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Productivity and linkages of the food web of the southern region of the western Antarctic Peninsula continental shelf

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ABSTRACT

The productivity and linkages in the food web of the southern region of the west Antarctic Peninsula continental shelf were investigated using a multi-trophic level mass balance model. Data collected during the Southern Ocean Global Ocean Ecosystem Dynamics field program were combined with data from the literature on the abundance and diet composition of zooplankton, fish, seabirds and marine mammals to calculate energy flows in the food web and to infer the overall food web structure at the annual level. Sensitivity analyses investigated the effects of variability in growth and biomass of Antarctic krill (*Euphausia superba*) and in the biomass of Antarctic krill predators on the structure and energy fluxes in the food web. Scenario simulations provided insights into the potential responses of the food web to a reduced contribution of large phytoplankton (diatom) production to total primary production, and to reduced consumption of primary production by Antarctic krill and mesozooplankton coincident with increased consumption by microzooplankton and salps. Model-derived estimates of primary production were 187–207 g C m^{-2} y^{-1}, which are consistent with observed values (47–351 g C m^{-2} y^{-1}). Simulations showed that Antarctic krill provide the majority of energy needed to sustain seabird and marine mammal production, thereby exerting a bottom-up control on higher trophic level predators. Energy transfer to top predators via mesozooplanton was a less efficient pathway, and salps were a production loss pathway because little of the primary production they consumed was passed to higher trophic levels. Increased predominance of small phytoplankton (nanoflagellates and cryptophytes) reduced the production of Antarctic krill and of its predators, including seabirds and seals.

1. Introduction

The traditional view of Southern Ocean food webs is that of a simple system dominated by Antarctic krill (*Euphausia superba*) that links diatom-based primary production with higher trophic levels in short efficient food chains (Everson, 1977; Laws, 1984; Murphy et al., 2012). However, this conceptual food web is not the dominant structure for many regions of the Southern Ocean where other zooplankton, such as copepods and crystal krill (*Euphausia crystallorophias*), as well as Antarctic silverfish (*Pleuragramma antarcticum*), provide the linkage between primary producers and higher trophic levels (Murphy et al., 2007, 2012; Ducklow et al., 2007; Smith et al., 2007, 2012). Even within the same region, the food web structure can vary in response to physical (circulation, sea ice) and chemical (micro and macro-nutrient supply) processes, which alter primary production, phytoplankton composition, the relative abundance of zooplankton species, and predator foraging dynamics (Murphy et al., 2007; Smith et al., 2007, 2012; Atkinson et al., 2008). Superimposed on regional and seasonal variability are the effects of climate-induced changes and harvesting of resources, which also produce perturbations to food web structure (e.g., Pakhomov et al., 2002; Atkinson et al., 2004; Smetacek and Nicol, 2005; Ballance et al., 2006; Ainley and Blight, 2009; Murphy et al., 2012).

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Descriptions of Southern Ocean food webs initially focused on qualitative descriptions of linkages in particular areas, such as the open ocean, sea ice, or coastal regions (Everson, 1977; Laws, 1984). Studies done during the past three decades provide the basis for quantification of food web models. Detailed analysis of food webs that are based on mass balance constraints, which require that predator consumption of a prey group does not exceed prey production, have been developed for the Ross Sea (Pinkerton et al., 2010), the Antarctic Peninsula-Scotia Sea (Cornejo-Donoso and Antezana, 2008) and the South Georgia shelf in the Scotia Sea (Hill et al., 2012). These modeling studies compiled and analyzed extensive and disparate data sets, which allowed identification and analysis of important trophic groups and interactions. The analysis of the Ross Sea food web was focused on the production of Antarctic toothfish (*Dissostichus mawsoni*) and the consequences of harvesting this species for its predators. The Antarctic Peninsula-Scotia Sea and South Georgia food webs showed that Antarctic krill was the primary link between low and high trophic levels, and also showed that alternative trophic pathways through other zooplankton species, benthic organisms, and fish provided support for the upper trophic levels.

The Antarctic Peninsula (Fig. 1a) is warming faster than most other regions on Earth, and is undergoing a transition from a maritime-Antarctic climate to a warmer sub-Antarctic-type climate (Montes-Hugo et al., 2009). Since the 1950s the western Antarctic Peninsula shelf has experienced significant increases in average air and sea water temperature (Turner et al., 2005; Meredith and King, 2005; review in Ducklow et al., 2007) associated with increased heat transport and glacial meltwater input and decreased sea ice extent and duration (Stammerjohn et al., 2008; Meredith et al., 2013).

In the northern part of the western Antarctic Peninsula, these changes in the physical environment have affected various components of the food web (Ducklow et al., 2007; Schofield et al., 2010). In particular, reductions in sea ice extent have been linked to observed changes in the composition of phytoplankton assemblages (Moline et al., 2004; Montes-Hugo et al., 2009), to reduced recruitment of intermediate trophic levels such as Antarctic krill and Antarctic silverfish that use the under ice habitat as a nursery (Atkinson et al., 2004; Ducklow et al., 2007; Chapman et al., 2011), and to reduced populations of vertebrate predators such as the Adélie penguin (*Pygoscelis adeliae*) that use the sea ice

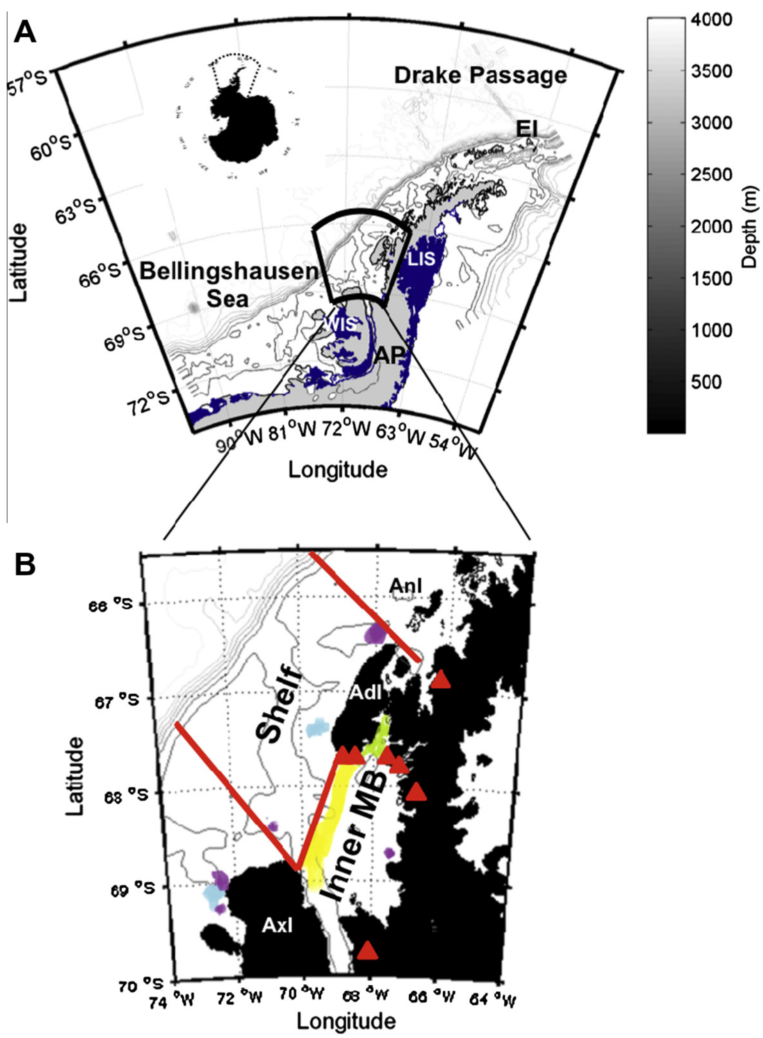

Fig. 1. Map of the Antarctic Peninsula (A) showing the SO GLOBEC study region and the partitioning of this region used for calculating inputs to the food web model (B, heavy black lines). Regions of enhanced concentrations of pelagic fish (green), seabirds (light blue), crabeater seals (purple) and baleen whales (yellow) that were observed during the SO GLOBEC survey cruises (Costa et al., 2007) are indicated. The location of Adélie penguin colonies (Ainley, 2002) is also indicated (triangles). Geographic features are identified as: Adelaide Island-AdI, Alexander Island-AxI, Anvers Island-AnI, Elephant Island-EI, George VI Ice Shelf-GVIIS, Marguerite Bay-MB, Marguerite Trough-MT, and Wilkins Ice Shelf-WIS. Bathymetric contours are in meters. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)