ARCTIC
VOL. 71, SUPPL. 1 (2018) P. 1–7
https://doi.org/10.14430/arctic4606

The Distributed Biological Observatory: Linking Physics to Biology in the Pacific Arctic Region

Sue E. Moore[1,2] and Jacqueline M. Grebmeier[3]

(*Received 21 November 2016; accepted in revised form 4 April 2017*)

ABSTRACT. In response to dramatic seasonal sea ice loss and other physical changes influencing biological communities, a Distributed Biological Observatory (DBO) was proposed in 2009 as a "change detection array" to measure biological responses to physical variability along a latitudinal gradient extending from the northern Bering Sea to the Beaufort Sea in the Pacific Arctic sector. In 2010, the Pacific Arctic Group (PAG) initiated a pilot program, focused on developing standardized sampling protocols in five regions of high productivity, biodiversity, and rates of change. In 2012, an academic team received funding to sample all five DBO regions, with collateral support from the Interagency Arctic Research Policy Committee (IARPC) DBO Collaboration Team. The IARPC team met monthly from 2012 to 2016 and advanced the DBO from a pilot phase to an implementation phase, including 1) the addition of three new sampling regions in the Beaufort Sea, 2) the goal of linking the observatory to existing community-based observation programs, and 3) the development of a plan for a periodic Pacific Arctic Regional Marine Assessment (PARMA) beginning in 2018. The long-term future of the DBO will depend on active involvement of international and national partners focused on the common goal of improved pan-Arctic assessments of regional marine ecosystems in an era of rapid change.

Key words: Pacific Arctic; ocean observatory; marine ecosystems; international collaboration

RÉSUMÉ. En réponse à la perte dramatique de glace de mer saisonnière et aux autres changements physiques ayant des incidences sur les communautés biologiques, un réseau d'observatoires biologiques distribués (Distributed Biological Observatory, ou DBO) a été proposé en 2009 en guise d'« outil de détection des changements » pour mesurer les réponses biologiques à la variabilité physique le long d'un gradient latitudinal s'étendant de la mer nordique de Béring à la mer de Beaufort dans la région arctique du Pacifique. En 2010, le Pacific Arctic Group (PAG) a lancé un programme pilote axé sur l'élaboration de protocoles d'échantillonnage normalisés dans cinq régions où la productivité, la biodiversité et les taux de changement sont élevés. En 2012, une équipe universitaire a reçu du financement pour échantillonner les cinq régions du réseau de DBO, avec l'appui conjoint de l'équipe de collaboration de DBO du comité interinstitutionnel des politiques en matière de recherche dans l'Arctique (Interagency Arctic Research Policy Committee, ou IARPC). L'équipe de l'IARPC s'est réunie mensuellement de 2012 à 2016 pour faire avancer le projet du réseau de DBO, qui est ainsi passé de la phase pilote à la phase de mise en œuvre, incluant : 1) l'ajout de trois nouvelles régions d'échantillonnage dans la mer de Beaufort; 2) l'objectif visant à relier les observatoires aux programmes d'observation communautaires qui existent déjà; et 3) l'élaboration d'un plan pour une évaluation marine périodique de la région arctique du Pacifique (Pacific Arctic Regional Marine Assessment, ou PARMA) à compter de 2018. L'avenir à long terme du réseau de DBO dépendra de la participation active des partenaires nationaux et internationaux dans leur objectif commun consistant à améliorer les évaluations panarctiques des écosystèmes marins régionaux en cette époque de changements rapides.

Mots clés : région arctique du Pacifique; observatoire océanique; écosystèmes marins; collaboration internationale

Traduit pour la revue *Arctic* par Nicole Giguère.

BACKGROUND

In 2009, in response to dramatic seasonal sea ice loss and other physical changes influencing biological communities, a Distributed Biological Observatory (DBO) was proposed as a change detection array to measure biological responses to physical variability along a latitudinal gradient extending from the northern Bering Sea to the Beaufort Sea in the Pacific Arctic sector (Grebmeier et al., 2010). By design, DBO sampling was focused on five regions of demonstrated high productivity, biodiversity, and rates of change (Fig. 1: regions 1–5). The DBO concept was vetted at numerous

[1] National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Science and Technology, 7600 Sand Point Way NE, Seattle, Washington 98115, USA
[2] Corresponding author: sue.moore@noaa.gov
[3] Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science, 100 Williams Street, Solomons, Maryland 20688, USA

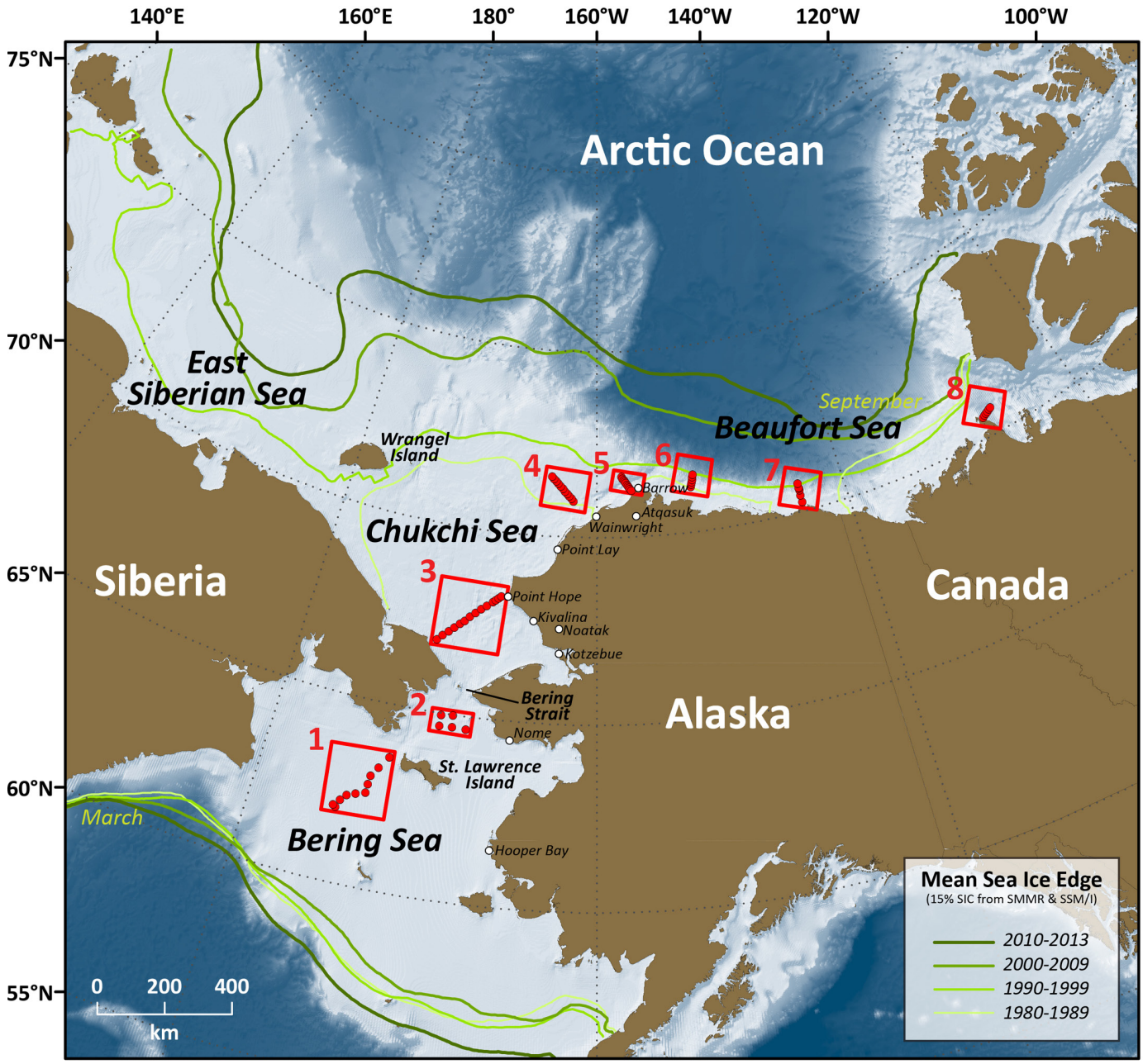

FIG 1. The Distributed Biological Observatory (DBO) consists of eight sampling regions focused on 'hotspots' of biological productivity and biodiversity, extending from the northern Bering Sea to the Beaufort Sea. Regions 1–5 were established during the DBO pilot phase; regions 6–8 were added during the implementation phase. Decadal maximum and minimum median ice extent based on SMMR and SSM/I Satellite-Derived Sea Ice Concentrations (1979–2012). Map courtesy of Karen Frey, Clark University.

scientific meetings and incorporated in various U.S. Arctic research planning documents (http://www.pmel.noaa.gov/dbo/about), including (1) the National Oceanographic and Atmospheric Administration (NOAA) Arctic Strategic Plan (NOAA, 2014), (2) the United States Geological Survey (USGS) 'Science Needs' Report (Holland-Bartels and Pierce, 2011), (3) the Bureau of Ocean Energy Management (BOEM) Alaska Region Research Plan (BOEM, 2015), (4) the National Ocean Policy Strategic Plan (White House Executive Office, 2011), and (5) the National Strategy for the Arctic Region (NSAR) (White House Executive Office, 2014).

In 2010, a DBO pilot program was initiated and focused on developing standardized sampling protocols in regions 3 and 5. International participation was coordinated by the Pacific Arctic Group (PAG), with national participation managed by NOAA. In 2012, the National Science Foundation/Arctic Observing Network (NSF/AON) program awarded a 5-year research grant to a collaborative team from the University of Maryland Center for Environmental Science, Clark University, and the Woods Hole Oceanographic Institution to provide support for standardized sampling in all five DBO regions. That same year, the Interagency Arctic Research Policy Committee (IARPC) developed

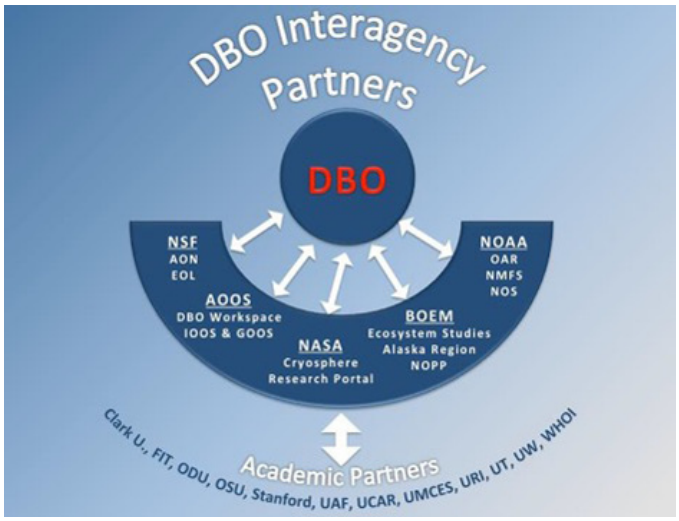

FIG 2. Government agency and academic partners collaborating in support of the DBO, via the U.S. Interagency Arctic Research Policy Committee (IARPC). See Appendix 1: Table S1 for an abbreviated list of contributions and Table S2 for a list of acronyms.

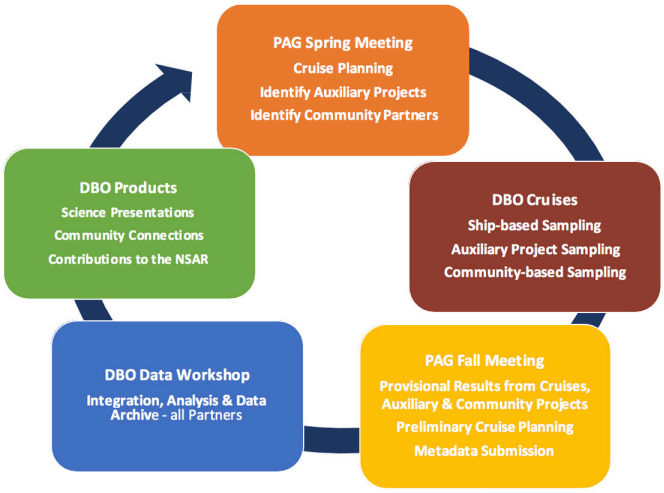

FIG 3. Five-step annual cycle for implementation of the DBO, from cruise planning to products.

a 5-year plan focused on seven research themes. The DBO Collaboration Team (CT) was formed under the first theme, Sea Ice and Marine Ecosystems, and met via teleconference through 2016 to guide the DBO from a pilot phase to the development of a decadal-scale implementation phase (http://www.iarpccollaborations.org/teams/Distributed-Biological-Observatory). In this paper, we summarize key partnerships, products, and science contributions achieved in support of developing the DBO as a regional ocean observatory for the Pacific Arctic. We also outline future activities to both enhance the DBO and to connect it to a pan-Arctic network of environmental observatories.

PILOT PHASE, 2010–14

Support from the PAG was essential to the success of the DBO pilot phase (http://pag.arcticportal.org/). PAG is a consortium of international institutions and individuals having a Pacific perspective on Arctic science. Organized under the aegis of the International Arctic Science Committee (IASC), the PAG has a mandate to serve as a Pacific Arctic regional partnership to plan, coordinate, and collaborate on science activities of mutual interest. The PAG meets each spring and autumn and has taken a leadership role in coordinating international and industry-based contributions to DBO sampling, including the provision of ship time at no cost. These international contributions to DBO sampling have provided an unprecedented capability to track inter- and intra-annual variability in DBO regions. Specifically, of the 51 cruises that contributed to DBO sampling during the pilot phase, 16 (31%) were conducted by non-U.S. colleagues, thereby contributing directly to an increased capacity to track variability in the DBO region (e.g., Itoh et al., 2015; Nishino et al., 2016). A listing of DBO cruises is developed at the annual PAG spring meeting and is available on both the PAG and NOAA DBO websites (http://www.pmel.noaa.gov/dbo/cruise-data). Subsequently, provisional results of each year's sampling are reported at the PAG fall meeting, which form the basis for science presentations given at various national and international meetings.

U.S. AGENCY AND ACADEMIC PARTNERS

Since its inception, the DBO has benefitted from strong support and collaboration from a number of US agencies and academic partners, coordinated by the IARPC DBO CT (Fig. 2). Five government agencies were especially helpful in providing a foundation for DBO activities: NOAA, the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), BOEM, and AOOS (Alaska Ocean Observing System). The North Pacific Research Board (NPRB) also provided resources in support of DBO sampling, with contributions to oceanographic sampling beginning in 2017. An abbreviated listing of contributions, accompanied by web links to sources of supplementary information is provided in Appendix 1: Table S1. Table S2 provides a list of acronyms.

Key Products

There have been numerous presentations and special sessions on the DBO at multiple science and policy venues since the initiation of the pilot phase. While a full listing of these activities goes beyond the scope of this paper, a summary of meetings (including three DBO Data Workshops) and significant findings are provided here: (https://www.pmel.noaa.gov/dbo/workshop-products).

A few examples of key products—such as workshops, data agreements, data archives, presentations and papers—that resulted from these meetings include:

- DBO Data Policy and Release Guidelines (2015): http://dbo.eol.ucar.edu/data_policy-dbo.html
- NCAR/UCAR/EOL DBO Data Archive (2010): https://www.eol.ucar.edu/field_projects/dbo
- Satellite products for the DBO (Comiso et al., 2017): http://neptune.gsfc.nasa.gov/csb/index.php?section=270
- Plenary presentations at various science meetings (e.g., American Geophysical Union, the Association for the Sciences of Limnology and Oceanography, Ocean Sciences Meeting, the NSF Arctic Observing Network, and the Alaska Marine Science Symposium)
- Peer-reviewed publications (e.g., Grebmeier et al., 2015a, b; Itoh et al., 2015; Grebmeier and Cooper, 2016; Nishino et al., 2016; Yamamoto-Kawai et al., 2016).

IMPLEMENTATION PHASE, 2015–24

Increasing interest in the DBO led to discussions within the IARPC CT to extend DBO sampling to regions in the Beaufort Sea. Where possible, Beaufort Sea sampling transects and regions were centered on areas of high productivity and biodiversity (Fig. 1: regions 6–8), as in the northern Bering and Chukchi Seas. Other factors considered in the selection of the new regions included: (1) availability of long-term data; (2) linkages to other programs; and (3) willingness of IARPC CT and other partners to participate in DBO sampling and data sharing. In 2014, draft maps of provisional DBO sampling sites were prepared and circulated among the IARPC CT and other interested colleagues for discussion and revision. By 2015, three new DBO regions were agreed upon for the Beaufort Sea, with locations embedded in a web-accessible map (https://www.pmel.noaa.gov/dbo/dbo-stations). This expansion of standardized sampling into the Beaufort Sea was a significant step in the process of developing a decadal-scale implementation plan.

FIVE-STEP ANNUAL CYCLE

Since the launch of the DBO, the PAG semi-annual meetings have been essential to field season planning, provisional data exchange, and collaboration on science products on an international basis. The annual cycle for of DBO activities (Fig. 3) proceeds in five steps:

- PAG Spring Meeting: The spring meeting coincides with the Arctic Science Summit Week (ASSW) of IASC, and includes a review of ongoing studies in the Pacific Arctic region and the initiation of the annual DBO Sampling Table, where planned DBO sampling is tabulated, and auxiliary research projects that can provide DBO-related data are identified. During the implementation phase, a new goal of identifying community partners will be initiated.
- DBO Cruises: Ship-based sampling is completed on various cruises from July to October, and DBO-related sampling is completed on various auxiliary and community-based projects.
- PAG Fall Meeting: The fall meeting often coincides with related Arctic science meetings and provides an opportunity to report actual DBO cruise sampling and related outcomes from auxiliary and community-based projects, along with preliminary field plans for the following year. During the implementation phase, a new goal of submission of metadata beyond the current DBO parameter file will be established.
- DBO Data Workshops: Three DBO Data Workshops have provided an opportunity for presentation of provisional results, multidisciplinary discussions, and planning for the data archiving. During the implementation phase, an annual DBO Data Workshop has been identified as a key activity in support of data integration, analysis, and archiving.
- DBO Products: These have included science presentations and community outreach at various annual science meetings and during informal discussions with agency and academic leaders. During the implementation phase, the goal of augmenting community connections to include active participation by local observers of biological change will be sought, via linkages with established community observing networks (e.g., the Community Observation Network for Adaptation and Security (CONAS), Exchange for Local Observations and Knowledge of the Arctic (ELOKA), and the Alaska Arctic Observatory & Knowledge Hub (AAOKH).

This annual cycle of DBO activities was developed iteratively during the pilot phase and has proven very effective at coordinating key activities associated with efficient annual sampling and reporting. It is anticipated that adherence to this cycle will foster success during the DBO implementation phase. As noted above, three important additions to the cycle for the implementation phase includes (1) a requirement for all contributors to upload DBO parameter files to the DBO data archive before or immediately after the PAG autumn meeting, (2) the conduct of an annual DBO Data Workshop, and (3) the goal of building connections with existing community-based observation programs, as described below.

CONNECTING TO COMMUNITY PROGRAMS

The development of a long-term implementation plan is an opportune time for the DBO to foster connections to existing community-based observation programs, in an effort to link offshore observations of biological change based on conventional science to local observations and Indigenous Knowledge. The term ‘Conventional

TABLE 1. Anticipated products and target dates for the development of a periodic Pacific Arctic Regional Marine Assessment (PARMA).

Product	Target date
Annual DBO Workshop	2017–23
Special Issue of DSR II: "The DBO – results since 2010"	2017
PARMA Guidelines: development and vetting	2017
Produce the 1st Pacific Arctic Regional Marine Assessment	2018
Revise PARMA @ 3-year intervals	2021, 2024
PARMA Review and Linkages to pan-Arctic assessments	2019
IARPC-IASC Panel Review at 3-year intervals	2020, 2023

Science' (CS) is used here to indicate standard practices undertaken by researchers with academic training in a science discipline and is used as a more inclusive term than 'Western Science.' The term 'Indigenous Knowledge' (IK) as used here is taken from the Inuit Circumpolar Council-Alaska food securities report (ICC, 2015:15), which states "Indigenous Knowledge is a systematic way of thinking applied to phenomena across biological, physical, cultural and spiritual systems." One approach toward the goal of linking CS and IK approaches is to identify communities close to DBO regions where local observations are already underway: e.g., Gambell, Savoonga, Wales, Diomede, Point Hope, Point Lay, Wainwright, Barrow, and Kaktovik. A second step is to initiate a dialogue with participants in existing local observing programs to explore areas of synergy between coastal and DBO sampling, which can be identified and acted upon. Identifying commonalities in approach between CS and IK should facilitate better connections between these two approaches toward understanding the Pacific Arctic marine ecosystem.

One key commonality of interest by practitioners of both CS and IK is the depiction of seasonal events within an annual cycle (Moore et al., 2016). This temporal approach to CS sampling and IK observations provides a connection in thinking about the marine ecosystem, essential to the development of a common understanding of the region.

Over the past decade of rapid environmental change, several community-based programs have been initiated to foster the inclusion of IK and local observations in assessments of changes in Arctic ecosystems (e.g., Johnson et al., 2015; Sigman, 2015). Three examples include the U.S.-based CONAS and ELOKA programs, and the Canadian-based Circum-Arctic Coastal Communities Knowledge Network (CACCON) program, which are briefly summarized below:

- CONAS consists of systematic observations made by subsistence hunters, fishermen, and other leaders from eight coastal communities in the Bering Sea (http://www.bssn.net). The existing network is comprised of three villages in Chukotka and five in Alaska, including Gambell and Savoonga on St. Lawrence Island (near DBO regions 1 and 2). The CONAS is funded by the NSF, is planning to expand northwards to include coastal villages along the Chukchi and Beaufort Seas, and has expressed an intention to partner with the DBO and AOOS.
- ELOKA was launched during the 2007–09 International Polar Year, with funding from NSF/Arctic Social Science program, to facilitate the collection, preservation, exchange, and use of local observations and knowledge of the Arctic. ELOKA continues to support a number of community-based observations and includes a long list of partner organizations including AOOS (http://eloka-arctic.org/).
- CACCON ("Catch-ON") is a new initiative aiming to build knowledge hubs to support, sustain, and share adaptation for coastal communities (http://caccon.org).

There are many other community-based programs (e.g., the Local Environmental Observer Network (LEO), the Sea Ice for Walrus Outlook (SIWO) program, and Coastal Community Ocean Observers (C2O2), where synergistic connections to the DBO might be fostered. In particular, a new initiative to support community observations and information sharing is the Alaska Arctic Observatory & Knowledge Hub (AAOKH; http://www.arctic-aok.com). This 5-year program will focus initially on the cryosphere and likely include aspects of several local observation programs already underway in the Alaskan Arctic. With a common focus on building knowledge hubs, the AAOKH and CACCON programs may provide a framework that can be applied in a pan-Arctic context.

PERIODIC ASSESSMENT OF THE PACIFIC ARCTIC MARINE ENVIRONMENT

The goal of the DBO implementation phase is to establish guidelines for the periodic assessment of the physical and ecological state of the Pacific Arctic marine environment. Notably, the DBO was launched in 2010 to assess how biodiverse 'hotspots' of marine organisms are responding to rapid physical changes in the Pacific Arctic region (Grebmeier et al., 2010). We envision the development of a Pacific Arctic Regional Marine Assessment (PARMA) as comprised of three product-focused steps: (1) an annual workshop supportive of evaluating the current state of the Pacific Arctic ecosystem, (2) completion of a PARMA at 3-year intervals, and (3) a review of the PARMA by national and international colleagues, in anticipation of its inclusion in pan-Arctic environmental assessments (see Table 1). As noted earlier, an annual DBO workshop is considered an essential component of this process. Annual workshops serve as fora where provisional results are reviewed and steps towards data integration and multidisciplinary synthesis are initiated. For example, at the 2016 workshop, participants agreed to a goal of producing a DBO-focused special issue of a peer-reviewed journal based on science discoveries achieved thus far. Initial discussions of

TABLE 2. Potential contributions to the DBO Implementation Phase from U.S. agencies, academic institutions, and industry.

Agency	Potential contributions
NOAA	Continue DBO sampling during AMBON cruises, on AFSC fisheries research cruises and with NOS-charting assets (e.g., *Fairweather*) whenever possible; support and host an annual DBO workshop; publish the Executive Summary of the PARMA as a contribution to the Arctic Report Card.
NSF	Continue support of DBO sampling in all regions, and support of the DBO Data Archive; establish a DBO Program Office.
NASA	Further refinement of DBO Cryosphere products, as needed. Note that satellite sea surface height and sea surface salinity are currently being added to augment existing DBO-focused data products. Also, NASA may provide coordination of sampling from shipboard programs (e.g. Arctic-COLORS), which may be developed over the next decade.
BOEM	Continue support of DBO sampling during all research programs in the Pacific Arctic whenever possible.
AOOS	Continue support of long-term biophysical mooring in the NE Chukchi Sea and initiate support for biophysical moorings in the Beaufort and northern Bering Seas; enhance DBO Workspace and linkages to DBO Data Archive; assist in the development of visualization products in support of the PARMA.
NPRB	Continue support of long-term biophysical mooring in the NE Chukchi Sea, as part of the Long-Term Monitoring Program; initiate DBO sampling during research programs funded via the Arctic Program.
ONR	Contribute to DBO sampling during research programs in the Pacific Arctic.
Academic Contributions	Universities provide research and delivery of peer-reviewed science, via support from U.S. Agencies; streamline funding processes through programs such as the National Oceanographic Partnership Program (NOPP), the Long Term Ecological Research Network, and NOAA/Cooperative Institutes.
Industry Contributions:	
– NOPP	Following the AMBON example, develop an inter-agency and industry call for a 10-year program of DBO support, in response to Integrated Ecosystems Assessment (IEA) goals common to all contributors.
International support and coordination:	
– PAG	Continued support of semi-annual meetings.
– IASC	Initiate inclusion of PARMA review at annual meetings of the IASC-Marine Working Group.
– Arctic Council	Integrate the PARMA in the work of CAFF/CBMP, PAME/EA, and other Working Groups.

PARMA guidelines will be refined and approved at the next DBO data workshop.

We anticipate that the first PARMA could be completed in 2018, and suggest that the assessment then undergo a review by a panel of scientists comprised of international and national colleagues (see Table 1). One option would be to establish a review panel comprised of members of the IASC Marine Working Group (MWG) and the IARPC Marine Ecosystems Collaborate Team (MECT). This panel would provide an evaluation of the DBO's effectiveness and recommend changes that might enhance the Observatory and its contribution to a pan-Arctic framework. The effectiveness of the DBO would be evaluated with reference to the stated goals of the IASC-MWG and those of the IARPC team, including the goals of the NOAA/IOOS, NSF/AON, NASA Cryosphere, and the BOEM Alaska Environmental Studies Program, among others. The panel would complete an evaluation every third year, starting in 2019, prior to the PARMA being incorporated in a pan-Arctic assessment framework.

Long-term support will be required for the PARMA to become a reliable contribution to a pan-Arctic assessment framework during the DBO Implementation Phase. In the United States, contributions by agencies, academic institutions and industry will all be required (see Table 2). The IARPC can provide essential linkages among these entities to ensure a long-term commitment of resources. Internationally, a DBO-type transect was developed in the northern Barents Sea as part of their Strategic Initiative Arctic (SI-Arctic) program. In addition, the IASC-MWG supported an international workshop in 2016, which included representatives from six countries (Norway, France, Germany, Great Britain, Poland, and the United States), to initiate the development of an Atlantic-focused DBO. Workshop participants completed a draft plan for standard sampling on transects in five DBO regions in the northern Barents Sea. This international support and participation can likely be bolstered by also linking the PARMA into the work of the Arctic Council via activities of the Circumpolar Biodiversity Monitoring Programme (CBMP) of the Conservation of Arctic Flora and Fauna (CAFF) and the Protection of the Arctic Marine Environment (PAME) activities, among others.

Ultimately, the effectiveness of the DBO at assessing the physical and ecological state of the Pacific Arctic will be demonstrated by contributions to science and to management and policy decisions. In the seven years since its inception, the DBO has demonstrated the value of integrated multidisciplinary sampling towards the goal of detecting links between physics and biology in a rapidly changing marine ecosystem. The maintenance and potential expansion of the DBO can serve as an essential framework upon which to build capability for a fully pan-Arctic ocean observatory.

ACKNOWLEDGEMENTS

This document is a revised and expanded version of a White Paper, vetted by the IARPC DBO CT and submitted to the 2016 Arctic Observing Summit (AOS). We thank all the members of the DBO CT for their contributions to the White Paper, and to the DBO Implementation Plan from which it was drawn. This paper includes new text, especially suggestions for development of the PARMA, which has not been vetted by the IARPC DBO CT or any US agency personnel, and thus is solely the opinion of the authors.

APPENDIX 1

The following supplementary tables are available at: http://arctic.journalhosting.ucalgary.ca/arctic/index.php/arctic/rt/suppFiles/4606/0

TABLE S1. U.S. agency and academic partners of the IARPC DBO.

TABLE S2. List of acronyms used in Table S1.

REFERENCES

BOEM (Bureau of Ocean Energy Management). 2015. Alaska annual studies plan, FY 2016. Anchorage: BOEM, U.S. Department of the Interior. http://www.boem.gov/akstudies/

Comiso, J.C., Frey, K., Stock, L.V., Gersten, R.A., and Mitchell, H. 2017. Satellite visualization data for the distributed biological observatory (DBO). Cryosphere Science Research Portal, NASA. https://neptune.gsfc.nasa.gov/csb/index.php?section=270

Grebmeier, J.M., and Cooper, L.W. 2016. The Saint Lawrence Island Polynya: A 25-year evaluation of an analogue for climate change in polar regions. In: Gilbert, P.M, and Kana, T.M., eds. Aquatic nutrient biogeochemistry and microbial ecology: A dual perspective. Dordrecht, Switzerland: Springer International Publishing. 171–183. https://doi.org/10.1007/978-3-319-30259-1_14

Grebmeier, J.M., Moore, S.E., Overland, J.E., Frey, K.E., and Gradinger, R. 2010. Biological response to recent Pacific Arctic sea ice retreats. EOS Transactions 91(18):161–162. https://doi.org/10.1029/2010EO180001

Grebmeier, J.M., Bluhm, B.A., Cooper, L.W., Danielson, S.L., Arrigo, K.R., Blanchard, A.L., Clarke, J.T., et al. 2015a. Ecosystem characteristics and processes facilitating persistent macrobenthic biomass hotspots and associated benthivory in the Pacific Arctic. Progress in Oceanography 136:92–114. https://doi.org/10.1016/j.pocean.2015.05.006

Grebmeier, J.M., Bluhm, B.A., Cooper, L.W., Denisenko, S.G., Iken, K., Kedra, M., and Serratos, C. 2015b. Time-series benthic community composition and biomass and associated environmental characteristics in the Chukchi Sea during the RUSALCA 2004–2012 program. Oceanography 28(3):116–133. https://doi.org/10.5670/oceanog.2015.61

Holland-Bartels, L., and Pierce, B. 2011. An evaluation of the science needs to inform decisions on outer continental shelf energy development in the Chukchi and Beaufort Seas Alaska. USGS Fact Sheet 2011-3048. http://pubs.usgs.gov/fs/2011/3048/

ICC (Inuit Circumpolar Council). 2015. Alaskan Inuit food security conceptual framework: How to assess the Arctic from an Inuit perspective. Technical Report, Inuit Circumpolar Council-Alaska. http://iccalaska.org/wp-icc/wp-content/uploads/2016/03/Food-Security-Summary-and-Recommendations-Report.pdf

Itoh, M., Pickart, R.S., Kikuchi, T., Fukamachi, Y., Ohsima, K.I., Simizu, D., Arrigo, K.R., et al. 2015. Water properties, heat and volume fluxes of Pacific water in Barrow Canyon during summer 2010. Deep Sea Research Part I: Oceanographic Research Papers 102:43–54. https://doi.org/10.1016/j.dsr.2015.04.004

Johnson, N., Alessa, L., Behe, C., Danielsen, F., Gearheard, S., Gofman-Wallingford, V., Kliskey, A., et al. 2015. The contributions of community-based monitoring and traditional knowledge to Arctic observing networks: Reflections on the state of the field. Arctic 68(Suppl. 1):28–40. https://doi.org/10.14430/arctic4447

Moore, S.E., Stabeno, P.J., Grebmeier, J.M., and Okkonen, S.R. 2016. The Arctic Marine Pulses Model: Linking annual oceanographic processes to contiguous ecological domains in the Pacific Arctic. Deep Sea Research Part II: Topical Studies in Oceanography. Corrected proof available online 29 October 2016. https://doi.org/10.1016/j.dsr2.2016.10.011

Nishino, S., Kikuchi, T., Fujiwara, A., Hirawake, T., and Aoyama, M. 2016. Water mass characteristics and their temporal changes in a biological hotspot in the southern Chukchi Sea. Biogeosciences 13(8):2563–2578. https://doi.org/10.5194/bg-13-2563-2016

NOAA (National Oceanic and Atmospheric Administration). 2014. NOAA's Arctic Action Plan: Supporting the National Strategy for the Arctic Region. Silver Spring, Maryland: NOAA, U.S. Department of Commerce. 30 p. https://www.afsc.noaa.gov/publications/misc_pdf/noaaarcticactionplan2014.pdf

Sigman, M., ed. 2015. Community-based monitoring of Alaska's coastal and ocean environment: Best practices for linking Alaska citizens to science. Fairbanks: Alaska Sea Grant, University of Alaska Fairbanks. https://www.npfmc.org/wp-content/PDFdocuments/CM/030615/CommunityMonitoringCoastOceanEnvir.pdf

White House Executive Office. 2011. U.S. National Ocean Policy. Washington, D.C.: U.S. Department of the Interior. https://www.doi.gov/pmb/ocean/national-ocean-policy

———. 2014. Implementation plan for the national strategy for the Arctic region (NSAR). White House. January 2014. http://www.virginia.edu/colp/pdf/national-strategy-arctic-region.pdf

Yamamoto-Kawai, M., Mifune, T., Kikuchi, T., and Nishino, S. 2016. Discussion paper for: Prolonged aragonite undersaturation in bottom water of a biological hotspot in the Chukchi Sea, Arctic Ocean. Biogeosciences Discussion 13(22):1–23. https://doi.org/10.5194/bg-2016-74