significant trend in the fishery is that the historic domination of the industry by Russia and Japan is being broken by the entry of vessels from other nations into the industry. In particular Norway has become a key player, accounting for around 40% of the 2007 recorded catch (CCAMLR 2008a).

It is likely that intensity of fishing for krill will increase in the future in the Antarctic Region. It is currently the largest fishery in the Southern Ocean (Everson 2000). The market for krill is expected to grow in line with increasing demand globally for aquaculture feed (Nicol & Foster 2003). Previous difficulties related to rapid spoiling of the catch and high levels of fluoride leaching from the shells into the meat have largely been overcome by improved and more rapid on-board processing techniques. Some facilities exist aboard vessels to manufacture bio-diesel from krill. The decline in sea ice in the south-western Atlantic has enabled the krill fishery to operate year round (Smetacek & Nicol 2005). This and the improved processing methods have effectively removed the last constraints that were limiting growth of this fishery. In addition, the development of new products is taking place, including the production of krill oil rich in omega-3 fatty acids as a human dietary supplement.

Management of the krill fishery is conducted under the auspices of Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). CCAMLR, under the Antarctic Treaty, arguably owes its existence to international efforts to forestall a "free for all" in fisheries in the region. In 1991, the first 'precautionary' catch limit for Area 48 was established at 1.5 million tonnes (ASOC 2007c). Following the CCAMLR 2000 Krill Synoptic Survey in Area 48 (Watkins *et al.* 2004), the total biomass of krill was estimated at 44.3 million tonnes (Hewitt *et al.* 2004). This was used to set a revised precautionary limit of 4 million tonnes (see also: Hewitt *et al.* 2002, ASOC 2007c) for Area 48. Subsequently, in Conservation Measure 51-01 (CCAMLR 2008b; ASOC 2007d) catches were limited to 3.47 million tonnes from Statistical Areas 48.1, 48.2, 48.3 and 48.4 in any one season, with an added proviso that, until this total catch limit could be allocated between smaller management units, then the combined catch should not exceed the trigger level of 620,000 tonnes. This, therefore, is an effective catch limit until such management units are actually defined according to the working principles outlined by Constable and Nicol (2002). Stricter conditions were also imposed on the operation of the fishery. Conservation Measure 51-02 set limits for division 58.4.1 of 440,000 tonnes subdivided across the area, and 51-03 a limit for 58.4.2 of 2.645 million tonnes again subdivided into two. No trigger level was set for 51-02, but with 51-03, trigger levels of 260,000 tonnes and 192,000 tonnes for the two subdivisions were set.

The new limits clearly allow for considerable potential expansion of the krill fishery in Antarctic waters. The trigger levels seem unlikely to interfere with the pursuit of the krill fishery at current levels of exploitation but it is significant that recent notifications to CCAMLR of intentions to fish for krill exceeded the trigger level of 620,000 tonnes (see: CCAMLR 2007). Moreover, the use of trigger levels and limit levels as effective management tools assumes that the basis for the management strategy itself is sound. This is questionable. Overall the management strategy, while aspiring to be precautionary, in fact lacks much of the empirical information required to manage a fishery on such a basis. Among the key areas of concern are:

- 1) Standing stock estimates of krill are subject to wide confidence limits on a regional and local basis. These estimates are based on relatively old survey data and the aggregate data do not comprise a sufficient time series to resolve key questions attached to long term krill population trends and potential impacts upon krill-dependent predators.

While the distribution pattern of krill is now relatively well established, large uncertainties exist as to the standing stocks around the continent. Large differences exist in estimates of standing stock according to the methods used, with acoustic surveys tending to give much higher values than net surveys. While recruitment can be predicted to an extent on the basis of seasonal sea ice extent, acoustic surveys around the South Shetland

Islands have shown a high inter-annual variation in recruitment of krill into the population (Hewitt *et al.* 2003) with apparent 3 and 8 year cycles in this location. A study in East Antarctica showed that varied krill abundance was reflected in breeding success of an Adélie penguin colony, reinforcing the relationships suggested above between krill and their predators (Nicol *et al.* (2008). Studies of krill carried out as part of the CCAMLR 2000 Synoptic Survey revealed considerable distributional and demographic complexities over the region (Siegel *et al.* 2004). At present, however, in relation to the observed declines in predator breeding performance outlined by Kock *et al.* (2007), it is not possible to resolve the magnitude in changes of overall krill supply relative to predator demand. It is very likely, however, that there has been a change from a situation with a large krill supply relative to predator demand in areas studied around South Georgia. This change may have begun in the 1990s, leaving krill supply close enough to predator demand to alter substantially local krill mortality rates. Finally, this situation could have removed any surplus that existed, leading to an increase in the frequency of years when krill populations are insufficient to support predator demands in the island areas affected.

- 2) Management of krill is on the basis of a single species model which cannot accommodate fully uncertainties and indeterminacies in the data. Impacts of climate change on krill have been poorly characterised but may be substantial. Currently the models used to manage the species do not account for long term environmental change. Factors associated with success of krill recruitment have not been well characterised.

Strategic fisheries management decisions have been based upon modelling exercises using the so-called 'Krill Yield Model' (KYM), which iteratively determines the proportion (γ) of the unexploited biomass (B_0) (estimated from surveys) which can be exploited each year. The process is described in detail by Constable *et al.* (2000). As noted by Thomson *et al.* (2000), this single species model only takes into account the needs of predators in a crude manner, assuming that if krill spawning biomass remains above 75% of its pre-exploitation level, then the needs of predators will be met. The basis on which this percentage figure was selected (in the absence of any empirical information on the needs of krill predators) was because it lay mid way between 100% (no exploitation) and the 50% optimal suggested by surplus production models. The authors go on to suggest that in fact this 75% figure may not be adequately protective of predator populations. The KYM has been developed within CCAMLR into a generalised yield model (GYM) which has also been applied to the management of other fisheries in the region. Recruitment of krill is one of the key components in the GYM so changes that occur with climate or other variability are critical to ensuring that the take is sustainable. The model does not include a function driven by physical variables. This is due in part to the unpredictability and poor understanding of impacts of physical variables on recruitment (Kock *et al.* 2007)

Hewitt *et al.* (2004) point out that the models assume a freely distributed krill population, homogeneously distributed predation pressure, and randomly determined recruitment. While the model accounts for some uncertainties in input parameters, spatial and temporal trends in krill demographics, predator demand and fishing pressure are not accounted for. Moreover, there is some evidence that populations in Area 48 may not be comprised of a single stock, confounding the model further. Hewitt *et al.* (2002, 2004) note that before any expansion of the fishery takes place to the limits specified by CCAMLR, it will be necessary to establish a system to prevent concentration of fishing effort near to colonies of land breeding krill predators.

The use of yield models by CCAMLR was adopted as an interim measure (Hewitt *et al.* 2002) to the preferred approach of a feedback driven scheme, whereby management measures are tuned in response to ecosystem monitoring. A full realisation of this approach will require a considerable expansion and development of the existing ecosystem monitoring programme, development of multispecies models accounting for predator/prey interactions and high quality information about the distribution of fishing effort.

- 3) Determinants and drivers of the population structure are incompletely understood and the causes of inter- and intra-annual variation in krill populations are poorly understood.

Knox (2006) details a number of key questions concerning the reproductive behaviour and ecology of krill which have been the target of relatively recent research but which have not been fully resolved as a result. Despite being studied for many decades, an holistic understanding of their biology which enables reliable predictions to be made about population dynamics in the face of environmental change has not been achieved (Kawaguchi & Nicol 2007). These authors note that over the last 30 years general concepts of krill biology and its life history have changed dramatically as more information has emerged both from field and laboratory studies. Hence, their

longevity, which was once thought to be between 2–3 years, is now known to be between 5–7 years. Some of the natural environmental interactions are better (but still incompletely) understood such as those with sea ice (see above), ocean currents and primary producers. Even in the case of sea ice, the best understood of the ecological drivers, the relationship with krill is not simple, with both annual and regional exceptions documented.

In addition to the variation between years, considerable intra-annual variation may exist in population densities in any given year. These may be explained in terms of horizontal or vertical migration, dispersion or advection. This has led to two essentially competing views of krill populations. One views the distribution and abundance of krill at a given location as a function of gross current flows through a much more extensive area. The second view is that krill populations may be relatively stationary and associated with specific physical features of the environment. In terms of fisheries management, the difference between these two conceptual views implies considerable differences in the way that fisheries would need to be managed in each case. Kawaguchi & Nicol (2007) suggest that the krill fishery itself could help in understanding of krill biology. They point out that the quantities fished, together with the fishing strategies employed and coupled with logistic considerations mean that the numbers of krill sampled, both in frequency and intensity, far exceed those characteristic of scientific surveys. There are, however, some limitations. Commercial fisheries concentrate effort in areas of open water where krill densities are high and may target the same population for an extended period of time, although targeting specific colours and sizes of krill to obtain an optimal product may lead to refocusing of effort (see: Everson 2000).

Accordingly, while fishery derived data may provide useful information about krill biology, this will not help in understanding krill behaviours under ice or close to the sea-bottom. Moreover, the CPUE data from the fishery will, therefore, reflect density in the targeted aggregation rather than reflect overall regional density of krill.

- 4) Predator-prey dynamics are incompletely understood and, therefore, management feedback systems are difficult to devise to assure full protection.

In the context of the role of krill in the wider ecosystem, the CCAMLR Ecosystem Monitoring Program (CEMP) was set up to monitor a few selected predators in a few areas, based upon the pragmatic view that full ecosystem monitoring would be impractical. Although elements of the programme have been in place since 1987, it remains unclear how the data could be used to demonstrate the effects of fishing to initiate a management response. Moreover, the impacts of fishing need to be differentiated from any impacts caused by environmental change (Constable *et al.* 2004) which is not possible as things stand.

As pointed out by Constable *et al.* (2000), the precautionary approach is entrenched as a concept within the management strategies used by CCAMLR. The corollary to this, however, is that essential work is still required to develop management procedures that are robust against the unknown and uncertain behaviours of the Antarctic ecosystem. Hence, while the current krill management system is regarded as a precautionary one, much of the framework has been put in place in the face of considerable gaps in the knowledge and that, in the absence of empirical data, approaches based on scientific consensus have been developed. Accordingly, Constable *et al.* (2000) are of the view that CCAMLR is yet to face the real test in its ecosystem approach.

In summary, therefore, expansion of the krill fishery is considered to be inevitable from the current level which is below the estimated long term precautionary yield. Before this occurs, methods will need to be developed to avoid localised (or indeed wider) ecosystem impacts and to establish relevant feedbacks upon the specific impacts of fishing for this target species. It seems, therefore, that more or less every metric of the fishery, or body of data, required to regulate adequately a fishery prosecuted upon krill in Antarctic and sub-Antarctic waters is inadequate to a greater or lesser degree, and given that it targets a keystone species, exploitation has the potential to disturb the whole ecosystem. In view of its potential role in sequestering carbon, exploitation coupled with adverse environmental conditions could also compromise carbon cycling in the region. In combination, the circumstances could conspire to undermine the basis on which the CCAMLR catch limits have been set. Although these limits were set with the intention of being precautionary, it is clear that the current models used to manage the species do not account for long-term environmental changes of the kind now being observed in the Antarctic, such that the alleged precautionary nature of the limits is far from assured.

MSC Certification for the Krill Fishery

Against this management background, Marine Stewardship Council certification is being sought by a single operator, the Norwegian based Aker BioMarine Co. Ltd., for a single vessel which operates within CCAMLR Statistical Area 48 in the Atlantic sector of the Southern Ocean. Aker Biomarine is forecasting a catch of 55,000 tonnes in the 2008/09 season. Even if this single vessel is following best practice and adhering strictly to CCAMLR regulations, it can be argued that, in the context of the fishery as a whole such individual certification runs counter to the principles of the MSC as an assurance of sustainability. It is perfectly possible in theory for a number of operators to be certified by the MSC and, whilst their individual operations may be acceptable, their aggregate operations could well be unsustainable when considered in whole ecosystem terms. Accordingly, in the interests of maintaining a level playing field, individual operation certifications should be discouraged.

Any application for certification must satisfy the three basic MSC principles as follows:

- 1) The fishing activity must be at a level which is sustainable for the fish population. Any certified fishery must operate so that fishing can continue indefinitely and is not over-exploiting the resources.

While this condition appears to be satisfied in relation to krill fisheries at current levels of exploitation, there are considerable uncertainties attached to krill ecology and population dynamics, together with long-term population trends which mean that sustainability cannot be guaranteed. Climate change impacts are not specifically accommodated by the management model, and long time-series data against which trends in population can be fully assessed are unavailable..

- 2) Minimising Environmental Impact. Fishing operations should be managed to maintain the structure, productivity, function and diversity of the ecosystem on which the fishery depends.

Such management cannot be guaranteed under the current framework. Antarctic krill (*E. superba*) is a keystone species. The management of krill is currently effected using a model which has only a limited capacity to respond to changes in input variables (see 2 above), and where some input parameters are estimated on the basis of survey work of limited frequency and intensity. In relation to the ecosystem approach mandated by CCAMLR, this aspect has not been developed in relation to krill dependent predators to any meaningful degree. Notwithstanding, the work carried out under the CEMP the predator/prey relationship impacts due to fishing cannot be differentiated from those caused by variation in physical variables, meaning that the management cannot be fine tuned in relation to fishing alone.

- 3) Effective management: The fishery must meet all local national and international laws and must have a management system in place to respond to changing circumstances and maintain sustainability.

Adherence to the operational legal framework by the Aker vessel cannot be taken as an assurance that the same is true of all vessels operating in the fishery. Hence, appropriate responses to changing circumstances cannot be assured for the fishery as a whole. Moreover, many of the drivers of krill population ecology are incompletely understood, and these uncertainties and indeterminacies mean that it may not be possible to respond to observed changes in an appropriate way.

Conclusion

The massive uncertainties regarding krill biology, krill population dynamics and its role in the wider ecosystem and ecosystem processes coupled with the unknown impacts of rapid climate change in the region, mean that although well-intentioned, CCAMLR's existing management regime cannot be considered precautionary. For these reasons alone, the MSC is not in a position to certify any Antarctic krill fishing operation, as such a certification would clearly be contrary to the MSC's guiding principles. In addition, Aker's application to undergo certification for its krill fishing operation in the Antarctic cannot be viewed in isolation, the certification must also be considered in the context of the fishery as a whole which, as noted above, is set to expand. Given the above, to certify Aker's operation as sustainable would seriously damage the credibility of the MSC.

References

Anisimov, O.A., D.G. Vaughan, T.V. Callaghan, C. Furgal, H. Marchant, T.D. Prowse, H. Vilhjálmsson and J.E. Walsh, (2007). Polar regions (Arctic and Antarctic). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, 653-685.

ASOC (2007a). Antarctic and Southern Ocean Coalition (2007) Krill Industry Report Number 3, September 15, 2007. <http://www.asoc.org/Portals/0/pdfs/Krill%20Industry%20Report%203-091507.pdf>

ASOC (2007b). Antarctic and Southern Ocean Coalition (2007) Krill Industry Report Number 2, July 12 2007. <http://www.asoc.org/Portals/0/pdfs/Krill%20Industry%20Report%202-%20071207.pdf>

ASOC (2007c). Antarctic and Southern Ocean Coalition (2007) The need for a strategic plan for the management of the Antarctic krill fishery. Paper for the XXVI Meeting of CCAMLR October-November 2007. <http://www.asoc.org/portals/0/pdfs/Antarctic%20Krill%20-%20CCAMLR%20XXVI.pdf>

ASOC (2007d). Antarctic and Southern Ocean Coalition (2007) Krill Industry Report Number 5, December 5, 2007. <http://www.asoc.org/Portals/0/Krill%20Industry%20Report%20No%205-120507.pdf>

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

Bracegirdle, T.J., Connelly, W.M., & Turner, J. (2008). Antarctic climate change over the twenty first century. *Journal of Geophysical Research*, 113, D03103, doi:10.1029/2007JD008933.

British Antarctic Survey (2007). Climate Change: Our view. Publ BAS Cambridge UK. http://www.antarctica.ac.uk/bas_research/our_views/climate_change.php

British Antarctic Survey (2008). The Antarctic Peninsula's retreating ice shelves. Science Briefing Publ. BAS Cambridge. http://www.antarctica.ac.uk/bas_research/science_briefings/antarctic_peninsula_retreating_ice_shelves.php

CCAMLR (2007). Report of the Twenty Sixth Meeting of the Scientific Committee Hobart Australia, 22-26 October 2007.

CCAMLR (2008a). Statistical Bulletin Volume 20 (1998-2007, Publ. CCAMLR, Hobart, Australia 236pp.

CCAMLR (2008b). Conservation Measure 51-01. Precautionary catch limitations on *Euphausia superba* in statistical Subareas 48.1, 48.2, 48.3 and 48.4, CCAMLR, Hobart, Australia.

Constable, A.J., de la Mare W.K., Agnew, D.J., Everson, I., & Miller, D. (2000). Managing fisheries to conserve the Antarctic marine ecosystem: practical implementation of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) *ICES Journal of Marine Science* 57: 778-791.

Convey, P. (2003). Maritime Antarctic climate change: signals from terrestrial biology. *Antarctic Research Series* 76: 335-347.

Convey, P., Scott, D. & Fraser, W.R. (2003). Biophysical and habitat changes in response to climate alteration in the Arctic and Antarctic. *Advances in Applied Biodiversity Science* 4: 79-84.

Cook, A.J., Fox, A.J., Vaughan, D.G. & Ferrigno, J.G. (2005). Retreating glacier fronts on the Antarctic peninsula over the past half century. *Science* 308: 541-544.

Everson, I. [ed] (2000). *Krill; Biology, Ecology and Fisheries*. Publ Blackwell Sciences 372pp.

Fraser, W.R. & 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.

Frenot, Y., Chown, S.L., Whinam, J., Selkirk, P.M., Convey, P., Skotnicki, M., Bergstrom, D.M. (2005). Biological invasions in the Antarctic: extent, impacts and implications *Biological Reviews* 80: 45-72.

Häder D.-P., Worrest, R.C. & H.D. Kumar H.D. (1991). Aquatic Ecosystems. Chapter 4 In: *Environmental Effects Of Ozone Depletion: 1991 Panel Report Pursuant to Article 6 of the Montreal Protocol on Substances that Deplete the Ozone Layer Under the Auspices of the United Nations Environment Programme (UNEP)*, November 1991.

Hewitt, R.P., Demer, D.A. & 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.

Hewitt, R.P., Watkins, J.I., Naganobou, M., Tshernyshkov, P., Brierley, A.S., Demer, D.A., Kasatkina, S., Takao, Y., Goss, C., Malyshko, A., Brandon, M.A., Kawaguchi, S., Siegel, V., Trathan, P.N., Emery, J.H., Everson, I., Miller, D.G.M. (2002). Setting a precautionary catch limit for Antarctic krill. *Oceanography* 15 (3): 26-33.

Hewitt, R.P., Watkins, J., Naganobou, M., Sushin, V., Brierley, A.S., Demer, D., Kasatkina, S., Takao, Y., Goss, C., Malyshko, A., Brandon, M., Kawaguchi, S., Siegel, V., Trathan, P., Emery, J., Everson, I. & Miller, D. (2004). Biomass of Antarctic krill in the Scotia Sea in January/February 2000 and its use in revising an estimate of precautionary yield. *Deep-Sea Research II* 51: 1215-1236.

Jenouvrier, S., Caswell, H., Barbraud, C., Holland, M., Stroeve, J. Weimerskirch, H. (2009). Demographic models and IPCC climate projections predict the decline of an emperor penguin population. *Proc Natl Acad Sci USA*. 26 Jan 2009 [Epub ahead of print].

Kawaguchi, S., & Nicol, S. (2007). Learning about Antarctic krill from the fishery. *Antarctic Science* 19 (2) 219-230.

Knox, G.A. (2006). *Biology of the Southern Ocean*. Publ CRC Press, Boca Raton 621pp.

Kock, K.-H., Reid, K. Croxall, J. & Nicol, S. (2007). Fisheries in the Southern Ocean: An ecosystem approach. *Philosophical Transactions of the Royal Society B*: 362: 2333-2349.

Lemke, P., J. Ren, R.B. Alley, I. Allison, J. Carrasco, G. Flato, Y. Fujii, G. Kaser, P. Mote, R.H. Thomas & T. Zhang. (2007). Observations: Changes in Snow, Ice and Frozen Ground. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Nicol, S. (2006). Krill, Currents and Sea Ice: *Euphausia superba* and its Changing Environment. *Bioscience* 56 (2): 111-120.

Nicol, S., Clarke, J., Romaine, S.J., Kawaguchi, S., Williams, G., Hosie, G.W. (2008). Krill (*Euphausia superba*) and Adelie penguin (*Pygoscelis Adeliae*) breeding performance in the waters off the Bechervaise Island colony, East Antarctica in 2 years with contrasting ecological conditions. *Deep-Sea Research II* 55:540-557.

Reid, K. & Croxall, J.P.(2001). Environmental response of upper trophic-level predators reveals a system change in an Antarctic marine ecosystem. *Proceedings of the Royal Society B* 268: 377-384.

Nicol, S. & Foster, J. (2003). Recent trends in the fishery for Antarctic krill. *Aquatic Living Resources* 16: 42-45.

Siniff, D.B. (1991). An Overview of the Ecology of Antarctic Seals. *American Zoologist* 31: 143-149.

Siegel, V., Kawaguchi, S., Ward, P., Litvinov, F., Sushin, V., Loeb, V., Watkins, J. (2004). Krill demography and large scale distribution in the south west Atlantic during January/February 2000. *Deep-Sea Research II* 51: 1253-1273.

- Smetacek, V. & Nicol, S. (2005). Polar ocean ecosystems in a changing world *Nature* 437: 362-368.
- Steig, E.J., Schneider, D.P., Rutherford, S.D., Mann, M.E., Comiso, J.C., Shindell, D.T. (2009). Warming of the Antarctic ice-sheet surface since the 1957 International Geophysical Year. *Nature* 457: 459-463.
- Swadling, K.M. (2006). Krill Migration: Up and Down All Night. *Current Science* 16 (5): R173-R175
- Tarling, G.A. & Johnson, M.L. (2006). Satiation gives krill that sinking feeling. *Current Biology* 16(3) R83-R84.
- Thomson, R.B., Butterworth, D.S., Boyd, I.L. & Croxall, J.P. (2000). Modeling the consequences of Antarctic krill harvesting on Antarctic fur seals. *Ecological Applications* 10 (6): 1806-1819.
- Trathan, P.N., Forcada, J. & Murphy, E.J. (2007). Environmental forcing and Southern Ocean marine predator populations: effects on climate change and variability. *Philosophical Transactions of the Royal Society B* 362: 2351-2365.
- Walther, G.-R. Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J.-M., Hoegh-Guldberg, O. & Bairlein, F. (2002). Ecological responses to recent climate change. *Nature* 416: 389-395.
- Watkins, J.L., Hewitt, R., Naganobu, M., Sushin, V. (2004). The CCAMLR 2000 survey: a multinational, multi-ship biological oceanography survey of the Atlantic Sector of the Southern Ocean. *Deep-Sea Research* 51: 1205-1213.