Physical data used in space averaging: Trophic modelling of the Ross Sea

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1. Introduction

The data on trophic compartments used in the model have been time and space averaged. The biomass for each compartment is an annual average, taking seasonal changes into account, where known. Spatial biomass averages are arrived at in various ways, depending on the compartment. Compartments near the beginning of the food web are strongly influenced by the extent of ice cover and its seasonal trajectory, whereas benthic compartments and those higher in the food web may have a strong bathymetric component. The data used in estimation of various model parameters are presented below.

2. Study region

The Ross Sea study region is bounded to the north by the 3000 m depth contour, and by 69°S line of latitude; to the south by the permanent ice shelf; to the east and west by land, and the 160°W and 170°E meridians. The total area of the study region is c. 637 000 km^2. This region was chosen for a number of reasons. The 3000 m bathymetric contour approximates the location of the Antarctic Slope Front (Jacobs 1991) which, in part at least, hydrodynamically separates the study region from the rest of the Southern Ocean. Cross-shelf transport is only partly understood and appears to be small, based on a modelling study (Dinniman et al. 2003; Rickard et al. 2009), though there is considerably more off-shelf volume flux via a relatively strong bottom Ekman layer. Langone et al. (1998) estimate a residence time in the Ross Sea of 50 years. Transport of water across the boundary of the study region may be higher in the northern part, under the influence of the narrow Antarctic Slope Current (Jacobs 1991; Dinniman et al. 2003). The study region covers the main fishing grounds for adult *D. mawsoni*, comprising Small-Scale Research Units (SSRU) 88.1H–88.1L, and some of SSRU 88.2A. The study region encompasses the intense localised burst of primary production associated with the Ross Sea polynya adjacent to the permanent ice shelf (Zwally et al. 1985; Kurtz & Bromwich 1985; Arrigo & van Dijken 2004). Finally, the study region is similar to that used in other Ross Sea studies (e.g. Ichii 1990; Ichii et al. 1998; Anderson 2000; Ainley 2002), allowing us to use published information even when access to the base data are not available.

3. Depth distribution

The depth distribution of area in the study region is given in Figure 1. In the study region, defined above, approximately 29% of the study region is shallower than 500 m, 41% of the region has depths 500–1000 m, and 30% is deeper than 1000 m bathymetry (data from Davey 2004). With divisions as shown in Table 1, 66% of the study area is shelf, 12% is slope, and 22% is deep water (>1800 m).

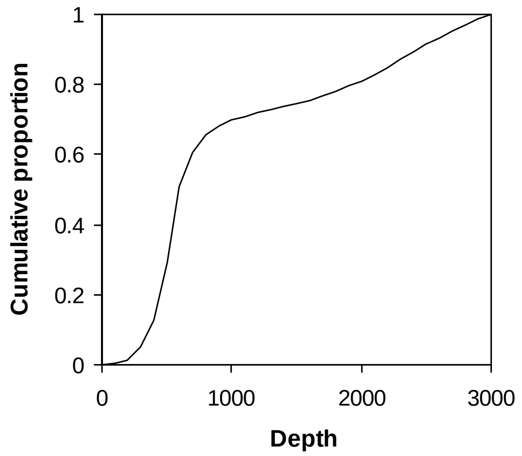

Figure 1. Cumulative distribution of depths in the study region, based on the bathymetric data of Davey (2004).

Table 1. Regions and corresponding areas for the study region used in this study, based on bathymetric data of Davey (2004).

	Region	**Depth (m)**	**Area (km^2)**	**Proportion (%)**
1	Shelf	0–200	8276	1.3
2	Shelf	200–400	73 364	11.5
3	Shelf	400–600	241 796	38.0
4	Shelf	>600	98 461	15.5
5	Slope	600–1200	35 818	5.6
6	Slope	1200–1800	39 388	6.2
7	Deep	>1800	139 895	22.0
		All	636 998	100

4. Ice extent

Average ice cover by calendar month was obtained from data spanning 26 October 1978 and 31 December 2004. Satellite ice data used in the present study were obtained from the National Snow and Ice Data Center (NSIDC) at the Earth Observing System Data and Information System (EOSDIS) Distributed Active Archive Center, University of Colorado, Boulder, US. Information and data were obtained from: http://www-nsidc.colorado.edu/data/nsidc-0079.html in May 2006. Sea ice concentrations were derived from the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) and the Defense Meteorological Satellite Program's (DMSP) DMSP-F8, -F11 and -F13, Special Sensor Microwave/Imager (SSM/I), using the Bootstrap algorithm (Comiso et al. 1997) with revised sets of tie-points (Comiso 1999, updated 2005). Data were gridded onto the SSM/I polar stereographic grid (25 x 25 km) (Figure 2).

For the purposes of the current study, we define five levels of sea ice cover (Figure 2a): (1) open water/ice free areas (OW); (2) marginal ice zone (MIZ); (3) open pack, first-year sea ice (OP); (4) close pack, first-year sea ice (CP); (5) multi-year sea ice and land-fast ice (MY). These levels are chosen to tie in with most ecological studies on sea ice ecosystems, and associated Antarctic flora and fauna. Areas of ocean are usually taken to be “ice-free” if the proportion of the sea covered with ice within a given area is less than about 10–15% (e.g. Arrigo & van Dijken 2004; Comiso 2003). Here, we use 15% as the limit. Sea ice concentrations between 15–40% are typically associated with marginal ice zone conditions, while concentrations between 40–70% are typically open pack conditions, and concentrations over about 70% are usually close pack conditions (Cavalieri et al. 1984; Comiso 1983, 1995; Gloersen & Cavalieri. 1986). Multiyear/landfast ice is taken as the minimum area during a year having an ice concentration >70%.

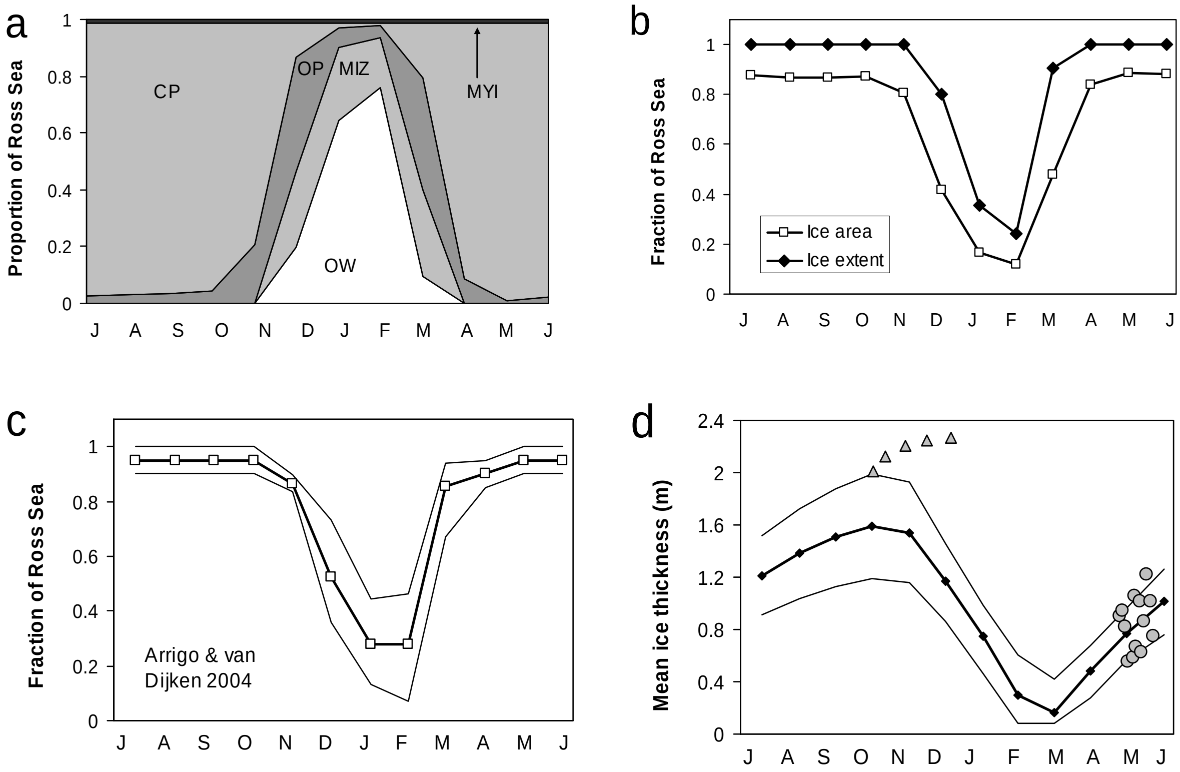

Figure 2. Ice cover in the Ross Sea. **a**: Proportion of the Ross Sea with (1) open water/ice free areas (OW); (2) marginal ice zone (MIZ); (3) open pack, first-year sea ice (OP); (4) close pack, first-year sea ice (CP); (5) multi-year ice (MYI). **b**: Mean ice area and ice extent by month derived from satellite data for the Ross Sea. **c**: Mean ice area and range over the period 1997–2001 (Arrigo & van Dijken 2004) given as a proportion of the total area. Note that this data pertains to a different Ross Sea area than that defined in the current study. **d**: Estimated ice thickness and likely range. Grey circles show measurements from DeLiberty & Geiger (2005), grey triangles from Grossi et al. (1987). See text for more details of the definitions and methods used in deriving these figures.

Two other descriptors of sea ice cover are used in various parts of the study (Figure 2b). “Ice extent” is defined as the area having an ice concentration >15% i.e. the total area that has appreciable sea ice (Comiso 2003). “Ice area” is defined as the total of the area of each observed pixel, multiplied by the concentration of ice in that pixel. This can be considered to be the total area of the sea that has ice of any kind on the surface. Ice extent is always found to be greater than ice area (Comiso 2003), though this is not necessarily the case.

For comparison, data from Arrigo & van Dijken (2004) is given (Figure 2c). Statistics on ice area for the Ross Sea, given by Arrigo & van Dijken (2004), were derived for an area bounded to the north and east by approximately by 73.5°S and 160°W. This region does not coincide exactly with the study region, and contains some waters deeper than 300 m at around 73°S 165°W, and does not include water shallower than 3000 m north of about 73°S. Some differences between the data we drive and that given by Arrigo & van Dijken (2004) is to be expected, but the figure shows that these differences are relatively small. Arrigo & van Dijken (2004) also show that there is substantial interannual variability in sea ice cover in the Ross Sea, even over the short period considered (1997–2001). The variations over this period are approximately ±36%.

5. Ice thickness

Numerical models of ice growth have been developed which are driven by satellite observations of ice and snow characteristics, and meteorological data (e.g. Timmermann et al. 2002a, b). Mean, annual ice thickness predicted by this model for the Ross Sea is approximately 1 m. Here, we assume that the growth in sea ice thickness follows the numerical model given by Eicken (2003). We assume that the minimum average sea ice thickness for single year ice occurs on 1 March at the end of the summer, that sea ice thickness starts to decline from a peak thickness in mid-Autumn (around 15 October), and that the decline is approximately linear with time. We assume that the variability in these timings is 20 days, and that the uncertainty in ice thickness is about ±25%. Hence, we estimate the mean sea ice thickness in the Ross Sea to follow Figure 2d. The mean annual ice thickness from this model is 1.00 m with a range of 0.68–1.35 m. Ship observations of ice thickness from May–June 1998 are also shown (DeLiberty & Geiger 2005).

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7. References

Ainley, D.G. 2002. The Ross Sea, Antarctica, where all ecosystem processes still remain for study, but maybe not for long. *Marine Ornithology* 30(2): 55-62.

Anderson, J.B. 2000. *Antarctic Marine Geology*. London, Cambridge University Press.

Arrigo, K.R.; Van Dijken, G.L. 2004. Annual changes in sea-ice, chlorophyll a, and primary production in the Ross Sea, Antarctica. *Deep Sea Research II* 51(1-3): 117-138.

Cavalieri, D.J.; Campbell, W.J.; Gloersen, P. 1984. Determination of sea ice parameters with the NIMBUS 7 SMMR. *Journal of Geophysical Research* 89: 5355-5369.

Comiso, J. 1999, updated 2005. Bootstrap sea ice concentrations for NIMBUS-7 SMMR and DMSP SSM/I, June to September 2001. Boulder, CO, USA: National Snow and Ice Data Center. Digital media.

Comiso, J.C. 1983. Sea ice effective microwave emissivities from satellite passive microwave and infrared observations. *Journal of Geophysical Research* 88: 7686-7704.

Comiso, J.C. 1995. SSM/I sea ice concentrations using the Bootstrap algorithm. National Aeronautics and Space Administration, Washington, D.C., NASA Report 1380.

Comiso, J.C. 2003. Large-scale characteristics and variability of the global sea ice cover. In: Thomas, D.N.; Dieckmann, G.S. (eds.), Sea Ice: An Introduction to its Physics, Chemistry, Biology and Geology, pp. 112–142. Blackwell Science, Oxford, UK.

Comiso, J.C.; Cavalieri, D.J.; Parkinson, C.L.; Gloersen, P. 1997. Passive microwave algorithms for sea ice concentration: A comparison of two techniques. *Remote Sensing of the Environment* 60: 357-384.

Davey, F.J. 2004. Ross Sea Bathymetry, 1:2 000 000, version 1.0, Institute of Geological and Nuclear Sciences geophysical map 16, Institute of Geological and Nuclear Sciences Limited, Lower Hutt, New Zealand.

DeLiberty, T.L.; Geiger, C.A. 2005. Temporal and regional variations in sea ice thickness in the Ross Sea during 1995 and 1998. Proceedings of 8th Conference on Polar Meteorology and Oceanography, part of the 85th AMS Annual Meeting (San Diego, CA), 12 January 2005. Available (May 2006) from: http://ams.confex.com/ams/pdfpapers/86923.pdf

Dinniman, M.S.; J.M. Klinck; W.O. Smith, Jr., 2003. Cross-shelf exchange in a model of the Ross Sea circulation and biogeochemistry. *Deep Sea Research* 50: 3103-3120.

Eicken, H. 2003. From the microscopic, to the macroscopic, to the regional scale: growth, microstructure and properties of sea ice. In: Thomas, D.N. & Dieckmann, G.S. (eds.), Sea Ice: An Introduction to its Physics, Chemistry, Biology and Geology, pp. 22–81. Blackwell Science, Oxford, UK.

Gloersen, P.; Cavalieri, D.J. 1986. Reduction of weather effects in the calculation of sea ice concentrations from microwave radiances. *Journal of Geophysical Research* 91: 3913-3919.

Grossi, S.M.; Kottmeier, S.T.; Moe, R.L.; Taylor, G.T.; Sullivan, C.W. 1987. Sea ice microbial communities. VI. Growth and. primary production in bottom ice under graded snow cover. *Marine Ecology Progress Series* 35: 153-164.

Ichii, T. 1990. Distribution of Antarctic krill concentrations exploited by Japanese krill trawlers and Minke whales. *Proceedings of the NIPR Symposium on Polar Biology* 3: 36-56.

Ichii, T.; Shinohara, N.; Fujise, Y.; Nishiwaki, S.; Matsuoka, K. 1998. Interannual changes in body fat condition index of minke whales in the Antarctic. *Marine Ecology Progress Series* 175: 1-12.

Jacobs, S.S., 1991. On the nature and significance of the Antarctic Slope Front. *Marine Chemistry* 35: 9-24.

Kurtz, D.D.; Bromwich, D.H. 1985. A recurring, atmospherically forced polynya in Terra Nova Bay. In: *Oceanology of the Antarctic Continental Shelf*, S.S. Jacobs (ed) Antarctic Research Series 43, AGU, Washington D.C., 177-201.

Langone, L.; Frignani, M.; Labbrozzi, L.; Ravaioli, M. 1998. Present-day biosiliceous sedimentation in the northwestern Ross Sea, Antarctica. *Journal of Marine Systems* 17: 459-470.

Rickard, G.J.; Pinkerton, M.H.; Roberts, M.J.; Williams, M.J.M.. 2009. Circulation of the Ross Sea sector of the Southern Ocean: representation in numerical models. Antarctic Science (submitted.)

Timmermann, R.; Beckmann, A.; Hellmer, H.H. 2002a. Simulation of ice-ocean dynamics in the Weddell Sea. Part I: Model configuration and validation, *Journal of Geophysical Research* 107(C3): 10.1029/2000JC000741.

Timmermann, R.; Hellmer, H.H.; Beckmann, A. 2002b. Simulations of ice-ocean dynamics in the Weddell Sea. Part II: Interannual variability 1985-1993, *Journal of Geophysical Research* 107(C3), 10.1029/2000JC000742.

Zwally, H.J.; Comiso, J.C.; Gordon, A.L. 1985. Antarctic offshore leads and polynyas and oceanographic effects. In: *Oceanology of the Antarctic Continental Shelf*, S.S. Jacobs (ed.), *Antarctic Research Series* 43, AGU, Washington D.C., 203-336.