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DECLINE OF THE ANTARCTIC TOOTHFISH AND ITS PREDATORS IN MCMURDO SOUND AND THE SOUTHERN ROSS SEA, AND RECOMMENDATIONS FOR RESTORATION

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EXECUTIVE SUMMARY

Ichthyologists, including those interested in the behavioral ecology, physiology and ecology of fish, beginning with the mere acquisition of specimens needed in experiments, began logging fishing effort in McMurdo Sound in 1971. This scientific fishing effort grew and interest turned also toward understanding annual and seasonal variation in the presence of Antarctic toothfish (*Dissostichus mawsoni*) in the area. Since 1971, more than 4000 Antarctic toothfish (*Dissostichus mawsoni*) have been captured, measured, tagged and released, by ichthyologists in McMurdo Sound. Total captures per year once numbered in the scores (200-500 per year), but recently, with similar effort, numbers are nearly zero. These dramatic declines are cause for alarm, and call into question the sustainability of the industrial toothfishery in place, at least for the Ross Sea region (SSRUs 88.1H-L). Aside from reporting a preliminary summary of these data, here we describe methods used and a history of the scientific fishing. The entire data set awaits computerization, but the summary we present (from a subset of the data) clearly shows the marked decline in Catch per Unit Effort in McMurdo Sound once a Ross Sea industrial fishery, which began in the 1996-97 austral summer, reached its maturity after 2001-02. The length-frequency of fish caught in McMurdo Sound once matched that of the Ross Sea fishery but very few fish and no adults have been caught since 2004-05, indicating a potential contraction in the range of the species. Thus far 17 tagged fish have been recaught, of those tagged since 1971, and at least one marked in McMurdo Sound was taken as far away as 1300 km to the north. Coincident with the virtual disappearance of toothfish from McMurdo Sound and the southern Ross Sea, the number of fish-eating Killer Whales (*Orcinus orca*) observed in the area has decreased, and the prevalence of silverfish (*Pleuragramma antarcticum*), the main prey of toothfish over the Ross Sea shelf, has increased markedly in the diet of Adélie Penguins (*Pygoscelis adeliae*), another major silverfish predator. We posit that the fishery has caused a trophic cascade as the food web begins to adjust to the disappearance of its most important predator. We recommend that the Total Allowable Catch of the fishery be reduced, including a moratorium on fishing over the Ross Sea shelf until the McMurdo Sound toothfish population is restored and a program is in place to monitor ecosystem effects of the fishery.

1 INTRODUCTION

The Antarctic toothfish (*Dissostichus mawsoni*) is a key component of the Ross Sea ecosystem (see Ainley et al. 2006a and references therein). Over the shelf, it is a major predator of other fish, especially silverfish (*Pleuragramma antarcticum*), and in turn is a major prey of Weddell Seals (*Leptonychotes weddellii*) and Killer Whales (*Orcinus orca*). It competes with the seals as well as Emperor and Adélie penguins (*Aptenodytes forsteri, Pygoscelis adeliae*), and perhaps the Killer Whales, for silverfish. In 1996, when a commercial fishery for this species began (Fig 1), humans began to compete with the natural predators of toothfish in the Ross Sea. In the past few years annual landings in the industrial catch have steadily grown, reaching >3388 tonnes by 2006. Most of the toothfish have been taken from the Ross Sea slope but some have been taken from the shelf as well (i.e., CCAMLR SSRUs 88.1G-L; Fig 2). The reported catch has attained the Total Allowable Catch (TAC) in the past few years (Dunn & Hanchet 2006a). Catch per unit effort (CPUE) of the fishery has varied annually but has generally been increasing at least through 2006 (Dunn & Phillips 2005; Fig 3).

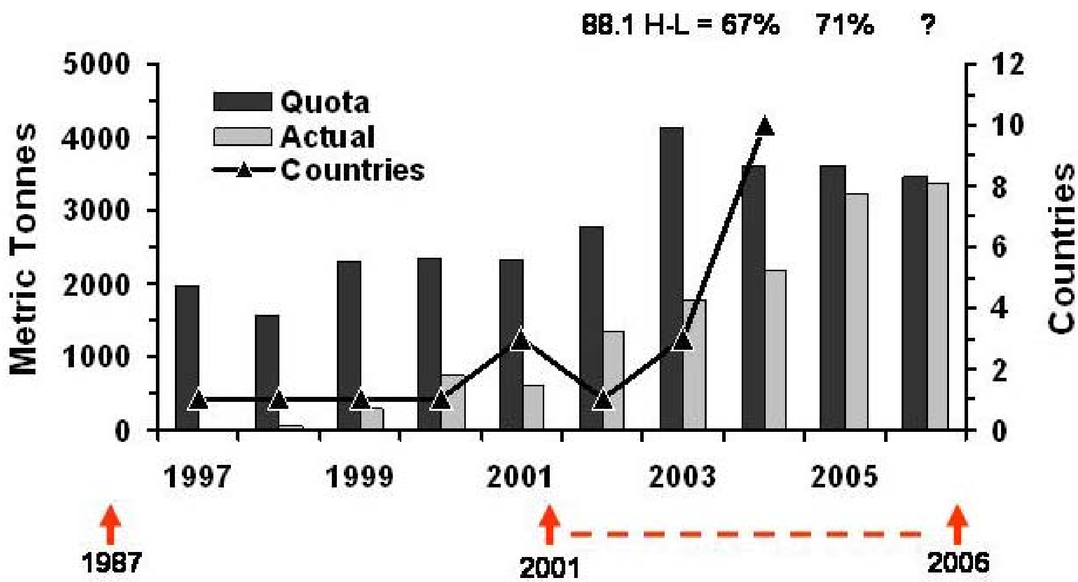

Figure 1. The commercial catch of toothfish in the Ross Sea beginning in the 1997 season (data from Dunn & Hanchet 2006, Hanchet et al. 2006). Shown at the top is the proportion of the catch from the Ross Sea proper. Not included is the IUU take, which also began at about the time as the CCAMLR-authorized take. The number of countries involved began to rise sharply after 2003. This paper compares attributes of catches made by scientists in McMurdo Sound (indicated by the arrows), using 1987 as typical of the pre-industrial era, and 2001-06 to show trends in recent years of apparent toothfish abundance in the southern Ross Sea (see below). Total scientific data set spans 1971-2007.

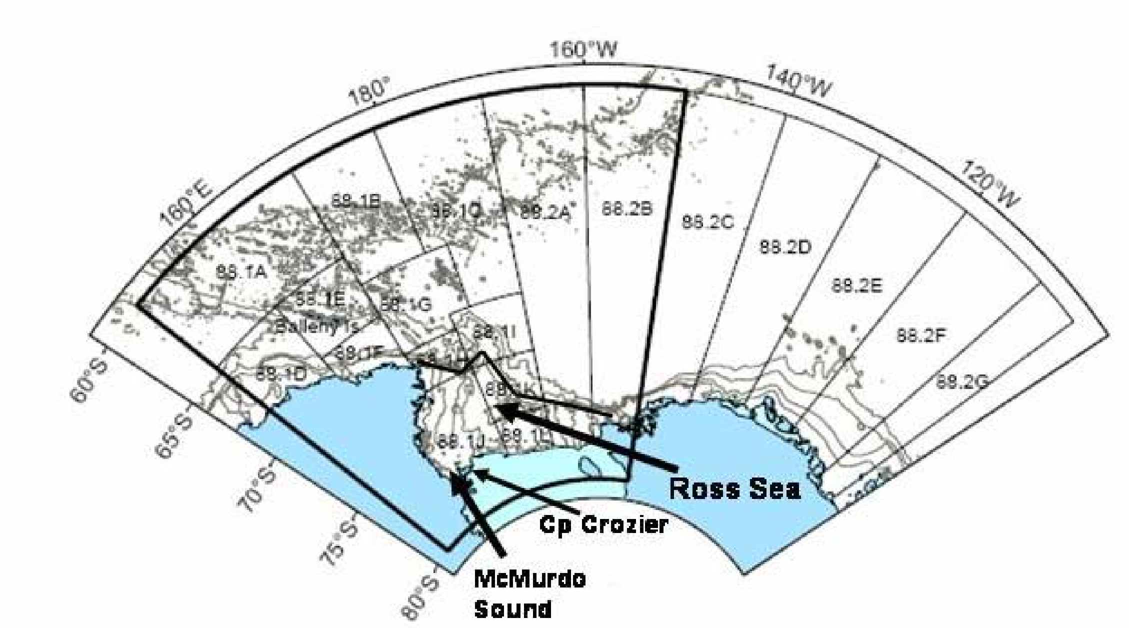

Figure 2. The Ross Sea showing: location of McMurdo Sound, site of a scientific catch of toothfish since 1971; Cape Crozier, site where observations of Killer Whales and penguin diet have been consistently gathered; and the SSRUs of the shelf and slope (SSRU 88.1 H-L). The dark line shows approximate edge of the continental shelf (500 m isobath). An industrial fishery has been in place since 1996, and fishes largely along the continental slope (500-3000 m). Base map prepared by F. Davey, from Hanchet et al. (2005).

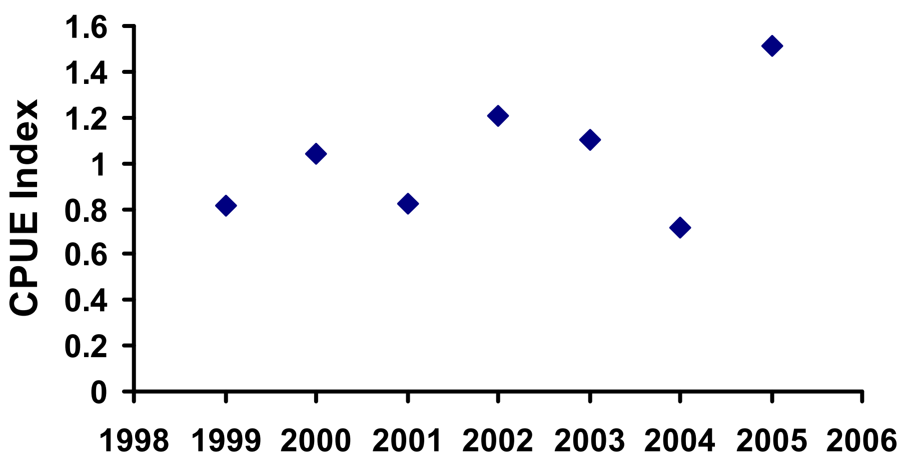

Figure 3. The average CPUE Index for the industrial catch throughout the Ross Sea; data from Dunn & Phillips (2005).

Research on the fishes of McMurdo Sound began in the 1960s and has continued almost annually ever since, with projects conducted by scientists from the USA and New Zealand. Most of this work was directed toward understanding adaptations of Antarctic fish for life at freezing temperatures. In 1971, scientists began to catch Antarctic toothfish to use in laboratory experiments, and in the next few years perfected catch techniques and also began to catch far more than needed for laboratory research (Raymond 1975). The latter fish were measured, weighed, tagged and released. Presented here is a description of that effort and a comparison of the size and catch effort to those reported for the industrial catch.

We also present trends in the abundance trends of at least one predator of toothfish in the McMurdo Sound vicinity: the fish-eating (ecotype 'c') Killer Whale.

1.1 A Note about Dates used in this Report

The fishery is in operation mainly during January – March, when the sea ice has withdrawn sufficiently for vessels to enter into and operate safely within the Ross Sea. Therefore, a date of e.g. 2001, for the fishery pertains to these months. The scientific catch in McMurdo Sound occurs during October-December, and therefore the exemplary year, e.g. 2001, pertains to the latter seasonal period October 2001 – December 2001). Finally, when talking about penguin diet or Killer Whale presence, and 2001 is the year in question, the time period is December 2001-January 2002. See details below.

2 DESCRIPTION OF FISHING

Scientific fishing occurred primarily from one site, about 4 km west of McMurdo Station (77^{o} 51' S, 166^{o} 40' E) and in 500 m of water, using a small hydro-winch with 3/32-inch wire and a 25 kg weight attached to the bottom end to keep the wire under tension (i.e. a vertical set line). The lines were deployed through a hole drilled through the annual fast ice and a heated fish house was placed over the hole. Initially 15-22 one-meter leaders with swiveled, #10 stainless steel hooks about 20-25 m apart were fished, but quickly it was found that most of the fish were caught near the bottom. Subsequently, leaders were shortened to 30 cm and hooks were spaced 3 to 5 m apart, starting 10 m from the bottom to avoid scavenging by benthic amphipods. Sometimes 12 hr sets were made but the large majority was 24 hr sets. Some ran 48 hr if poor weather prevented access to fish houses, but the fish caught were often exhausted after such prolonged time on hooks. Thus, thereafter, this long a soak time was avoided. Initially, live *Pagothenia borchgrevinki* were used for bait, but later it was found that dead bait worked just as well and so thereafter New Zealand yellow eyed mullet (*Aldrichettu forsteri*), cut in half, were used.

Captured fish not used for experiments were placed in a V-trough (with a seawater soaked cloth over their eyes), measured to the nearest cm; weighed to the nearest pound (weights hereafter converted to kilograms in this report); tagged with a numbered 'Floy' dart tag behind the 2nd ray of the 2nd dorsal fin and a tail locking tag; in many cases injected with tetracycline; and released. Tetracycline served as an otolith annuli marker in case the fish was recaptured. This procedure, lasting 3-5 minutes, was done on the floor of the heated fish hut so that the fish neither warmed nor froze. The open, sea surface was 0.5 m below the level of the floor so that the fish could be gently lifted by their gill covers and returned to the water without abrading their skin and causing scale loss.

Beginning around 2000, the fishing site was moved slightly closer (0.5 km) to McMurdo Station because of conflict with the Sea Ice Runway location and the requirement of being well away from the aircraft approach to the runway. The 2001 site appeared to fish (catch frequency) as well as the earlier site in its initial use.

So far, only the scientific catch data for 1987 and for 2001-2007 have been computerized, and results are showed in this report, although qualitative comments are made on the catch between 1971 and 2000. This fishing activity was not part of the research for which funds were received, and therefore neither have there been funds for the additional computerization needed.

3 CHARACTERIZATION OF THE CATCH

Since 1972, ~4500 fish have been caught and ~250 of those were collected for experiments including those whose survival was in doubt (which were used for human food in some cases). The largest fish caught was ~120 kg (195 cm) and the smallest 5 kg; the average was 25-30 kg (Fig 4). Specimens <85 cm have rarely been caught, likely indicating their scarcity, as mature adults are known to prey upon them. In addition, small fish on the line for any length of time, appear prone to being attacked by large fish, as they often had many parallel teeth marks on both sides of their body as well as many missing scales. This is consistent with the reports of fishers aboard the Russian-flagged vessel *Yantar*, who have found intact small toothfish (0.6 m long) in the stomach of a 1.8 m adult. Because standard, stainless steel, long-shank hooks were used (not short-shank with the gap of the tip being less than that at the lower part of the curve, like a tuna hook), most of the fish larger than 160 cm were lost. The evidence for this is that some of the hooks were straightened out or broken. Although Weddell Seals or Killer Whales can not be ruled out as causing this as they took fish from the line, no other fish approach the toothfish in size in McMurdo Sound, so other fish species would be ruled out. On the few occasions when a large treble or short-shanked, curled hook was used, more of the larger specimens were caught (cf. Fig. 4). These hooks, however, left large hook wounds in the jaw likely leading to reduced survival. Therefore, their use was discontinued.

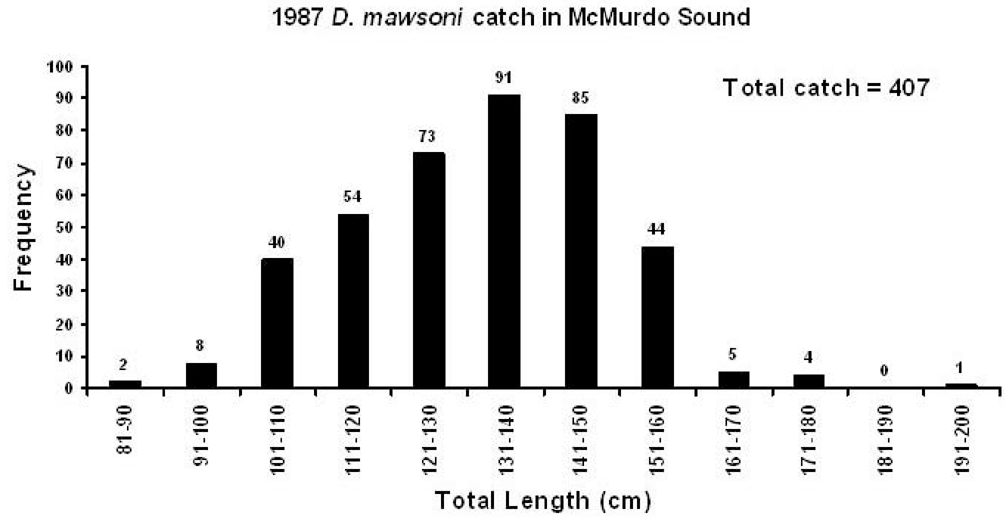

Figure 4. The length-frequency of toothfish caught by scientists in McMurdo Sound in 1987; the range in size overlaps almost exactly that of the fishery beginning in 2002, with the average slightly higher for the industrial catch and centered around 140 cm (see Hanchet et al. 2003). The difference can most likely be attributed to the use of the long-shanked hooks that failed to retain the larger specimens in the scientific catch.

Of the 4500+ fish tagged and released in McMurdo Sound, 17 have been recaptured at the McMurdo fishing site, with annual growth rate being 2.0 cm in length and 1 kg in mass per year (DeVries, unpubl. data). These growth rates are slightly below those reported from analyses of the industrial catch (cf. Horn 2002). Most of the recaptures occurred at the McMurdo fishing site, but one was recaptured by the Russian boat, *Yantar*, and 4 have been reported by the New Zealand fleet. One tagged individual was recaptured as far as 1300 km north of the McMurdo site indicating that the species migrates off the Shelf, possibly for spawning. Some of the NZ-vessel and McMurdo recaptures had been injected with tetracycline and analyses of the otoliths show that the annuli correspond to yearly growth rings (DeVries & Eastman 1998, Horn et al. 2003). Most recaptured McMurdo fish had been “away” from McMurdo Sound (i.e., not recaptured) for 4-5 years after release, with the longest gone for 18 years. The few recaptures that occurred more than 7 years after initial tagging, over the 30 years of fishing, is puzzling even though capture and release procedures have always been the same. Their absence may indicate migration out of the Ross Sea region.

3.1 CATCH SUCCESS

Before commercial fishing began in 1996, the scientific catch of *D. mawsoni* varied from year to year depending upon the fishing effort, which was determined by factors such as priority of laboratory experiments, sufficient help and weather. In general, though, 200-500 fishes were caught in a 2.5 mo season, setting once a day. We view 1987 as a typical year in catch results (Fig. 4-6). The field season began in early October (i.e., month of scientist arrival on the ice). The catch rate generally began to drop during late November/early December, when mainly smaller fish, 15-20 kg in size, were caught. By mid-December very few were caught. However, during some years there were reports of fish being caught by the seals diving in the 600 m water at the Ross Ice Shelf/sea ice transition near Scott Base (77° 51´ S 166° 46´ E), during January and February. A 60 kg fish with its gut stuffed full of *P. antarcticum* was obtained there during February.

From 2003 on the catch drastically declined despite the same fishing effort. The fact that all baits were present indicated that few toothfish were passing through the waters. Occasionally seals at fishing and penguin study sites (where isolated holes were drilled through the ice for experiments) sometimes brought up small fish, 15-20 kg (see Ponganis & Stockard 2007), which in some cases were good enough for lab experiments. Not enough fish have been caught since 2002 to warrant a tagging and releasing program.

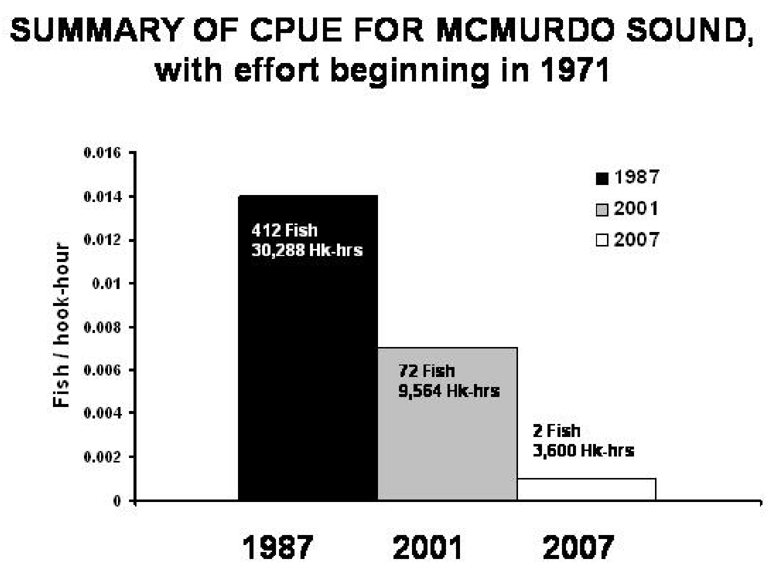

Figure 5. The catch-per-unit effort (Fish per hook hour) of one pre-industrial-era year compared to two recent, industrial-era years for toothfish caught in McMurdo Sound (A. DeVries, unpubl. data).

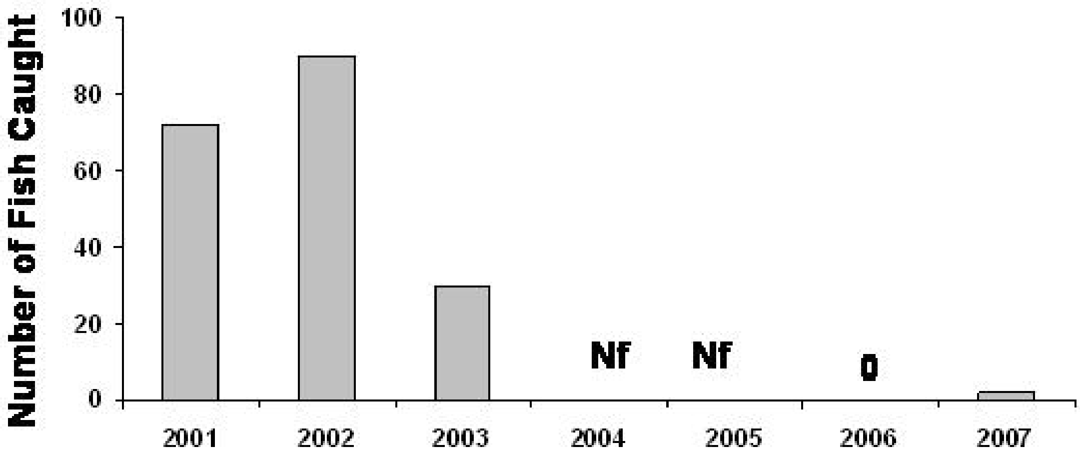

Figure 6. A summary of catch success, uncorrected for effort, for toothfish caught by all scientists in McMurdo Sound. See Figure 5 for more detailed data with corrected CPUE in 1987, 2001 and 2007. Nf = no fishing. No fish were caught in 2006 despite deployment of 7 sets, composed of 12 hooks, fished 24 hours; as a comparison, in 2001 ten sets were made.

4 DECLINE IN THE PREVALENCE OF FISH-EATING KILLER WHALES IN MCMURDO SOUND AND VICINITY

As noted, the type ‘c’ Killer Whale preys on toothfish in the Ross Sea. Many observations have been made of Killer Whales surfacing in the waters of the McMurdo Sound Ice Channel with toothfish in their mouth (Ainley et al. 2006a). The numbers of these predators have been logged consistently by daily watches conducted at Cape Crozier, Ross Island, just outside of McMurdo Sound. These daily watches, weather permitting, lasted at least an hour and involved scanning the waters in sight, from an altitude of 400 m (Ainley et al. 2006b). Search effort was about the same every year.

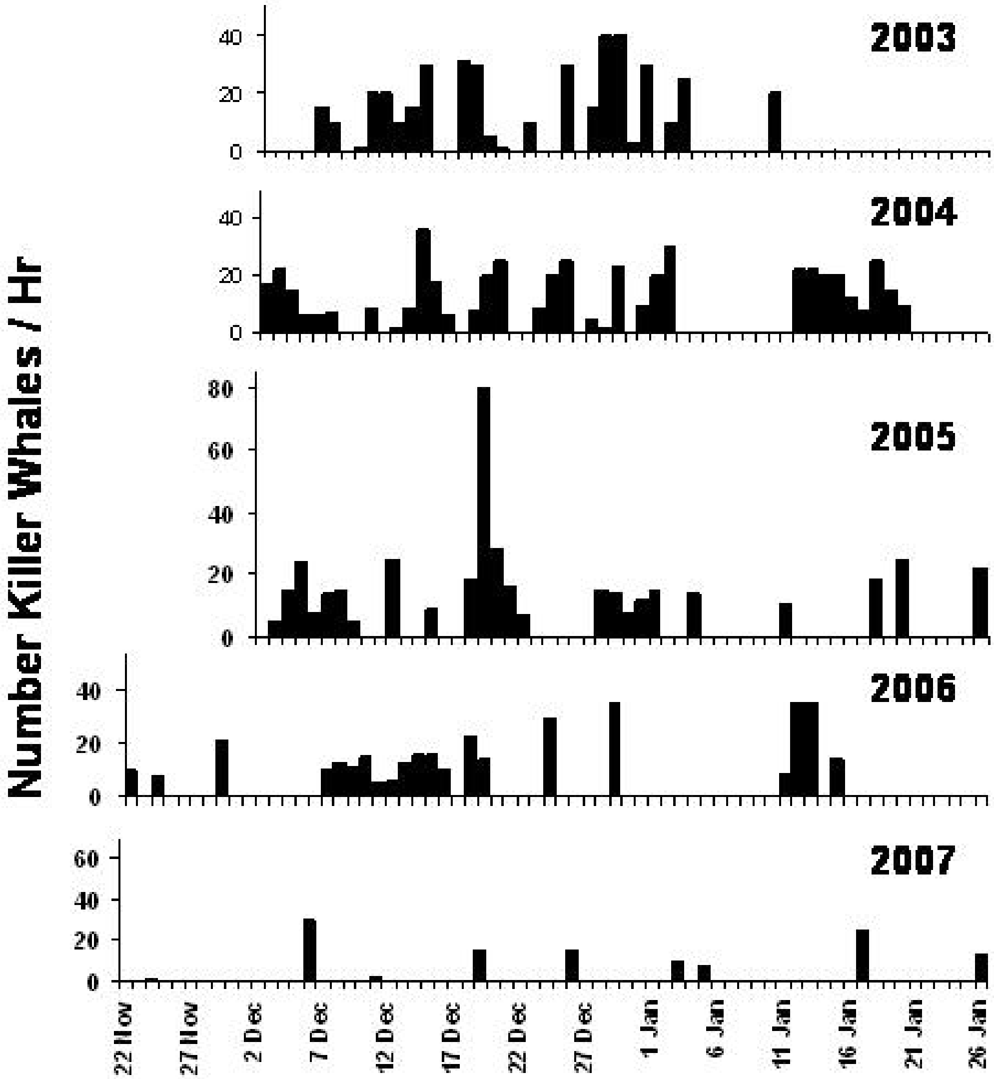

Figure 7. A summary of the number of type-c Killer Whales seen from a lookout at Cape Crozier, Ross Island. Data for 2004 and 2005 from Ainley et al. (2006b); sightings based on 1-3 hr spent each day, weather permitting, scanning waters within sight from a vantage point 400 m high.

Killer Whales often dove for long periods under the edge of the Ross Ice Shelf, there, somewhat reminiscent of the seals taking toothfish at the Ice Shelf edge near Scott Base (see above). Sightings of Killer Whales at Cape Crozier became infrequent in January 2006 (when two long-line vessels began fishing in the vicinity), compared to previous years, with very few seen in 2007. Very few were seen in McMurdo Sound in 2007, as well, although the sighting effort there is far less suitable than the situation at Cape Crozier and, therefore, no comparable long term data series is available. In 2007, as well, the Adélie Penguins nesting at Cape Crozier fed on silverfish to a greater degree during chick feeding (late December-January) than they usually do (Fig. 8; Ainley et al., unpubl. data). Normally they feed first on crystal krill (*Euphausia crystallorophias*) and then switch to silverfish when krill-eating baleen whales and Killer Whales show up (Ainley et al. 2006a). During the period 1994-2000 (when sampling was far less frequent), in only one summer did the percent of fish exceed 50% (1996-97, see Ainley et al. 2003; first year of experimental fishery when a number of boats fished off Cape Crozier for long periods). The prevalence of Killer Whales in that year is not known. It is possible that removal of toothfish increased the availability of silverfish, which contributed to a decreased availability of krill.

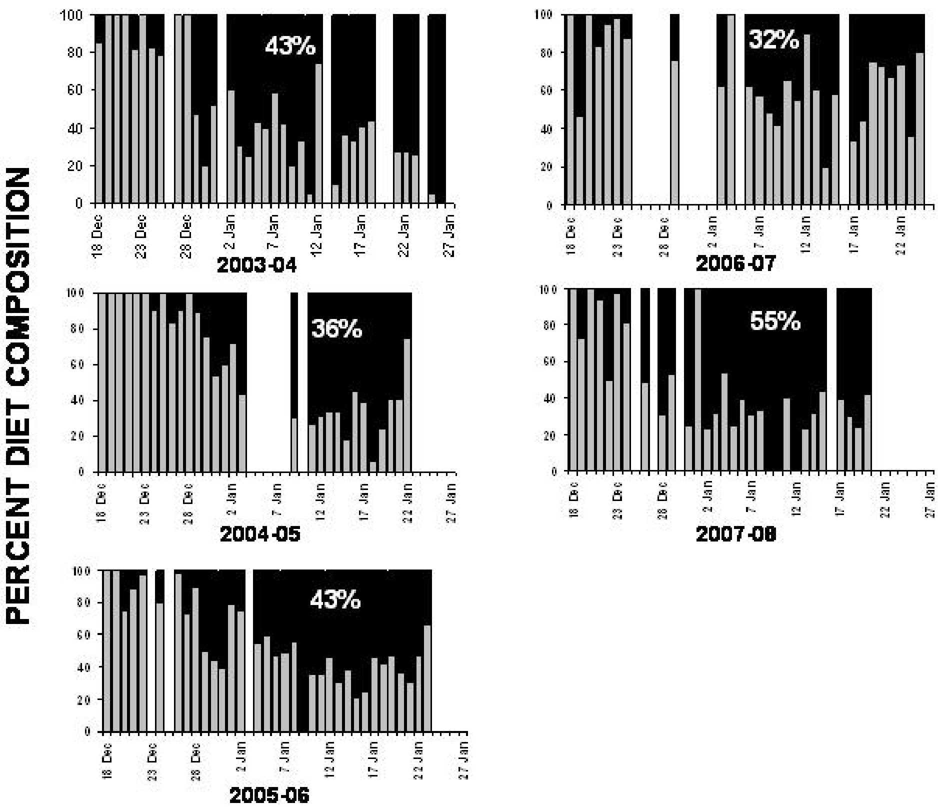

Figure 8. Diet of penguins at Cape Crozier, Ross Island (see Ainley et al. 2006a for methods). Percentages indicate prevalence of silverfish in diet during the period 18 December to 20 January, the period common to all years shown here. Blank lines represent periods of no data.

5 FURTHER DISCUSSION

The fact that the presence of toothfish in the Sound decreases seasonally, as indicated by the scientific catch data, with timing of the decline corresponding to the arrival of Killer Whales may not be a coincidence. At the same time, abundant adult Weddell seals, another toothfish predator, are relieved of pup-tending duties and are very much in need of replenishing diminished body condition; there is an influx of non-breeding seals into the Sound in late November and December as well (Smith 1965). These predators may deplete the number of toothfish, but a complementary explanation is that the apparent timing of toothfish movement away from the area may have evolved, at least in part, as an anti-predator strategy. A similar seasonal pattern of fish movement/presence-absence relative to the seasonal population dynamics of top-predators has been proposed for large, deep-living fish on the Scotia Shelf (Eversen 1970).

We interpret the annual trends in scientific CPUE as indicating a contraction of the Ross Sea population of toothfish at its periphery, and in the case of the southern Ross Sea, northward as industrial fishing continues to remove fish from the central portion of the stock, principally from the Ross Sea continental slope. The latter is where the industrial fishing has been concentrated (Fig. 9). Given that this fish lives 35-40 years, likely there has been little if any replacement to compensate for the increased extraction rate above what natural predators take from the total population. There now might well be less competition for whatever resources attract toothfish to the Ross Sea slope (an area of rich resources; see Smith et al. 2006 and references therein). Complementing these trends in the southern Ross Sea is the reduction in presence of the fish-eating Killer Whale. It is plausible that Killer Whales likely are now occupying waters where the toothfish are still abundant, i.e. the outer Ross Sea Shelf and Slope, consistent with the non-varying industrial CPUE.

Involved in these trends may be a trophic cascade resulting in more forage fish and less krill for Adélie Penguins to consume, a cascade related to the disappearance of the toothfish which competes for the same fish prey with the penguins (seals and whales). Over the shelf, the toothfish is a major predator of silverfish, which is the major predator of crystal krill (Ainley et al. 2006a, b; Smith et al. 2006). Fewer toothfish perhaps leads to more silverfish and, owing to increased predation by the latter, less krill. With toothfish disappearing there may now be more silverfish and less krill available for the penguins, thus leading to a change in penguin diet. In 2007, the penguins at Cape Crozier, and elsewhere on Ross Island, had one of the best breeding seasons among the previous 10 (Ainley, Lyver et al. unpubl. data). The reproductive success may be correlated with a change in prey composition and perhaps also greater abundance. The results of this ‘experiment’ (removal of toothfish by fishing) perhaps helps to explain better the predator-prey patterns described in Ainley et al. (2006b): the Killer Whales that visit McMurdo Sound are more attracted to the toothfish than to the silverfish as a prey item. Whether or not Weddell seals have been affected by this ‘experiment’ is not yet known; as they are long-lived *K*-selected species, no perturbation in population size would be evident for decades. There is no monitoring of seal diet underway. Nor is there any monitoring of seal populations outside of McMurdo Sound, nor of their post-breeding movements, both of which would likely be affected by an altered Ross Sea food web.

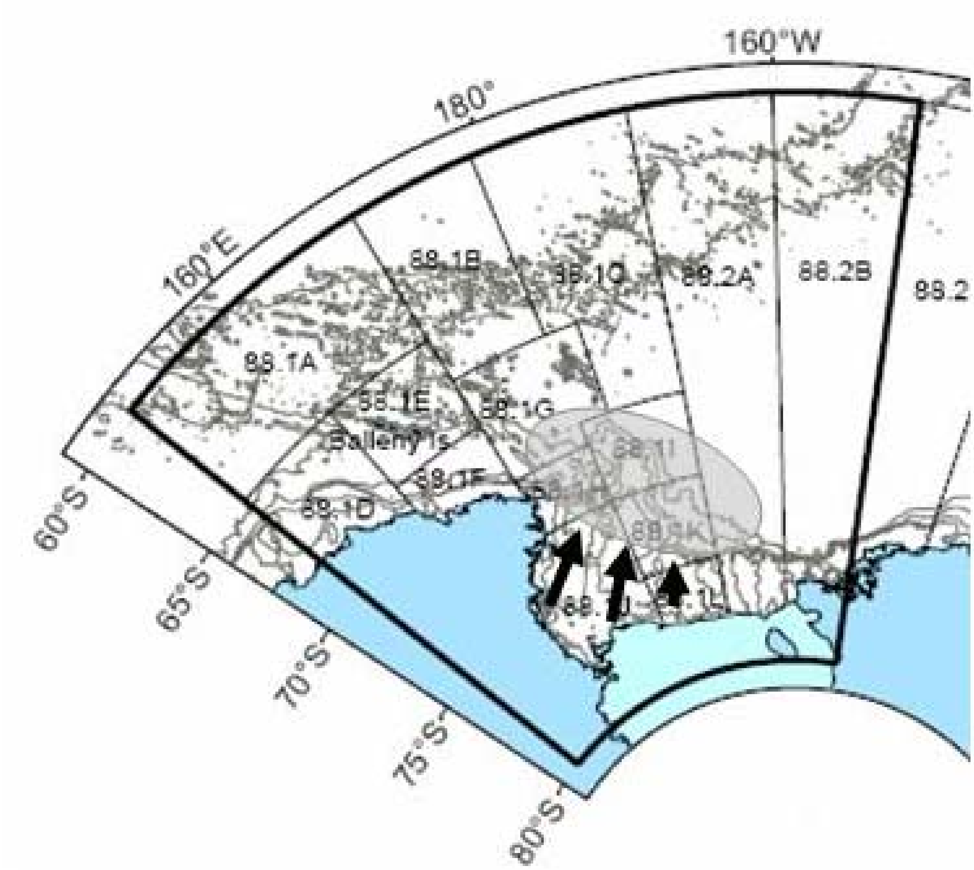

Figure 9. The area of where industrial fishing is mostly concentrated (gray; see Hanchet et al. 2005), and the proposed northward contraction of the toothfish population as the stock is depleted as indicated by the disappearance of toothfish in the southern Ross Sea. Whether or not toothfish are disappearing elsewhere than the southern Ross Sea shelf remains for others to determine. Base map prepared by F. Davey, from Hanchet et al. (2005).

McMurdo Sound, and perhaps the southern reaches of the larger Ross Sea as well, appears now to be effectively without its major piscine predator, the toothfish, which certainly would be (have been) *the* major predator in the ecosystem (e.g. Sheffer et al. 2005). In fact, Eastman (1993) classifies the Antarctic toothfish as the most voracious piscine predator in the Southern Ocean.

Although there are other possible explanations for observed trends besides the most obvious one (onset of a major fishery), for instance inter-decadal variation in fish presence and movement, we feel that the combined observational evidence for these ecosystem-level effects as being propelled by the fishery is compelling. Extended fast ice in the Sound during 2001-05, owing to big grounded icebergs, likely would have protected toothfish from predation by air-breathing predators (see Ainley et al. 2006b). Nearshore fishes appeared to have been negatively affected (C. Evans, pers. comm.), as were Weddell seals, by the thickened ice in shallow waters and along tide cracks, but the seals at least recovered their numbers entirely and immediately upon departure of the icebergs and extended fast ice (July 2006; Siniff et al. in press). Cape Crozier, where the penguin and Killer Whale data were obtained was not affected by the extended fast ice overlying McMurdo Sound during the iceberg years.

Given the implications of long-term food web effects to the southern Ross Sea ecosystem brought by loss of one of its main predators, we suggest that increased precaution in management of the toothfish fishery is warranted. Further, since the large majority of tag recoveries have been within 50 km of tagging location but, also, that fish tagged over the Shelf (including those in McMurdo Sound) have been recovered over the Slope and to the north (see Dunn & Hanchet 2006b), we recommend that the TAC of the Ross Sea toothfish fishery be reduced significantly until:

1. the McMurdo Sound/southern Ross Sea toothfish population is restored;

2. a research program is set in place to investigate the ecological ramifications of a likely major perturbation to the McMurdo Sound food web (removal of top-down structuring among fish), thus, to assess ecosystem effects of the fishery and ecosystem recovery potential, as required in Article 11 of the CCAMLR convention; and

3. a monitoring program is developed in order to keep track of ecosystem trends throughout the Ross Sea over the long term, also in line with Article 11 of the Convention, at the least, by establishing time series of predator populations (seals, whales) along Victoria Land.

The reduction in TAC should include a moratorium on fishing over the Shelf, i.e. SSRUs 88.1J, K, L, and a reduced TAC for 88.1G, H and I.

6 ACKNOWLEDGMENTS

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