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EDITORIAL

Impacts of climate warming on polar marine and freshwater ecosystems

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Polar regions have been identified as being most sensitive to climate warming in the planet. The Arctic is experiencing the highest warming on Earth with air temperature increasing at a rate of two to three times that of the global average temperature (International Panel on Climate Change 2007). Atmospheric warming has increased Arctic Ocean temperature and accelerated ice melting, with sea ice decreasing in thickness and extent at a rate of 10% per decade (Comiso et al. 2008). Warming and the associated ice loss appears to have been accelerating in the past few years in the Arctic and in some regions of Antarctica as well (Steig et al. 2009). The Arctic Ocean experienced a massive loss of ice in the summer of 2007, representing the lowest ice cover in the last 40 years, and an unusually warm Arctic Ocean surface layer were recorded (Steele et al. 2008; Zhang et al. 2008). Provided the critical role of ice cover in determining the functioning and traits of polar marine and freshwater ecosystems, rapid ice loss is expected to severely impact these ecosystems at multiple levels.

The impact of warming and ice loss will affect, in turn, the radiative balance of polar waters, affecting their thermal and light, including UV, environments. Recent overviews of results from observational studies of atmospheric and climate-sensitive variables (e.g., sea ice, snow cover, river discharge, glaciers and permafrost) concluded that, taken together, a reasonably coherent portrait of recent change in the northern high latitudes is apparent. Ice loss will intensify air–water interactions in polar ecosystems and will also severely impact all species, from microbes to megafauna, that depend on ice as a habitat. Warming and ice loss will affect key biological and biogeochemical processes of aquatic polar ecosystems and may induce ecological regime shifts, associated with possible losses of biodiversity and an increased vulnerability to invasions of species from lower latitudes.

The goal of this special issue is to bring together recent research results addressing impacts of warming and ice loss in both Antarctic and Arctic aquatic ecosystems. "Impacts of Climate Warming on Polar Marine and Freshwater Ecosystems" was the title of a topical session of the Aquatic Science Meeting of the American Association of Limnology and Oceanography (ASLO), held in Nice (France) from 23 to 30 January 2009, during which results from both benthic and pelagic, freshwater and marine polar ecosystems were presented. Susana Agustí and Mikael K. Sejr acted as Chairs of this ASLO session, which received financial support by the Prince Albert II of Monaco Foundation. Some papers presented in the session are published in this special issue of Polar Biology.

Results from Antarctic aquatic ecosystems presented in this special issue highlight the temporal variability of marine and freshwater systems of the Antarctic Peninsula in the west of the continent, which is the region experiencing the strongest warming (Steig et al. 2009). The significant increase in temperature across most of West Antarctica, exceeding 0.1°C per decade over the past 50 years, is attributed to global warming and to the increased strength of the circumpolar westerlies in response

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to changes in stratospheric ozone (Steig et al. 2009). Moreover, satellite remote-sensing data of ice elevations and ice motion show significant glacier ice loss in the range of 31–196 Gt year^{-1} in West Antarctica in recent years, whereas the East Antarctica ice sheet seems to remain in balance or slightly gain mass (Chen et al. 2009).

Moreau et al. (2010, this special issue) report the changes in the microbial community from fall to spring in a bay in the Melchior Archipelago (Antarctic Peninsula) in 2006. Presenting rare original data from both winter and spring periods, they showed that the spring phytoplankton bloom was lower than expected for the prevailing conditions and attributed this to the early disappearance of sea ice in spring, leaving surface waters exposed to high ultraviolet B radiation.

Rochera et al. (2010, this special issue) examined the temporal variability in meteorological and limnological conditions on the Byers Peninsula (Livingston Island, Antarctic Peninsula), an area characterised by abundant freshwater in shallow lakes, ponds, seepages and streams. Their results highlight the high meteorological variation observed during a period of 3 years, with major consequences in the timing and duration of the ice-free period. These changes have profound consequences for the limnological conditions and biology of the lakes, pointing to the high sensitivity of freshwater ecosystems to climate change occurring in this region.

Most studies presented in this special issue examined the impacts of ice loss and warming of the Arctic Ocean. Wassmann et al. (2011) recently summarised evidence for footprints of climate change on Arctic marine ecosystems and found remarkably few such evidences, despite the acute rate of warming and ice loss in the region. They attributed this to low research effort in the Arctic and called for renewed efforts to assess these footprints (Wassmann et al. 2011). The results presented in this special issue help addressing this plea.

Arp et al. (2010, this special issue) identified the interface between land and sea as an area particularly vulnerable to climate change, with potential for habitat loss for Arctic birds and megafauna, for which this interface represents a critical habitat. In a coastal plain ecosystem at the Beaufort Sea in northern Alaska they investigated the mechanisms of high rates of coastal erosion, which resulted in a shoreline regression of 17 m year^{-1} from 2007 to 2009 and salt water intrusions into lakes.

The variability in oceanic primary production in the European sector of the Arctic Ocean in relation to changes in ice cover was modelled by Wassmann et al. (2010, this special issue) based on data from several cruises between 1995 and 2007. For this time interval, before the massive decline of sea ice in the summer of 2007, they did not find evidence for a significant increase in gross primary production.

Regaudie-de-Gioux and Duarte (2010, this special issue) studied the net metabolism of planktonic communities in the Greenland Sea and Fram Strait, from open water to the ice margin, during the summer of 2007. Describing the variability of gross primary production, community respiration and the net community production, they showed that an important proportion of the area was characterized by a net heterotrophic metabolism, suggesting high allochthonous inputs of organic matter supporting excess heterotrophic activity. Based on these findings, they discuss the role of warming, and the ensuing increase in freshwater run-off from continental ice melting, in shifting the net metabolism of Arctic Ocean waters from an autotrophic to a net heterotrophic state and, hence, in changing from a net sink to a net source of CO_2.

The direct effect of increasing temperature on metabolism and respiration rates of surface marine planktonic communities in the European Arctic sector was examined by Vaquer-Sunyer et al. (2010, this special issue) in experiments conducted during a series of oceanographic cruises. They found that planktonic communities did not respond to warming during late fall–early winter, whereas respiration rates increased in response to warming in spring and summer, although with variable strength.

Kritzberg et al. (2010, this special issue) analysed the effect of increasing temperature and the availability of resources on Arctic bacterial carbon metabolism. Heterotrophic bacteria process vast amounts of organic carbon in the ocean, which may be enhanced further by the effects of warming and increased inputs of organic carbon through continental ice melting. Bacterial assemblages from the Fram Strait exposed to experimental manipulations of temperature and resources showed enhanced production and respiration, but respiration responded more strongly to temperature, in support of the parallel results on net metabolism of planktonic communities presented in other papers of this special issue.

Arctic oceanic bacteria use of organic substrates was examined by Sala et al. (2010, this special issue). Surface waters of low temperature and low salinity, originating mainly from melted ice, contained very sparse bacteria populations. These bacteria supported, however, high specific bacterial production, and showed a preference for utilizing carbohydrates and significantly higher specific activities of the glycosidases assayed, i.e., b-glucosidase, xylosidase, arabinosidase, and cellobiosidase. The authors discuss how climate change and the associated melting of Arctic ice might induce changes in bacterioplankton functional diversity by enhancing the turnover of carbohydrates.

Bacterial losses due to viral infections or protist grazing were examined by Boras et al. (2010, this special issue) in Arctic waters of the Greenland Sea, Fram Strait and the ice margin. Overall, protist grazing was more important in bacterial carbon fluxes than viral activities. In waters influenced by ice melting, this pattern was strongest, leading the authors to discuss possible impacts of ice melting on the transfer of bacterial carbon to higher trophic levels.

The phytoplankton community in the Atlantic sector of the Arctic Ocean was studied by Lasternas and Agustí (2010, this special issue) during summer 2007 when the Arctic sea ice declined to a record minimum extent (Zhang et al. 2008; Lindsay et al. 2009). Lasternas and Agustí (2010) following the ice retreat north of the Fram Strait, they found that *Phaeocystis pouchetti*, present in its harmful colonial form, dominated the phytoplankton, while diatoms, small flagellates and dinoflagellates, which were expected to dominate the ice-melt waters in this sector of the Arctic Ocean, were practically insignificant.

Alcaraz et al. (2010, this special issue) studied during the same cruise the stoichiometry of Arctic zooplankton excretion products to analyze whether their metabolism was based on lipids and/or herbivorous feeding. Since low C:N values of C:N generally indicated starvation, the authors discuss the hypothesis of a change in the catabolic pathway of zooplankton as a consequence of the dominance of *Phaeocystis pouchetti*, which is hardly available as a food source to copepods.

Finally, Forest et al. (2010, this special issue) studied vertical particle fluxes on the basis of a 6-year time series of sediment trap data from the Fram Strait. They found that total and new simulated primary production averaged for different areas centered on the mooring location explained at best 20–44% of the observed biogenic particle fluxes. They discuss the role of global warming in promoting a reduction in export matter and a transition towards a more retentive ecosystem in the Fram Strait, consistent with results suggesting increased heterotrophy as presented by Vaquer-Sunyer et al. (2010, this special issue).

The conclusions of the results obtained from the European sector of the Arctic Ocean, the area for which most studies were presented in this special issue, depict a consistent notion. Increasing warming and ice melting in the Arctic are expected to impact the structure and net metabolism of the planktonic communities, resulting in a shift towards a pelagic system that is dominated by net heterotrophic metabolism and characterized by food webs including harmful *Phaeocystis pouchetti* colonies. The dominant microbial loop in the upper water column will lead to decreased exports of biogenic material to the sea floor and thus to a shift of the planktonic ecosystem from a CO_2 sink to a CO_2 source.

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