

## **SIMULATED POLAR FOOD WEB RESPONSES TO REDUCED ICE COVER: A SOUTHERN OCEAN PERSPECTIVE ON AN ICE-FREE NORTH POLE**

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An ice-free North Pole was just observed during August 2000. What will be the biotic responses of Arctic Seas to continued loss of ice cover? Some recent model results of Antarctic Seas may provide insight into the answers to this question. Over the last 50 years, for example, a decline in local sea-ice extent of the Bellingshausen Sea has been related to a 2-3°C increase of air temperature around the Antarctic Peninsula. Here on the western side of the Peninsula, a 75 % reduction in area of the Wordie Ice Shelf within less than 3 decades may reflect the expected polar amplification of global warming. Indeed, based on circumpolar whaling records, ice extent may have declined everywhere in the Southern Ocean by 25 % from 1950 to 1973, when satellite data became available, impacting the biological productivity of all Antarctic Seas.

Within wind-driven, nutrient-rich surface mixed layers [SML] of >80-m extent in the Southern Ocean, pelagic sun-adapted phytoplankton are thought to require meltwater-induced stability of the water column to provide sufficient light for initiation of their spring-summer blooms in coastal waters. A continued decline of ice cover may induce a future shift in the phytoplankton base of this food web, from sun-adapted, larger diatoms of shallow SML in marginal ice zones [MIZ] to shade-adapted, smaller nanoflagellates of deep SML in ice-free waters, if light, rather than grazing, is the most important control factor.

The survival of krill larvae, feeding on diatom populations of the shallow SML may then be reduced, if their food supply determines most of their population fluctuations. Concomitantly, a transition in the dominance of the major herbivores, from long-lived, diatom-grazing euphausiids to ephemeral, flagellate-consuming salps, may occur, with different sequestration of atmospheric CO<sub>2</sub> as detrital organic carbon at depth, if sinking fluxes of zooplankton fecal pellets and phytoplankton debris also change. Similar questions about other functional groups of predators and prey pertain to future perturbations of the Arctic halocline (Walsh, 1989).

A traditional N-P-Z [Nutrient-Phytoplankton-Zooplankton] model with one state variable each to represent the plant and animal communities of the biological pump is incapable of addressing questions of altered rates of element cycling effected by changing composition of competing groups of plankton. A basically one-dimensional numerical model of three dominant groups of the Antarctic phytoplankton community [diatoms, cryptophyte flagellates and colonial prymnesiophytes] and four types of herbivore [protozoans, salps, copepods, and euphausiids] has thus been constructed (Walsh et al., 2000). Under the same changes of ice cover, it is used to explore the seasonal importance of both light limitation and grazing pressure on the annual amount of inorganic carbon sequestered as DOC and POC within contrasting deep SML of oceanic and shallow SML of neritic waters of the Southern Ocean, where respective validation data have been gathered during austral spring by the European JGOFS and RACER programs.

With imposition of moderate and large grazing stresses - thought to be typical of offshore waters - within the deep SML of our model, we were able to replicate the European JGOFS 1992 observations of light penetration, phytoplankton biomass, primary production, pCO<sub>2</sub>, bacterial biomass, labile DOC, ammonium, and total particle effluxes at 100 m. The fidelity of such a large set of simulated state

variables with the “real world” suggested that multiple limiting factors were indeed operating on different components of the oceanic phytoplankton community - selective grazing losses on the flagellates [cryptophytes and prymnesiophytes], but light limitation of diatoms. On an annual basis, weak sequestration of atmospheric CO<sub>2</sub> was simulated in a habitat typical of the Polar Front, while evasion of carbon dioxide occurred under biophysical conditions of the Antarctic Circumpolar Current.

Moving into the relatively deep water column (>500 m) of coastal waters in Bransfield Strait, compared to the <50-m depths of most of the Bering/Chukchi shelves, stratified shallow SML and the same absolute grazing demands by krill and copepods allowed sun-adapted diatoms of our model to bloom at the expense of shade-adapted cryptomonads and *Phaeocystis*, eaten by salps and protozoans. We were also able to replicate RACER-I observations of the same suite of state variables in 1986-87, as well as the observed ten-fold range of detrital fluxes caught by other sediment trap deployments during 1980 and 1983 along the Antarctic Peninsula. In western Bransfield Strait, coastal waters were a strong sink for atmospheric CO<sub>2</sub> within parcels of Bellingshausen Sea origin, but not perhaps in those from the Weddell Sea, which resembled the oceanic regime of deep SML. We conclude that even in shallow neritic SML, some protozoan rivals of larval krill must still crop flagellates to ensure sufficient abundance of diatom food for both euphausiid survival and possible clogging of the mucous nets of other salp rivals.

We might thus expect that a continued reduction of the spatial extent of the coastal MIZ will result in an even smaller sink of atmospheric CO<sub>2</sub> in the Antarctic Seas - and by analogy in ice-free Arctic Seas - unless salp pellets are a more effective biological pump. Within regions of deep SML of our model, however, large salp populations eventually starve - after exhausting both their plant and protozoan supplies of food, while yielding an annual detrital flux of only ~10% of the other cases of smaller salp populations. Since model predictions of detrital export within the different grazing scenarios of coastal waters matched interannual observations of debris caught in Bransfield Strait by sediment traps in December 1980, 1983, and 1986, we thus assume that our model structure is a reasonable approximation of predator-prey interactions among the 7 groups of phytoplankton and zooplankton.

Accordingly, a replacement of krill by salps may not yield greater POC fluxes to the aphotic zone. In terms of other food web consequences of reduced ice cover in coastal regions of the Southern Ocean, we might expect a decline of both diatom stocks and of larval survival of krill and copepods, but no major increments of cryptophyte stocks should occur, unless protozoans are removed. Without adult krill to disperse prymnesiophyte colonies as smaller-size food for protozoans, however, blooms of *Phaeocystis* may instead ensue. If salps can not use the colonial form of prymnesiophytes, their populations may also decline - their mucous webs would no longer be clogged by diatom blooms, but the supply of single cell *Phaeocystis* would be less, and cryptophyte biomass would not have increased. If the present trend of ice loss around the Antarctic Peninsula continues, time will tell!

Which of these simulated outcomes of polar phytoplankton competition are relevant scenarios for relatively nutrient-poor Arctic Seas? Our prior studies of the 10-fold shallower shelf of the Bering Sea included the additional state variables of sediment debris (POC and DOC) and bioturbation by the benthos (Walsh and Dieterle, 1994), where in situ nitrification was an important process. Here, our model results suggested that these Arctic shelves switched from a source to a sink of carbon dioxide about 250 yr ago, mainly as a consequence of rising levels of atmospheric CO<sub>2</sub>.

Yet, if the diatomaceous phytoplankton of the western Arctic cases of this model were somehow replaced by ungrazed, sulfur-emitting and mucous-secreting colonial prymnesiophytes - *Phaeocystis*, now dominant in the deeper Barents Sea (Sakshaug and Walsh, 2000)- the influx of atmospheric CO<sub>2</sub> doubled, with more storage in the form of DOC, exported to the Arctic basins (Walsh et al., 1997). In an Antarctic scenario of ungrazed *Phaeocystis* populations, with consumption instead of their competitors by

protozoans and crustaceans, a very large invasion of atmospheric CO<sub>2</sub> was also found (Walsh et al., 2000).

As in the Southern Ocean, our prior models of the shallow Bering and Chukchi shelves thus contained *Phaeocystis* (Walsh and Dieterle, 1994), flagellate (Penta and Walsh, 1995), and diatom (Walsh et al., 1997) state variables as well, but they did not compete against each other in any of these earlier simulation runs. We instead assumed that light-limitation of diatoms favored seasonal succession of *Phaeocystis* within the deeper Barents Sea, but not in the shallow parts of the western Arctic (Sakshaug and Walsh, 2000), where nutrient-limitation was used to restrain flagellates, in contrast to protozoan control (Penta and Walsh, 1995). Successful ecological models are data-driven, of course, distilling qualitative hypotheses and aliased field observations into simple analogues of the real world in a continuing cycle of model testing and revision. Clearly, future field studies of this polar food web must thus now include more complex numerical food webs as an integral part, lest “Greenhouse surprises” continue to first occur within ice-free Arctic waters.

### References

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