PAME I-2019: Agenda 4.2
Project Proposal

Modelling Arctic oceanographic connectivity
to further develop PAME's MPA toolbox

This project proposal is a continuation to PAME's
Framework for a Pan-Arctic Network of Marine Protected Areas

The Arctic Council's Protection of the Arctic Marine Environment Working Group (PAME) released a Framework for a Pan-Arctic Network of Marine Protected Areas in 2015. This report sets out the vision for an 'ecologically connected, representative and effectively-managed network of protected and specially managed areas'. Further technical work and coordination at the pan-Arctic level is needed to advance this vision, which this proposal aims to address.

The modelling of Arctic oceanographic connectivity will support further development of PAME's MPA toolbox. It will require close collaboration with CAFF and is considered a multi-year and iterative project based on best available baseline data, incorporating new data and studies by the Arctic Council, the Arctic States and others, as relevant.

PAME recognizes that each Arctic State pursues MPA development based on its own authorities, priorities and timelines.

Project Title:

Modelling Arctic oceanographic connectivity to further develop PAME's MPA toolbox

Aim & objectives

- To further develop the PAME MPA toolbox;
- To map oceanographic connectivity in the Arctic region using biophysical modelling; and
- To identify major barriers to gene flow based on modelled marine connectivity.

Background

PAME's mandate is 'To address marine policy measures and other measures related to the conservation and sustainable use of the Arctic marine and coastal environment in response to environmental change and from both land and sea-based activities, including non-emergency pollution prevention control measures such as coordinated strategic plans as well as developing programs, assessments and guidelines, all of which aim to complement or supplement efforts and existing arrangements for the for the protection and sustainable development of the Arctic marine environment'.

PAME's Framework for a Pan-Arctic Network of Marine Protected Areas sets out the vision for an 'ecologically connected, representative and effectively-managed network of protected and specially managed areas'. Further technical work and coordination at the pan-Arctic level is needed to advance this vision. The proposed project is a tool to further develop this framework. PAME recognizes that each Arctic State pursues MPA development based on its own authorities, priorities and timelines.

This project could also help inform the scoping process that is planned in the Conservation of Arctic Flora and Fauna's (CAFF) Circumpolar Biodiversity Monitoring Program (CBMP). Therefore, this project will be in close collaboration with CAFF/CBMP, so to include the expertise from countries participating in the CBMP expert networks supported by the Arctic countries. CAFF plans to hold a marine scoping project workshop in 2019 about future monitoring of the biotic components in the Arctic marine ecosystems. This workshop could be an opportunity to share preliminary results from this project and exchange expertise and knowledge ensuring knowledge sharing of Arctic marine ecosystems. Discussions have also been held with CAFF/CBMP to have a general CAFF/PAME meeting in 2019 about marine projects, and this project could be part of such a meeting as well.

Biophysical modelling

Ongoing climate change may facilitate increased access to the Arctic region, and potential new economic opportunities, but may also bring potential challenges to the Arctic marine and coastal environments. These changes could benefit from more integrated approaches to Arctic marine management, including the consideration of MPA networks design to aid in the sustainable use of the Arctic environment.

Networks of MPAs can be one effective tool to moderate the impacts of extractive activities and local disturbance on marine ecosystems and their services (Lester & Halpern 2008). When considering the geographic boundaries of MPAs in networks, it is important to ensure that the overall network design has the capacity to protect target populations. Design criteria should engender "ecologically coherent" networks (HELCOM 2016). Key aspects of this design are management objectives of the network as a whole, as well as for individual MPAs, the geographic boundaries of individual MPAs, and how they are connected through dispersal to the ambient environment. Organisms with long-distance dispersal may require very large MPAs, or a network of smaller MPAs that can exchange dispersal stages within the network, or with surrounding areas.

More than 70% of marine invertebrates and fish disperse with large numbers of tiny larvae that may drift for days to months with the ocean circulation. Although larvae disperse passively, they may nonetheless influence their own transport through vertical migration to different depths with different current patterns. This makes it very difficult to make direct observations of dispersal in the field, although genetic methods can be used to coarsely infer dispersal. Biophysical modelling is increasingly used to estimate dispersal in the seascape. A physical oceanographic circulation model predicts how the physical water transport varies in space and time. The predicted current velocity fields are then used to simulate transport paths of virtual larvae *in silico*. This method permits the simulated "release" of many millions of virtual larvae at many spawning sites (sources), and includes temporal variability in currents on scales from days to years. These patterns are then combined with a biological model that defines the traits for a particular species (or dispersal strategy), such as spawning time, drift (planktonic) duration of the larvae, and any larval behavior, e.g. vertical migration or ontogenetic shifts in drift depth. The results from such biophysical modelling are usually summarized in a connectivity matrix where each element gives the probability of dispersal from site A to site B for each of the simulated species or dispersal strategies. For the area included in the model, the connectivity matrix fully describes connectivity for the target species (or dispersal traits) in the seascape (Cowen and Sponaugle 2009).

Design of Marine Protected Areas

Given the marine environment is highly complex, models can be useful tools to help decision makers in designing MPA networks.

These connectivity matrices help bring into focus possible ecologically coherent networks of MPAs. The first step in this process is to calculate the weighted mean dispersal distance and direction from each location. This is a good indicator to use when considering geographic boundaries and overall network design. Where there is sufficient information about the geographic distribution of a species, this can easily be incorporated into the connectivity model. Technically, the connectivity matrix is simply multiplied with a distribution matrix.

The second step is to identify possible optimal networks of (multiple) MPAs. This is defined as the network in which the joint connectivity best supports the overall network objective. The identification of optimal networks applies a new theoretical framework (Nilsson Jacobi & Jonsson 2011) based on eigenvalue perturbation theory (EPT). When the conservation objectives concern several species – perhaps a specific community – different species will often have different dispersal strategies. In such cases, each species (or dispersal strategy) will typically result in a unique optimal MPA network. However, by using a variant of the EPT framework, it is possible to identify a ‘consensus network’ that provides the optimum design for multiple species, in support of network objective(s) (Jonsson et al. 2016).

The third, and final, step in this process involves identifying dispersal barriers, such as the Lagrangian Coherent Structures, that might restrict gene flow between subpopulations. Again, the connectivity matrix is used to together with a cluster analysis where results can be easily visualized on a map as color-coded areas where color transitions indicate barriers (Nilsson Jacobi et al. 2012). Such barrier maps can be used to generate hypotheses of where important local adaptations may be present, and can also be used to ensure that areas separated by barriers are considered for inclusion in an MPA network.

Project description

We welcome and encourage engagement with Permanent Participants and the inclusion of traditional and local knowledge.

Oceanographic circulation model

We intend to use an existing oceanographic model. There are several options, but the data assimilative TOPAZ4, which includes the Arctic Sea and North Atlantic, is a possible candidate (Xie, Girshick et al. 2017). This model has been developed at the Nansen Centre in Bergen over a number of years, and as of today its operational mode is run by the Norwegian Meteorological Institute. It is the main operational model for the Arctic Sea in the marine Copernicus data portal. This model has a horizontal resolution of 11-16 km with 28 horizontal layers. Daily averaged velocity fields are available for 1991-present. It also includes wave model output, which can be used to describe wave-induced drift from 2016. All available velocity fields will be downloaded and prepared for use in a Lagrangian particle tracking model that simulates dispersal trajectories. Mean drift patterns as well as interannual variability will be analysed. Model setups with higher resolution exist, but results are not easily available for long-term analyses (i.e., they may require new production of velocity fields from the hydrodynamical model).

Particle tracking model

The Lagrangian particle model uses available model prediction of ocean currents (including Stokes drift, or the wave induced drift) to move particles in the horizontal. Ice drift can also be included if required. We will use in-house models such as an own developed code in MATLAB and/or the freely available code OpenDRIFT, that runs in a Python environment, developed by Norwegian Meteorological institute.

A critical decision for the particle tracking simulations is how many release sites to select, the number of release time points, and how many particles to release on each occasion. The first step is to identify the relevant (dominant) elements of Focal Ecosystem Components (FECs, e.g. ecological key species, species relevant for ecosystem services) and their respective habitat distributions for which connectivity will be modelled. The ideal situation is if all model grid cells that overlap with the target habitat are included as sources of particles in the Lagrangian tracking model. Initial studies will be needed to collate information about habitat distribution of key elements within FECs. The recent State of the Arctic Marine Biodiversity Report (CAFF, 2017), together with additional literature, provides a starting point from which such data can be collated, and gaps identified, e.g. on biodiversity hotspots, taxonomic composition, and key invertebrate and fish species. The project may also show how habitat use and historically important areas for seabirds and sea mammals can be linked to the results. Where habitat distribution data are absent, or have low coverage, an alternative approach is to use depth intervals to define habitat for different classes of species. Then model grid cells that represent a certain depth interval are included in the Lagrangian simulation of dispersal within each habitat. For example, depth intervals of 0-50 m, 50-100 m, 100-200 m, will represent different coastal/shelf habitats. Depending on funding, we aim to model 3-5 dispersal strategies covering a range of FECs that could benefit from MPAs. Simulation designs could take many forms, for example, to repeat each combination of dispersal strategy and habitat for 5 years and to record the trajectory position after 5, 10, 20, 30 and 60 days. Such approaches can be used to provide a suite of scenarios that encompass most of the connectivity patterns among FECs.

The dispersal trajectory data produced by the Lagrangian particle tracking model are summarized into connectivity matrices specifying dispersal probabilities between all model grid cells that represent each habitat. Each dispersal strategy and habitat combination will result in a specific connectivity matrix. With 3 habitats, 3 spawning times, 5 drift durations and 5 years this would result in 225 connectivity matrices, however we anticipate that these would be averaged over the 5 year experimental period to yield 45 mean matrices.

Calculation of dispersal range as a guide to minimum MPA size

For each model grid cell that was included in the Lagrangian trajectory model, the weighted mean of dispersal distance is calculated as an indicator of MPA minimum size to allow persistence based on self-recruitment (Jonsson et al. submitted). Minimum size will be context-dependent and vary between geographic locations, habitat distributions and for different dispersal strategies.

Identification of optimal MPA networks

Based on the connectivity matrices we will identify a preliminary set of optimal MPA networks for individual dispersal strategies for species with planktonic larvae (Nilsson Jacobi & Jonsson 2011), but also a combined network that offers conservation opportunities for multiple strategies (Jonsson et al. 2016).

Identification of dispersal barriers

Bathymetric features, habitat distribution and consistent circulation patterns may lead to dispersal barriers in the seascape with consequences for exchange of individuals and genes between sub-populations. With a newly developed clustering method, we will identify such barriers based on the connectivity matrices (Nilsson Jacobi et al. 2012). Barriers may differ among dispersal strategies and habitats. Strong barriers may indicate the presence of locally adapted sub-populations with unique genetic combinations, as exchange of individuals is fully or near-fully prevented. Weaker barriers may indicate some, but limited, exchange of individuals, which may call for separate management plans for harvested populations.

Timeline and major activities during the 2019-2020 period

The time required for computer simulations of dispersal trajectories will depend on the number of connectivity matrices that the project will produce.

1. Downloading of velocity fields from the oceanographic model (e.g. TOPAZ4), and preparation of velocity fields to drive the Lagrangian trajectory model – 2 months (100%)
2. Development of existing code for Lagrangian trajectory model – 1 month (100%)
3. Review of available data on habitat distribution of key species / elements of FEC's – 3 months (100%)
4. Simulation of dispersal trajectories and summarizing into connectivity matrices – 6 months (30%)
5. Calculation of the MPA metrics: dispersal range, optimal networks, dispersal barriers – 3 months (100%)
6. Coordination, meetings and report – 4 months (100%)

Regular meetings (in person and via phone) will be planned to maximize expert input from PAME, CAFF, and other Arctic Council Working Groups and organisations wishing to participate. The work will be presented periodically at CAFF's and PAME's biannual meetings, as well as at expert group meetings. Should the CAFF/PAME meeting on marine projects take place in 2019, this project could be part of that.

Overall estimated budget (2019-2020)

Consistent with the overall Arctic Council approach, the development of this project will be financed through voluntary contributions.

Item	Budget (USD)
Data management and trajectory simulation	65.000
Planning, calculation o MPA metrics, reporting	38.500
Review of habitats and dispersal traits	38.500
Calculation of optimal network and barriers	15.200
Travels	3.335
Hardware	1.200
Software	1.200
Estimated total	162.935

Project team structure/lead Countries

- ✓ Lead: Sweden
- ✓ Sweden welcomes co-leads that are working on oceanographic connectivity in the Arctic.

Collaboration with other Arctic Council working groups as relevant, in particular with CAFF and its Circumpolar Biodiversity Monitoring Program (CBMP).

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