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Biological Response to Recent Pacific Arctic Sea Ice Retreats

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Although recent major changes in the physical domain of the Arctic region, such as extreme retreats of summer sea ice since 2007, are well documented, large uncertainties remain regarding responses in the biological domain. In the Pacific Arctic north of Bering Strait, reduction in sea ice extent has been seasonally asymmetric, with minimal changes until the end of June and delayed sea ice formation in late autumn. The effect of extreme ice retreats and seasonal asymmetry in sea ice loss on primary production is uncertain, with no clear shift over time (2003–2008) in satellite-derived chlorophyll concentrations. However, clear changes have occurred during summer in species ranges for zooplankton, bottom-dwelling organisms (benthos), and fish, as well as through the loss of sea ice as habitat and platform for marine mammals.

To discover and track ecosystem changes under further loss of sea ice, a coordinated campaign of observations would be beneficial. Recognizing this, researchers studying Arctic biology have suggested the implementation of an international distributed biological observatory (DBO) in the Pacific Arctic region (PAR; defined as the region north of St. Matthew Island to the Beaufort Sea and the Arctic Ocean) focused on four locations along a latitudinal gradient from the northern Bering to the western Beaufort seas. Through intense study of these areas, scientists will be able to better understand how climate change affects Arctic biology and to be able to start piecing together how this in turn affects the Earth system.

Biological Response to Extreme Sea Ice Retreats

Sea ice is fundamental to primary production for ice algae and phytoplankton, both of which bloom in early spring when the water column is stabilized by melting sea ice. The timing and location of primary production and associated grazing by zooplankton have a direct influence on organic carbon partitioning between the upper water column and benthic communities. In the short and efficient Arctic food webs, even small changes in production pathways can have large cascading effects on higher trophic organisms. Thus, a fundamental question is how best to assess the response of the marine ecosystem to the shifts in seasonal sea ice retreats that are now routine in the Pacific Arctic.

The extreme sea ice retreats in 2007–2009 lengthened the open-water season in fall in the Pacific Arctic by roughly 4 weeks. Further, the amount of thick multiyear sea ice has been reduced by 40% compared with a decade ago. Nearly sea ice–free summers are now forecast before midcentury if not sooner [*Wang and Overland,* 2009]. The response of primary productivity to this seasonal ice reduction is uncertain. While temporally constrained models indicate that primary production has increased over the Chukchi Sea shelf [*Arrigo et al.,* 2008], recent 6-year time series show that chlorophyll *a* concentrations are not increasing throughout the region as a whole (Figure 1). Thus, researchers must exercise caution before summarily assuming that increased primary production accompanies an extended open-water season—biological processes vary greatly with seasonal solar input, timing of sea ice retreat, effects of open-water storm events on mixed-layer depth, increased freshwater runoff, and nutrient limitation [*Bluhm and Gradinger,* 2008]. A shift to smaller algal species sizes with Arctic Ocean freshening [*Li et al.,* 2009] may affect food web structure and carbon cycling with continued warming.

Biological changes are occurring at the level of secondary production and higher. Pacific zooplankton intrusions northward into the Beaufort Sea [*Nelson et al.,* 2009] are coincident with observation of Pacific

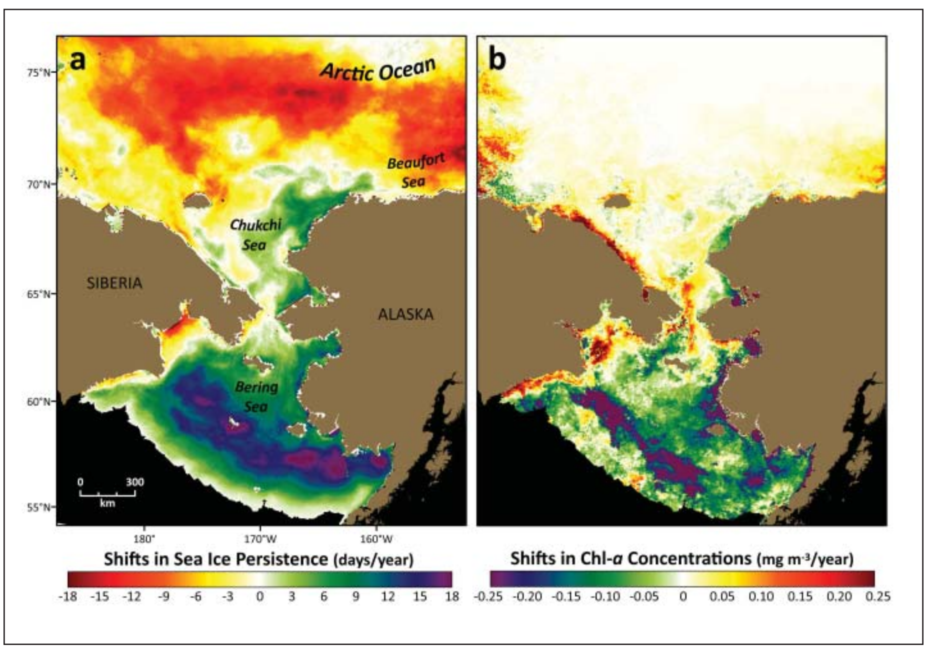

Fig. 1. Shifts in (a) annual sea ice persistence and (b) chlorophyll a *(Chl-*a*) concentrations between 2003 and 2008. Sea ice persistence is based on daily passive microwave sea ice concentrations using a threshold of 15% (available from the University of Hamburg; http://www.ifm.zmaw.de), and chlorophyll* a *concentrations are based on monthly Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) satellite products (available from NASA; http://oceancolor.gsfc.nasa.gov).*

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clam species found north of the Bering Strait [*Sirenko and Gagaev,* 2007]. A limited presence of commercially fished species from the southern Bering Sea, including walleye pollock, Pacific cod, and Bering flounder, now occurs in the Beaufort Sea. Also, anomalous, commercial-sized snow crabs have been found in these more northern waters. Declines in dominant clam populations critical as prey in the northern Bering Sea are concomitant with dramatic declines in certain seabird populations, specifically in the numbers of spectacled eiders [*Lovvorn et al.,* 2009]. In the western Beaufort Sea, black guillemots have lost access to ice-associated Arctic cod due to the extreme ice retreats and more frequently suffer predation by land-based polar bears. Polar bears have switched denning habitat from sea ice to land [*Fischbach et al.,* 2007], have been seen drowned at sea, and are being seen more regularly on beaches. This combination of range expansions and/or changes to community composition and the timing of life history events are all clear indicators of an ecosystem in transition.

Measuring Response: A Distributed Biological Observatory

To detect, measure, and track the combined effects of changing oceanographic conditions on the ecosystem, scientific approaches need to be holistic, integrating measurements of basic oceanographic variables with data on species- and trophic-level interactions, from primary producers to marine mammals. A good way to do this is through a DBO along a latitudinal gradient in the Pacific sector. The DBO is envisioned as an array to identify and consistently monitor biophysical responses in four pivotal geographic areas that exhibit high productivity, biodiversity, and rates of change. These areas are (1) the northern Bering Sea, (2) the Bering Strait and southeastern Chukchi Sea, (3) the central Chukchi Sea, and (4) the Barrow Arc (Figure 2). Production and biomass hot spots occur in each of these regions based on existing but fragmented time series data; these historic sources of information, including International Polar Year (IPY) 2007–2009 data, provide the observational basis for establishing the DBO.

The DBO would support a suite of in situ time series measurements to evaluate ecosystem status, supplemented by satellite observations. Sea ice observations include ice and snow thickness and biological sampling to evaluate changes to productivity in sea ice systems and habitat sustainability for predators. Standard measurements at time series transect sites would include hydrography (temperature, salinity, nutrients, chlorophyll), biomass, and species composition, as well as the size and condition of key organisms at each trophic level. For the short generation times of lower trophic levels (mainly microbes, phytoplankton, and zooplankton), sampling at least every year

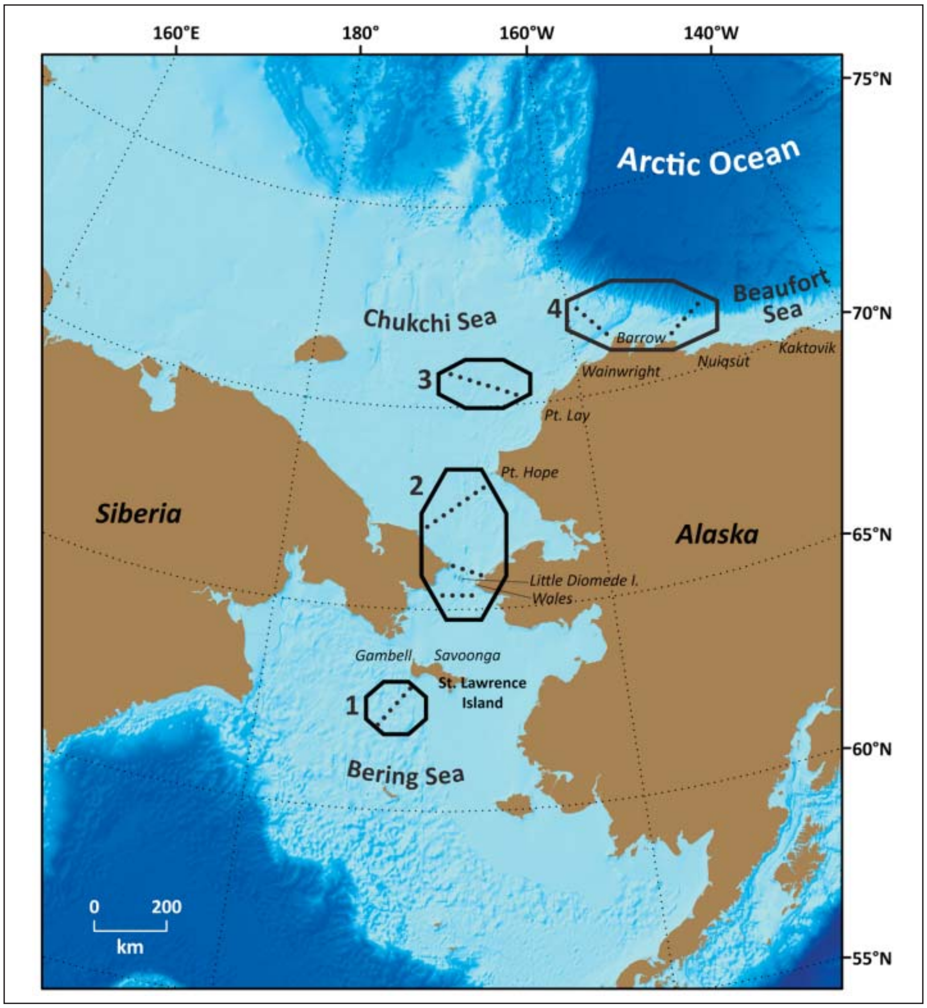

Fig. 2. Conceptual map showing a distributed biological observatory (DBO) in the Pacific Arctic region. Octagons represent intensive observation locations: 1, the northern Bering Sea; 2, the Bering Strait and southeastern Chukchi Sea; 3, the central Chukchi Sea; and 4, the Barrow Arc. Dashed lines represent potential shipboard sampling sites.

should help scientists detect and track shifts in ecosystem structure, while the more slowly growing benthic faunal biomass and composition could be measured at time intervals of 1–3 years. Fish populations are to be surveyed annually via active acoustics, with trawl sampling included every 3–5 years to track shifts in species composition. Seabirds can be assessed via standard visual surveys on ship transects and through indicator colony studies. Similarly, marine mammal visual and passive acoustic sampling can be incorporated via shipboard operations and on ocean observation moorings, respectively. Finally, coastal residents who subsist on fish, seabirds, and marine mammals would partner in DBO activities by contributing observations and tissue samples so that shifts in ice conditions, species diet, and contaminant levels can be tracked in higher-trophic organisms.

International Cooperation and the DBO

Seasonal and annual occupation of DBO stations can be sampled through an international network of ship operations, both ongoing and planned. These include Canadian, Chinese, Korean, Japanese, Russian, and U.S. research vessels currently being coordinated through the international Pacific Arctic Group (PAG), a network of governments and scientists working in the Pacific Arctic sector. The DBO would also include land-based research out of coastal communities using helicopters and small ships as well as access to tissue sampling within research partnerships between scientists and local communities.

In addition, incorporation of the DBO concept within the development of the international Sustaining Arctic Observing Networks (SAON) provides a foundation for a system-level investigation of the ecological response to Arctic climate change and for improving the linkage between community-based monitoring and science-based measurements. The Arctic Council, an intergovernmental forum of Arctic governments and indigenous communities, has recognized the contribution of the SAON process to securing an IPY legacy and has agreed to support continuation of these activities in cooperation with the International Arctic Science Committee (IASC) and other relevant partners (see http://www.arcticobserving.org).

The Arctic is no longer predictable. Clear changes in the ecosystem from plankton to polar bears are evident. It is critical that biological measurements be included in international ocean-observing systems to track and forecast the fate of Arctic marine ecosystems.

Acknowledgments

We thank the participants of the workshop "Biological Response to Sea Ice Reduction in the Pacific Arctic Region," held in Seattle, Wash., 6–8 May 2009, sponsored by the U.S. National Oceanic and Atmospheric Administration (NOAA) through the Climate Program Office's Arctic Research Program (see http://arctic.cbl.umces.edu/#Distributed_Biological_Observatory_Initiative). This is Pacific Marine Environmental Laboratory (PMEL) contribution 3548.

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Author Information

Jacqueline M. Grebmeier, Chesapeake Biological Laboratory, Center for Environmental Science, University of Maryland, Solomons; E-mail: jgrebmei@cbl.umces.edu; Sue E. Moore, Fisheries Science and Technology, NOAA, Seattle, Wash.; James E. Overland, PMEL, NOAA, Seattle, Wash.; Karen E. Frey, Clark University, Worcester, Mass.; and Rolf Gradinger, University of Alaska Fairbanks

GEOPHYSICISTS

Honors

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Nine AGU members are among the U.S. National Academy of Sciences' (NAS) newly elected members and foreign associates, selected "in recognition of their distinguished and continuing achievements in original research." Newly elected NAS members include **Douglas W. Burbank**, professor of geology and director, Institute for Crustal Studies, University of California, Santa Barbara; **Neil Gehrels**, chief, Astroparticle Physics Laboratory, NASA Goddard Space Flight Center, Greenbelt, Md.; **Gary A. Glatzmaier**, professor of Earth and planetary sciences, Department of Earth and Planetary Sciences, University of California, Santa Cruz; **David Jablonski**, William R. Kenan Jr. Professor, Department of Geophysical Sciences, University of Chicago, Chicago, Ill.; **Jonathan I. Lunine**, professor of planetary sciences, University of Arizona, Tucson; **Ignacio Rodríguez-Iturbe**, James S. McDonnell Distinguished University Professor of Civil and Environmental Engineering, Department of Civil and Environmental Engineering, Princeton University, Princeton, N. J.; **Roberta L. Rudnick**, professor of geology, Department of Geology, University of Maryland, College Park; and **Susan E. Trumbore**, director, Institute of Geophysics and Planetary Physics, and professor, Department of Earth System Science, University of California, Irvine. Elected as an NAS foreign associate is **Victor A. Ramos**, Profesor Titular de Geotectonica y Tectonica, Andina, Departamento de Ciencias Geológicos, Universidad de Buenos Aires, Buenos Aires, Argentina.

The United Nations has awarded **Taro Takahashi** a "Champions of the Earth" award, its highest honor for environmental leadership. Takahashi, a geochemist at Columbia University's Lamont-Doherty Earth Observatory, Palisades, N. Y., was recognized for his research on the oceans' uptake of carbon dioxide and its implications for global warming.

LETTERS

Comment on "The Prediction of Two Large Earthquakes in Greece"

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Uyeda and Kamogawa [2008] reported on the VAN experimental method for short-term earthquake prediction (VAN was named for three Greek physicists, Panayiotis Varotsos, Kessar Alexopoulos, and Konstantine Nomicos), which reportedly recorded seismic electric signals (SESs) before the M_w 6.8 earthquake on 14 February 2008. They claimed that a prediction is documented by P. A. Varotsos et al. (Seismic electric signals and 1/f "noise" in natural time, version 3, 2008; available at http://arxiv.org/abs/0711.3766v3) and in the newspaper *Ethnos* (10 February 2008; http://www.ethnos.gr/article.asp?catid=11424&subid2&tag=8777&pubid=444473). This claim is unjustified because the prediction was not submitted to Greece's Permanent Special Scientific Committee for the Assessment of Seismic Hazard and the Evaluation of Seismic Risk. According to Greek legislation, the committee is officially charged with analyzing and vetting earthquake hazard assessments (including predictions and ongoing seismic crises) and ultimately advising the government. Through civil protection authorities, the government handles the social, economic, and other negative consequences of impending earthquakes. But perhaps more scientifically grievous, this prediction was not documented elsewhere beforehand.

The only relevant statement by P. A. Varotsos et al. (2008) says that for the SES of 14 January, "…the subsequent seismicity is studied in the area B of Fig. 9 as well as in the larger area N38.60-36.00, E22.50-20.00 and in the one surrounding the epicenter (N36.00-E23.00)." But this neither gives the expected earthquake magnitude or time nor provides a clearly defined area of expected earthquake occurrence. The probability for the prediction to come true is also missing.

In reply to this comment, *Uyeda and Kamogawa* [2010] recognize that P. A. Varotsos et al. (2008) failed to indicate the prediction time window but claim that this has been done in the *Ethnos* article. However, there is no information about the prediction time in the *Ethnos* article. Further, *Uyeda and Kamogawa* [2010] again fail to pinpoint the prediction statements by P. A. Varotsos et al. (2008) and *Ethnos.* Additionally, Uyeda and Kamogawa fail to specify the precise target area, and their claim that a magnitude over 6 was predicted is not documented.

Confusion and ambiguity do not lie solely with *Uyeda and Kamogawa* [2008, 2010].