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Dietary analysis of Weddell seals (*Leptonychotes weddellii*) as concluded from scat collection in McMurdo Sound, Antarctica.

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Weddell seals (*Leptonychotes weddellii*) in McMurdo Sound have a long history of dietary analyses, with understanding their feeding ecology essential to determining ecological role, trophic links, and prey consumption in the Ross Sea. Twenty-one faecal samples collected in summer 2009 revealed a diet primarily dominated by fish – the tentatively identified nototheniid *Pleuragramma antarcticum* in particular – with over 83% of samples exhibiting some evidence of piscines. Despite this, often a large percentage of samples will not contain identifiable otoliths, and as such no direct confirmation for the believed major prey item Antarctic toothfish (*Dissostichus mawsoni*) consumption was exhibited, especially with the tendency for Weddell seals to avoid eating the head, skin, and vertebral column. The excessive presence of plankton (in 100% of samples) has led to supporting the proposal of secondary ingestion, and similar theories have been applied to the occurrence of rocks and stones (in over 16% of samples). With all this uncertainty, the future of dietary analysis in Weddell seals is moving away from taxonomic identification of faecal hard parts, and more towards molecular methods such as DNA and stable isotope analysis, as combined methods tend to have a greater success rate than singular identification techniques.

Weddell seal (*Leptonychotes weddellii*) hauled out at a tide crack near Little Razorback Island, Ross Dependency, Antarctica. Image source: Jessie McEldowney 2012.

Introduction

The dietary requirements of Weddell seals (*Leptonychotes weddellii*) have been continuously studied for nearly fifty years in the McMurdo Sound region (Dearborn 1969; Calhaem and Christoffel 1969), with understanding their feeding ecology essential to determining ecological role, trophic links, and prey consumption in the Ross Sea.

A fast-ice obligate breeder, this species is the only air-breathing predator able to forage in both benthic and pelagic habitats over the Antarctic continental shelf (Lake *et al* 2003). In McMurdo Sound, pelagic fish dominate the diet, with cephalopods also forming a substantial part (Burns *et al* 1998). The most common piscine prey species in is the nototheniid *Pleuragramma antarcticum* (Dearborn 1965; Plötz 1986; Green and Burton 1987; Plötz *et al* 1991; Casaux *et al* 2006; Lenky *et al* 2012), mainly due to its high lipid content and schooling behaviour. The Antarctic toothfish, *Dissostichus mawsoni*, while rarely represented in scat samples, has been known from observational evidence to be an important part of Weddell seal diet, especially for the animals recovering from reproduction or a fasting period (Calhaem and Christoffel 1969, Lenky *et al* 2012).

Plankton are also found in large proportions in Weddell seal scats, however there has only been one confirmed case of direct consumption of euphausiids by a Weddell seal (Plötz 1986). The presence of such items has led to the speculation of secondary ingestion, where the major prey species (fish and cephalopods) have consumed planktonic organisms, and due to the tendency of the seals to swallow their prey whole, the plankton have ended up fairly intact in the gut and faeces of the seal (Dearborn 1965; Plötz 1986; Plötz *et al* 2001; Daneri *et al* 2012). Similar theories have been proposed for rocks, stones and sand, where seals have ingested fish which have eaten rocks while hunting benthic plankton (Burns *et al* 1998); although it is equally as likely that the rocks were swallowed on purpose to aid mechanical digestion (Lake *et al* 2003), or even consumed by accident as the seals sought benthic prey (Dearborn 1969).

This study aims to determine if the composition of Weddell seal diet in McMurdo Sound, Antarctica has apparently changed, compared with previous studies which show a high dependence on *P. antarcticum*, *D. mawsoni*, and cephalopods.

Materials and Methods

Twenty one scat samples were collected in 2009 by Phil Emnet of the University of Canterbury Chemistry Department from three locations around Ross Island, Antarctica (unpublished data): five samples from Cape Evans, thirteen samples from Little Razorback Island, and three samples from Cape Armitage (Figure 1). The three samples from Cape Armitage were discarded in the analysis phase, as in the field they were misidentified as faecal pads when they were in fact ice discolourations, and as such held no Weddell seal dietary information.

After Green and Burton 1987, the remaining eighteen samples were washed with tap water through a 1 mm mesh sieve, and the resulting retained hard parts identified under a dissecting microscope; as no otoliths or whole squid beaks were found, the species could only be speculated.

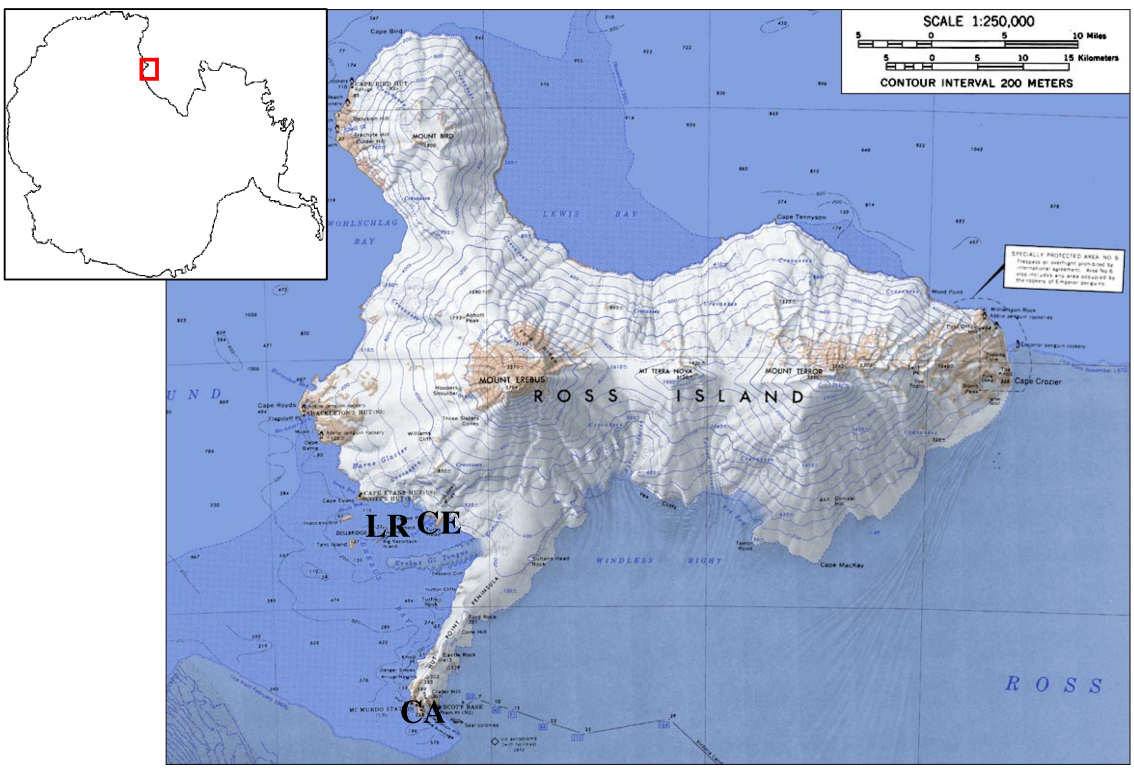

Figure 1: Locations of Cape Evans (CE), Little Razorback Island (LR), and Cape Armitage (CA), on Ross Island, Antarctica. These spots were the sites of Weddell seal (*Leptonychotes weddellii*) scat collection in 2009, while the animals were hauled out on fast ice. The samples from Cape Armitage were discarded, as they were not collected from valid faecal pads. Image sources: worldatlas.com and riktindall.wordpress.com/category/mount-erebus/

Results

Vertebrae of a fish tentatively identified as *Pleuragramma antarcticum* (the most common fish prey items for Weddell seals, after Burns *et al* 1998 and Casaux *et al* 2006) were found in over 83% of samples (Figure 2), with a size range of between 2 mm and 5 mm; however, 50% of samples exhibited 4 mm vertebrae, suggesting these seals preferred fish of a certain length.

Evidence for planktonic organisms such as euphausiids, copepods, parasitic and polychaete worms appeared in every sample.

The least common items, which appeared in only one sample each, were a single, badly eroded cephalopod beak, and a nearly-whole crustacean (Figure 3).

Interestingly, over 16% of samples (all from Little Razorback Island) had small rocks present, along with a variety of other hard parts (including krill and fish pieces). This suggests one of three things: that the seals are foraging along the bottom of McMurdo Sound for benthic organisms, and accidentally consuming rocks along the way; that the rocks are maybe contributing to mechanical digestion; or that the seals are exhibiting secondary digestion from fish which have consumed the rocks.

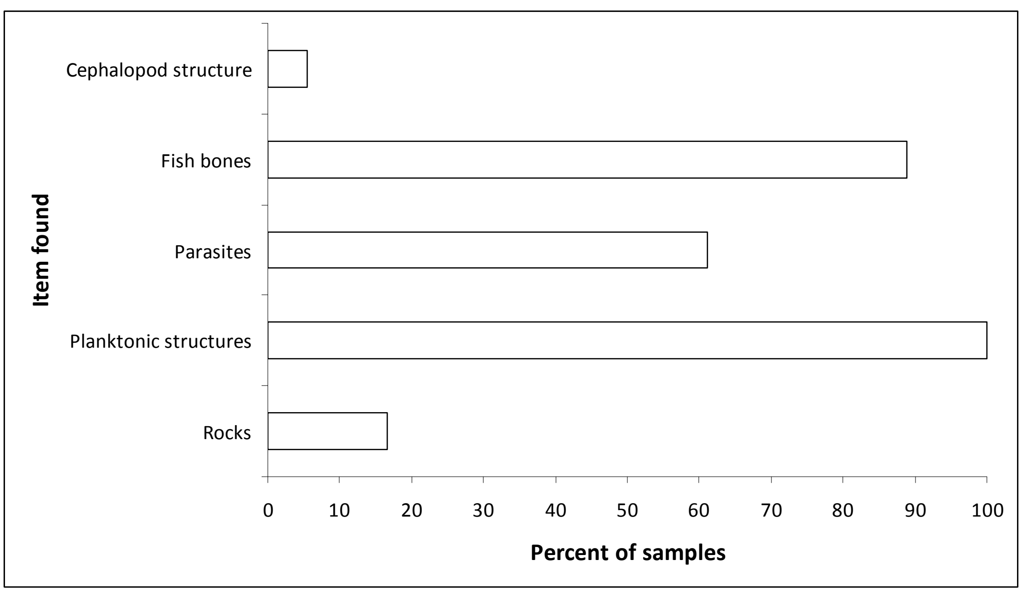

Figure 2: Types of hard parts identified in the scat of *Leptonychotes weddellii*, collected at Ross Island, Antarctica, and the percent of samples they appeared in. Eighteen samples were analysed, and all of the scats had one or more hard part identified in it. The three major groups of prey type are represented, with fish, cephalopods, and planktonic organisms.

Figure 3: Whole crustacean found in Sample CE.19.5.60 from a Weddell seal (*Leptonychotes weddellii*) at Cape Evans, Ross Island, Antarctica. This demonstrates the seals' desired method of consuming their prey whole, swallowing as they swim along, which leads to secondary ingestion of the stomach contents of fish and cephalopods. Image source: Jessie McEldowney.

Discussion

Often, a large percentage of faecal samples will not contain identifiable otoliths or cephalopod remains, which may result in underestimation of the importance of certain prey species (Casper *et al* 2007). Another factor to consider is that the species with no otoliths, the species which contain otoliths that are very small, or where the seal does not ingest the otoliths (such as with Antarctic toothfish, *Dissostichus mawsoni*), will not be represented in scat samples (Prime and Hammond 1990). This study supports previous literature on the diet of Weddell seals, even though very little was positively identified in the faecal samples; however, it provides a basis for future, in-depth dietary analyses to be conducted on one of the top predators in McMurdo Sound.

Piscine vertebrae were tentatively identified as belonging to *Pleuragramma antarcticum*, as this species is the most abundant fish in McMurdo Sound, and fish tend to dominate the diet of the seals here (Green and Burton 1987). Many studies have positively identified *P. antarcticum* in the stomach contents, vomitus, and scats of Weddell seals from all around the continent, suggesting this nototheniid is a vital part of seal summer diet (Dearborn 1965; Plötz 1986; Green and Burton 1987; Plötz *et al* 1991; Casaux *et al* 2006; Lenky *et al* 2012).

This preference may be due to the abundance of the species, their tendency to school in large numbers, or their relative richness in lipids compared to other species (Lenky *et al* 2012). McMurdo Sound exhibits relatively deep water, where pelagic prey such as fish and squid tend to be more widespread; however, multiple prey species are typical of Weddell seal diet in this area, which minimises the coupling between Weddell seal population dynamics and prey availability (Lake *et al* 2003). Some common prey items include Antarctic toothfish (*Dissostichus mawsoni*), cephalopods, and planktonic species. No direct confirmation for *D. mawsoni* consumption was discovered in my study, but there is evidence in the literature of toothfish ingestion, for example Plötz (1986), who found three otoliths in 1983 and 1985. Weddell seals have also been known to cache toothfish, a behaviour that has never been reported in other pinnipeds, indicating the special nature of this resource (Ainley and Siniff 2009). This hoarding is most likely due to the large size and very high lipid content of *D. mawsoni*, making it the greatest value fish prey item, and as such advantageous to seals recovering from reproduction or a fasting period (Lenky *et al* 2012).

While relatively recent studies have noted no toothfish otoliths in scats (Pinkerton *et al* 2008), observations have shown that the seals do not eat the head, skin, or vertebral column of these fish; instead they violently shake their prey until pieces are torn free (Calhaem and Christoffel 1969). This would account for the lack of otoliths in vomitus and faecal samples, as the otoliths are simply not being ingested. There may also be individual preference for prey species, as Calhaem and Christoffel (1969) observed a particular seal in 1966, which always took only toothfish, and the only *P. antarcticum* specimen encountered was regurgitated by a toothfish while it was being eaten. Interestingly, this study found this seal consumed approximately 68 to 90 kg of fish per night; this has dramatically decreased over time, as Ainley and Siniff (2009) found an average, non-breeding, 250 kg Weddell seal will devour only 18 kg of toothfish daily. This may be due to differing breeding statuses, different seasons in which the seals were observed, different hunting areas, or different seal ages; however, it is worth noting that Calhaem and Christoffel (1969) only observed one seal over eighteen days, while Ainley and Siniff (2009) reviewed multiple studies from multiple years. Nevertheless, there appears to have been a reduction in the amount of toothfish consumed by Weddell seals, which may be attributable to one or more factors (for example, Antarctic climate change, or an expanding Ross Sea toothfish fishery).

While some prey species tend to be scarcely represented in McMurdo Sound diets, cephalopods are excepted, and generally constitute a major part of prey caught (Casaux *et al* 2006). In fact, after fish, cephalopods are the major prey item across the Antarctic continent for Weddell seals (Daneri *et al* 2012), despite the fact that only one, profoundly degraded beak was found in my study. Dearborn (1965) found that all of the seal stomachs that contained fish also contained cephalopods, but there was no evidence of secondary ingestion, i.e. the cephalopods had been fed on directly. Of these species, octopods tend to comprise the bulk of the cephalopods; however, it is important to note that beaks tend to degrade quite heavily, and identification can only be tentative (Daneri *et al* 2012).
Planktonic species, including euphausiids, copepods, polychaete worms, and non-cephalopod molluscs have all been found in seal stomachs or scats (Dearborn 1965; Plötz 1986; Plötz *et al* 2001; Daneri *et al* 2012), and were present in 100% of the retained samples in my study. While Plötz (1986) exhibits direct evidence for the consumption of euphausiids, with approximately 11,500 crystal krill (*Euphausia crystallorophias*) individuals found in the intestine of one seal, plankton is usually explained away as secondary ingestion. Dearborn (1965) showed evidence of polychaete worms in the digestive tract of Weddell seals, and as polychaetes, amphipods, bivalves, and gastropods are among the commonest prey for cephalopods (Daneri *et al* 2012), it has been hypothesised that the plankton appear when their direct predators (the cephalopods and fish) are ingested by the seal. This is correlated by Plötz *et al* (2001), who examined 230 whole *P. antarcticum* specimens vomited up by a seal in 1998, all of which contained Antarctic krill in their tracts; the tendency of Weddell seals to swallow their prey in one piece contributes to the unsurprising presence of plankton in their guts. This may also be the way in which the seals are parasitised by nematodes and cestodes, but it is possible that this is just a natural state for these animals (Dearborn 1965).
While not technically a prey species, rocks and stones were found in over 16% of samples in my study, as well as found in the stomach contents and scats of Weddell seals in previous studies (Dearborn 1965; Burns *et al* 1998). This suggests one of three things: that the seals are hunting along the bottom of McMurdo Sound for benthic organisms, and consume rocks along the way by accident (Dearborn 1965); that the rocks are perhaps contributing to mechanical digestion in some way, and are swallowed on purpose (Lake *et al* 2003); or that the seals are exhibiting secondary digestion like before, as fish accidentally consume rocks

while hunting benthic plankton, and are in turn predated on by the seals (Burns *et al* 1998). It is possible that the scat samples came from juvenile seals, as they tend to prefer foraging in shallow benthic environments (Burns *et al* 1998); although, this is pure speculation, as the age for the seals belonging to each faecal pad was not recorded.

The future of dietary analysis in Weddell seals is moving away from taxonomic identification of faecal hard parts – which is entirely dependent on the skill of the scientist analysing the sample, as well as the presence of representative species remains – and more towards molecular methods, such as DNA-based and stable isotope analyses. Combining data from both morphological and molecular analyses enhances interpretation of the diet of top predators, allowing previously 'invisible' information to come to the fore, and to further characterise the importance of different prey items in the diet (Casper *et al* 2007; Burns *et al* 1998). Pooled techniques are powerful, enabling researchers to gain a greater understanding of dietary factors; for example, Casper *et al* (2007) discovered the proportion of samples which appeared to have no dietary information decreased from 25.9% with a single method, to 9.3% when utilising both DNA and morphological analysis. Despite all the benefits, there are still limitations to the newer methods, for example: target DNA needs to be present in satisfactory amounts to provide positive test results; species may have similar biological markers, making prey differentiation nigh impossible from blood samples alone; and there may be false positives resulting from secondary ingestion procedures (Casper *et al* 2007; Burns *et al* 1998). This evidences the strong need for further development in the field of dietary analysis, as a simple visual scat analysis alone does not provide enough information for a comprehensive understanding of the diet of this top predator; a long-term dataset utilising multiple methods would be indispensable in examining prey composition of Weddell seals in McMurdo Sound, as well as any changes or fluctuations which may occur through the years.

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