Krill is an increasingly valuable commodity which has an untapped biomass in the Southern Ocean. A review of biomass considerations when setting fishing quotas will be reviewed taking into account other significant food web species such as the Antarctic silverfish.

Krill in General

Antarctic krill or *Euphausia superba* is considered as a central component to the Antarctic food web. It has been written that different parts of the marine ecosystem are made up of predators that rely directly or indirectly on the heath of the krill within the system (Gascón & Werner, 2005). It is one of the most successful animal species on the plant, with a biomass that may be the largest of any creature on the planet, is recorded as having the largest aggregation of marine life and have the most powerful prteolytic enzymes found on earth (Gascón & Werner, 2005). As krill mature, they congregate in swarms or schools, with thousands of krill packed into a cubic metre of water, which can be kilometres deep or wide (Gascón & Werner, 2005). This swarming behaviour is what is attractive to commercial fishing. Mostly these swarms form at depth, and only rise to the surface at night (Nicol & Endo, 1999), which then causes a feeding frenzy for surface predators when they appear.

The Antarctic Food Web

Species within an ecosystem are connected in many ways, and when one species feeds upon another is the considered as the most significant, called a trophic relationship (Fuiman, Davis, & Williams, 2002; Pinkerton, Hanchet, & Bradford-Grieve, 2007). Hence fishing one species can affect many others through the trophic connection (Pinkerton, Hanchet, & Bradford-Grieve, 2007). Much literature identifies three trophic levels in the Antarctic ecosystem, dominated by the phytoplankton-krill-top predators chain, and only complimented by alternative food pathways (Constable, de la Mare, Agnew, & Miller, 2000; Cornejo-Donoso & Antezana, 2008; Gascón & Werner, 2005). Removing for example, krill from the food web would have a trophic impact on predator species that rely on it for sustenance. This is what would be known as a first-order effect, where fishing affects species one trophic level or connection from its prey (Pinkerton, Hanchet, & Bradford-Grieve, 2007).

Biomass surveys have estimated that there may be from 60 to 155 million tonnes of krill in the circumpolar region (Gascón & Werner, 2005; Nicol & Foster, 2003). CCAMLR, the Convention on the Conservation of Antarctic Marine Resources is a legal regime within the Antarctic Treaty designed to involved wide-ranging conservation principles in an ecosystem approach to managing Antarctic fisheries (Constable, de la Mare, Agnew, & Miller, 2000; Constable & Nicol, 2002; Nicol & Endo, 1999; Reid, Croxall, Briggs, & Murphy, 2005). This was created with the specific intent of preventing the over-exploitation of Antarctic krill (Bredesen, 1999; Constable, de la Mare, Agnew, & Miller, 2000). This was because the basis of the Antarctic food web is noted as krill.

Within this convention, there is the CCAMLR Ecosystem Monitoring Program (CEMP), which aims to firstly, detect and record significant changes in critical components of the marine ecosystem within the Treaty Area, which is used as a basis for the conservation of Antarctic marine living resources. Secondly, distinguish between changes due to harvesting of commercial species and changes due to environmental variability, encompassing both physical and biological changes (CCAMLR, 2008; Nicol & Endo, 1999; Reid, Croxall, Briggs, & Murphy, 2005). Its major function is to monitor the key life-history parameters of selected dependent species, identified as 'indicator species', which are likely to respond to changes in the availability of harvested species (CCAMLR, 2008). Krill is identified as a 'harvest species' with 'dependant species' identified as penguins, seals and flying birds (CCAMLR, 2008).

Increase in krill as a commodity

Recent years have seen an increase in the amount of krill fished in the area, as its value as a commodity has increased with both aquaculture using krill as a feed source, and the interest in krill by pharmaceutical companies driving the demand (Bredesen, 1999; Gascón & Werner, 2005; Nicol & Endo, 1999; Nicol & Foster, 2003). With Japan also using 40% of its krill harvest for human consumption, marketed as an organic seafood, similar to lobster, rich in Omega 3, oils, vitamins, minerals and anti-oxidants (Gascón & Werner, 2005; Nicol & Endo, 1999). The krill fishery may also be about to undergo a dramatic increase for reasons not mentioned above.

Whilst the krill fishery to 2003 was stable for the 9 preceding years, a 4000 tonne krill trawler capable of producing products for animal feed, human grade meat and meal for aquaculture is now in operation, with plans for more vessels to be run (Nicol & Foster, 2003; Reid, Croxall, Briggs, & Murphy, 2005) and this may impact the market dramatically.

CCAMLR

These issues concerning krill have lead to discussion and imposition of fishing quotas that will protect the marine environment taking into account the ecosystem as a whole (Gascón & Werner, 2005). The fundamental aim for the conservation of a harvested marine resource is to ensure that the harvest is conducted at a level that provides long term sustainability for the resource (Everson & de la Mare, 1996). There is a belief that localised, excessive overfishing might impact species dependant on krill for food, especially during breeding seasons, as little is known of feeding areas and consumption rates of seals, whales, dolphins, squid or seabirds (Gascón & Werner, 2005). The Everson & de la Mare (1996) article details a precautionary measure for krill, which appears ‘safe’, until more accurate measures can be determined (Everson & de la Mare, 1996). This was accomplished in the 1990’s, when two criteria were satisfied, that the probability of spawning biomass dropping below 20% of its pre-exploitation median level over a 20-year harvesting period was 10%; and that the median krill esacapement in the spawning biomass over a 20-year period is 75% of the pre-exploitation median level (Everson & de la Mare, 1996). The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), the international regime responsible for the management of Antarctic krill stocks in the Southern Ocean works within the framework of the Antarctic Treaty. The CCAMLR convention’s inception was in part based on the krill fishing question, and the need to account for ecosystems as a whole in fisheries management (Bredesen, 1999; Gascón & Werner, 2005; Nicol & Endo, 1999).

Fishing quota research/data

Gascon & Werner (2005) highlight CCAMLR's ecosystem approach to harvested species and the ecological inter-relationships between harvested and non-harvested species, thereby limiting the impact to the ecosystem as a whole. This article does not include other species in the harvested category, only krill. The simulation model detailed for krill, the KYM (Krill Yield Model) developed utilising information resulting from research in to the krill biomass (Everson, 2002). Using this model the level of krill escapement of 75% of the pre-exploitation biomass was determined (Everson & de la Mare, 1996; Gascón & Werner, 2005). A level of 50% escapement is the single-species managed limit. CEMP was specifically designed to detect and record significant changes in the critical (krill) components of the ecosystem (Gascón & Werner, 2005).

Silverfish in general

The *Pleuragramma antarcticum* or Antarctic silverfish (hereafter refered to as the silverfish), is the dominant pelagic fish in the waters of the Antarctic regions (Vacchi, la Mesa, Dalu, & Macdonald, 2004; Zane et al., 2006). Its life cycle and development is still uncertain, but breeding appears linked to the sea ice (Mintenbeck, 2008; Vacchi, la Mesa, Dalu, & Macdonald, 2004). Much of the data concerning silverfish numbers is provided by trawlers, where catches have shown that the silverfish is the most abundant fish in most shelf areas of the Southern Ocean (Fuiman, Davis, & Williams, 2002). With the silverfish providing a food resource for main species such as fishs, seals, whales and penguins, so much so that it is considered a keystone species in the food web, on the same trophic level as krill (Fuiman, Davis, & Williams, 2002; Mintenbeck, 2008; Zane et al., 2006). However despite its importance, little is known about its ecology, with research indicating that they may undergo diel vertical migration (vertical migration in relation to intensity of light) (Fuiman, Davis, & Williams, 2002; Mintenbeck, 2008).

Lack of silverfish inclusion in data

Generally, all data provided to calculate krill biomass and fishing quotas implies that krill is the limiting factor in the southern ocean food web, a weak link or bottleneck that if exploited and degraded will affect the entire upper-trophic level in the food web (Everson, 2002). Whilst this is highly probable, that krill exploitation and harvesting over estimated quotas will harm the food web, the calculations and consideration of the food web all fail as a whole, to take into account alternate or co-habitation on the food web by the Antarctic silverfish. Everson and de La Mare (1996) in their article about precautionary measures for krill fisheries consider the application of krill quotas to specific areas in the Southern Ocean are examples of this. This problem is compounded by Everson's 2002 article detailing ecosystem management and the KYM model for krill biomass calculations where no mention is made of any other species supporting the predator trophic level in the Southern Ocean. The article does pose some questions concerning the assessment as well as ecosystem monitoring including: is the availability of krill changing?; are populations of dependant species in decline?; and how much krill is required by the dependant species? This article attempts to answer these questions, and does consider that fish species exist in upper levels of the food web for example, penguin colonies however the lack of detail is a common problem (Everson, 2002). Everson's article (2002) details how the KYM is able to adequately answer the overall question of whether the krill fishery is sustainable over the long-term, taking into account dependant species requirements. However, the failure to take into account impact on other food sources for predators. If krill is removed, or whether other food sources exist, such as the silverfish, then the model cannot be accurate. Hence it in turn affects krill quotas and poses restrictions on the model, incorporating additional questions such as: are dependant species being adversely affected by krill fishing?; and if a decline is noted, is the decline due to fishing? These may allow for impact of the silverfish to be considered however it is noted only in terms of dependant species relationship. The Everson (2002) article mentions that a balance may have to be struck if a fellow harvested species, for example, the icefish, is impacted, with economic factors of the two industries considered. However, as the icefish in the predator trophic trophic level of the food web, this comment, whilst valid, would not have the same impact as a harvest species such as the silverfish on the mid-trophic food web level.

The article by Constable et al (2000) mentions how the Antarctic silverfish is considered as a potential harvestable resource, and is key in the Antarctic ecosystem, along with krill, and it notes that in some regions, the silverfish replaces krill as the viable food source. However it then details sites for monitoring krill within CEMP and fails to integrate or even attempt to integrate silverfish into the monitoring system or program. This data was used as the basis for management of krill fishing. Data sets have been collected since 1987, however the reliability in demonstrating ecosystem effects is not known. The articled also notes two specific limitations, firstly, that even with monitoring of krill within the ecosystem, it is unknown if it could detect a change in the krill fishery allowing for a real time change in management to prevent damage. Secondly it is unable to consider environmental changes within the ecosystem and whether fishing changes should be recalibrated accordingly (Constable, de la Mare, Agnew, & Miller, 2000). A third limitation is the lack of comprehensive ecosystem monitoring across the krill and silverfish range to encompass a more diversified food web and how it may affect of be affected by krill fishing.

Bredesen's (1999) thesis utilised a different model for effects krill fisheries might have on the ecosystem. The Ecopath system, with Ecosim (EwE) provided a polaroid snapshot of biomass moving through a food web in a defined ecosystem. This incorporated the flow of biomass and secondly, the energy within the system. This model also defined krill as the sole mid-trophic species in the food web (Bredesen, 1999). Whilst there is little doubt that krill have major links to other groups across trophic levels, they are not alone on the mid-trophic level. This study identifies that fish also make up an important part of predator's diets, however fails to identify fish on the same trophic level, such as the Antarctic silverfish. However Bredesen (1999) does concede that there is insufficient data, especially concerning abundance estimates impacting the evaluation of more trophic interactions when considering fish within the food web. This research recommends that a refinement of research into the abundance and diet information of fish species be conducted, which is important in teasing apart causal relationships within any ecosystem modelling (Bredesen, 1999).

Constable and Nicol (2002) provided an informative article about the monitoring of krill fisheries based on predator behaviour in any designated area (the Antarctic Treaty area broken up into sections identified through CCAMLR). Refinement of this area or unit of monitoring would in theory allow smaller units to be strategically monitored and other units where no fishing was occurring could be used as a control to ascertain whether the catch limit would be likely to cause undesirable effects on predators in the predator units. This designation of predator units for monitoring, would allow a more accurate assessment of fishing on mid-trophic species, as a multi-variable diet of a predator would be an unintended variable that could be included in calculations of fishing impact. As opposed to krill only calculations and monitoring, the upper trophic species monitoring encompasses many mid and lower-trophic species within the food chain, and would be more thorough than accounting for a single species as limiting the food web.

Reid et all (2005) provides a detailed argument as to why the modelling of biomass incorporates a limited range of key species, with the choice of proxies dependant on a number of factors such as functional or structural importance, amenability to measurement, and the extent to which they integrate variably at other levels of the ecosystem. Upper trophic (often predator species) are chosen as indices on diet, reproductive performance, and population size as an ecosystem indicator species. These higher trophic level species varying in accordance with lower or mid-level trophic species (Reid, Croxall, Briggs, & Murphy, 2005). This relationship is simplified when, as Reid argues, the centre of the food web is dominated by a single, mid-trophic species, such as krill in the Southern Ocean. However, this is not the case, with other species identified in this mid trophic level of the food web such as the Antarctic silverfish (Pinkerton, Hanchet, & Bradford-Grieve, 2007). Hence questions evaluating the utility of predator responses as indicators, with hypotheses are resulting flawed. This article by Reid, Croxall, Briggs, & Murphy (2005) examined whether a change in krill abundance produces a predictable change in the value of predator response and this was measured across several species. Results found that a multi-species approach including species with different levels of dietary dependence, was able to observe a broader ecosystem response to changes in krill, however the relationship must be further refined to determine the functional relationship between krill and individual predator species.

There are also limits identified with the level of change this system might detect from fishery induced changes (Reid, Croxall, Briggs, & Murphy, 2005).

Clearly overfishing of krill is not something to be encouraged, as it is an important link in the Southern Ocean food web. Any impact on species in the mid-trophic levels including both krill and silverfish will damaging the whole ecosystem. Silverfish, like krill are a key link between primary producers (low trophic level species) and higher predators (Pinkerton, Hanchet, & Bradford-Grieve, 2007), adding to the diet of penguins, seals whales, Antarctic toothfish and other fish. In the high Antarctic shelf, krill are rare and the silverfish takes its place in the centre and bottleneck of the trophic food chain (Mintenbeck, 2008). As such, modelling for a single biomass species in the food web, when the aim of CCAMLR is to encompass the entire ecosystem for protection via monitoring and regulating fishing quotas, is clearly flawed. Ecosystem effects when only one species is modelled for as the limiting food source, is not accurate, and provides room for dispute over actual harvest quotas which may damage the CCAMLR and CEMP processes and system for years to come. Given the costs associated with ecosystem monitoring, the use of a single species for modelling and quota management is reasonable, however the lack of provision for error or alternate hypothesis when degrees of correlation between species are not considered, is disturbing as its impact on error is compounded. It also means anomalies may be missed, causing erroneous quotas to be enacted and monitoring results to be skewed. If krill quotas are provided and the fishery managed to this extent, with little or nil resulting change in predator/indicator species, the result may not be from an overabundance of krill, but a diversified food chain. This diversified food chain could provide an alternative food source. As such, krill quotas may be increased beyond what the silverfish, possibly providing a trophic-commensurate food source, is able to sustain. The result could be more than predicted damage to the food web, with two species stressed. Mintenbeck (2008) goes so far as to call the silverfish, Antarctica’s Achilles’ heel, with indirect or direct impact on silverfish levels severely compromising the areas ecological functioning.

Research by Cornejo-Donoso & Antezana (2008) into a more detailed trophic model of the Antarctic Penisnsula ecosystem supports the existence of alternative food pathways, aside from krill. Whilst they identify krill as a keystone component of the food web, they assign enhanced complexity to the system by noting 9 trophic levels, not three. Hence both krill and the silverfish need to be considered in modelling of the ecosystem and fishing quotas. Thus far the ecological modelling is far from perfect and far more thought needs to be put into the food web structure within the models used to calculate fishing quotas. However, CCAMLR does provide two unique aspects that may cause this problem to be mitigated in some respects. Firstly, conservation and management can be achieved with provisional data and so that implementation of measures can be achieved, even when little is know. Secondly, methods for attaining consensus amongst treaty nations even when there us uncertainty about scientific data has been achieved (Constable, de la Mare, Agnew, & Miller, 2000). This provides hope for swift action by CCAMLR if data is collected indicating the importance of the Antarctic silverfish. Hence more research into the abundance of silverfish is clearly needed to tease out ecosystem impacts of species within the mid-trophic food web level.

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