The purpose of the ArcNet Analysis Technical Report is to document how the ArcNet Network of priority areas for conservation was identified and to give an overview of the analysis and steps taken to obtain the final results.

The report also serves as an index organising a number of links (numbers in brackets) to other more detailed reports and technical documents compiled during the process and gives access to metadata and data collected for the project and uploaded to the dedicated ArcNet Google Drive folder. These supporting materials are available upon request to info@arcticwwf.org.

NB: The analysis was iterative and adaptive by design and some principles, parameters and numbers evolved or were refined over the course of the project. In this report we describe only the final version of the principles, approaches to target setting, processes etc. The entire evolution of the parameters can be reviewed through the set of documents available on our Google Drive, with links embedded throughout this document.

1 WWF Russia, Moscow, Russia, bsolovyev@wwf.ru
2 Severtsov Institute of Ecology and Evolution of Russian Academy of Sciences, Moscow, Russia, platonov@sevin.ru
NB: The working title of the project was PAMPAN (Pan-Arctic Network of Marine Protected Areas) and, thus, most of the working documents use this title. For technical purposes, PAMPAN and ArcNet are synonymous.

I. Goal and objectives of the analysis
The goal of the analysis was to identify and map an ecologically representative and well-connected pan-Arctic network of priority areas for conservation (PACs) of biodiversity that operate cooperatively to support the resilience of biological diversity and ecological processes across the Arctic marine environment. In doing so, the analysis applied and build on the vision of the Arctic Council framework for a pan-Arctic network of marine protected areas (Arctic Council 2015).

The first objective of the analysis is to showcase and apply a transparent and inclusive process for the identification of the Arctic Ocean-scale network of PACs and produce resulting maps as concrete proposals for processes by competent bodies concerned with the planning and implementation of a pan-Arctic network of marine conservation areas that is integrated in an ecosystem approach to the wider seascape (Arctic Council, 2015).

Another analysis objective is to initiate and engage a community of practice in an open and inclusive process for marine conservation area network planning across the Arctic. It is emphasized that building marine protected area (MPA) networks is a process that will continue to evolve over the coming years, and that additional perspectives and knowledge can be added throughout. At present, the project focused on engagement with two communities: biological/ecological scientists and conservation scientists/planners.

The project uses a systematic conservation planning approach (Margules and Pressey, 2000) involving a series of expert-advised spatial analyses using a decision-support tool (Marxan (Ball and Possingham, 2000)) to produce analyses and candidate sites maps of a Pan-Arctic network of protected areas in a transparent, objective, and reproducible way, based on best available data.

II. Participants of the ArcNet initiative and their roles
The analysis was organized according to the following scheme (Fig. 1):
Fig. 1. Key participants, management and communication of the ArcNet analysis

Key participants and their roles were:

- The WWF steering committee supervised the process and advised participants on the principal issues;
- The project management team was involved in day-to-day project organizing and supporting issues;
- The scientific analysis team organized the analysis itself, including the work of the thematic teams, and conducting the Marxan analysis and the post-Marxan review;
- A GIS expert assisted the scientific analysis and thematic teams;
- Thematic teams included Marine mammal, Seabird, Fish, Sea-ice biota and plankton, and Benthos groups and were responsible for data collection and reviewing the respective aspects of the Marxan analysis. Each group included a lead – an expert in the relevant field- and other scientists helping them. We did not have a lead for the coastal features so a member of the Scientific Analysis Team compiled relevant data using the help of external experts.
- Independent reviewers: Scientists who reviewed data collected by the thematic teams, outputs of the Marxan analysis, our target setting approach, and the methods of analysis itself. The review process was organized by the Project Management and Scientific Analysis Teams.
- Consultants: The Project Management team, the Scientific analysis team and the thematic leads consulted independent experts at all stages of the analysis, from identifying the principles and approaches to helping with obtaining necessary data and discussion of the outputs.

A full list of key participants is available (II.1).
III. Introduction and main steps

The ArcNet project started in May 2017; its main principles and approaches were identified in January 2018; the thematic leads identified and started their work in February 2018, the first Marxan analysis was done in June 2018 and the last one included in this report in November 2019. The outputs were finalized in March 2020.

No field data was collected; the study was based on existing data, both published and unpublished. Marxan software was selected as a decision support tool to structure and process data and assist experts in identifying the priority areas for conservation. The work was organized around a series of workshops. In between meetings experts continued to work individually and in groups.

The main steps of the analyses were:

1. Identify principles and inputs of the analysis including the geographical scope, scale, criteria for Conservation Features selection etc.
2. Identify Conservation Features (CFs) to be represented in the analysis in the context of long-term conservation of Arctic marine biodiversity.
3. Collect spatial data sets that are sufficiently consistent to serve as surrogates for CFs across the Pan-Arctic region.
4. Set quantitative conservation targets for individual Conservation Features
5. Conduct several iterations of a spatial analysis using all above mentioned data and parameters, with associated internal and external expert reviews, to map scenarios of a Pan-Arctic network of areas. This involves setting and reviewing parameters and formulating objectives for the Marxan analyses.
6. Interpret the outputs of the analysis and provide technical description for each PAC.

In the following sections details for each of these steps is presented.

1. Principles and inputs of the analysis
1.1. Geographical scope of the Analysis

The general geographical scope of the ArcNet analysis is the Arctic Large Marine Ecosystems’ (LMEs) southern borders (PAME, 2013). Based on the advice from ecological scientists to i) focus on the Artic realm, to ii) make the ArcNet analysis more feasible and to iii) reduce overlap with other potential ocean analyses the project team decided to exclude the Faroe Plateau LME, Norwegian Sea LME, Aleutian Islands LME, West Bering Sea LME, and the East Bering Sea LME. Figure 2 depicts the geographical scope of the ArcNet analysis.

The only area where the study area border deviates from LME borders is the Bering Sea shelf. Only the shelf portion of this LME is included as a part of the ArcNet analysis (approximately) according to Marine Ecosystems of the World (MEOW) (Spalding et al., 2007).

1.2. Spatial Resolution

Determining the planning unit (PU) size is guided by the following criteria:

- Data quality used for the analysis: planning units should be no finer than the supporting data,
- The size of the analysis region: a PU should have a size appropriate to the size of the study area.

Taking into account the size of the ArcNet analysis region (more than 17 million Km$^2$) and the issue of the data quality (which will vary between different datasets and between sub-regions), a planning unit edge size of 30 km (i.e., planning units of 900 km$^2$) was selected. The total number of units across the Arctic planning region thus is 22,678. A square shape of PUs is chosen for simplicity.

### 1.3. Objectives and criteria for selecting conservation features

Conservation features (CFs) are usually defined as the features that constitute important biological, ecological and socio-ecological elements of the system under analysis. In other words, a CF is a measurable, spatially definable component of biodiversity that is to be conserved within a planning network. CFs are the subjects of the analysis of areas of conservation interest, and in general they also are the features that a Pan-Arctic network of PACs will aim to conserve. In aiming to design a network of PACs, two objectives were set to guide the selection of CFs:

1) Representativeness. Include features that are representative of the system’s diversity.
2) Distinctiveness. Include features that are special, critical, rare, unusual, or unique.

Four general ecological categories and their spatial representations were considered to create a list of representative and distinct CFs:

- Species (populations) and their habitats,
- Communities and their biotopes,
- Biogeocenoses and seascapes,
- Ecosystem functions and the areas representing them.

Populating these CF categories was informed by internationally accepted criteria for identifying important areas for conservation (CBD EBSA/ IUCN MPA/IMO PSSA – a summary table for these criteria can be found in Arctic Council, 2015):

- Uniqueness or rarity,
- Special importance for life history stages of species,
- Importance for threatened, endangered or declining species and/or habitats,
- Vulnerability, fragility, sensitivity, or slow recovery,
- Biological productivity,
- Biological diversity,
- Representation of biogeographic “type” or “types”,
- Ecological integrity (supporting ecosystem structure and function).

With a focus on a warming Arctic we added a criterion on refugia (Morelli et al., 2016):

- Special importance for refugia: features supporting habitat stability or species persistence because of locally unique combinations of physical characteristics, such as climate variables, oceanography, or topography.

We furthermore added a social-ecological criterion:

- Species, populations (and their key habitats) of special importance for human coastal communities, including indigenous communities.
Table 1 below lists examples of CF sets linked to the above selection objectives and criteria.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Criteria</th>
<th>CF sets (examples)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Representativeness:</strong> Typical features of the system’s diversity.</td>
<td>Examples of all natural marine habitats/biotopes, including pelagic, sea-ice (sympagic) and benthic. Examples of zoogeographic units</td>
<td>Units of benthic, pelagic and sympagic regionalization schemes</td>
</tr>
<tr>
<td><strong>Distinctiveness:</strong> Significant, rare, unusual, or unique features</td>
<td>Areas of high biomass or elevated biological productivity</td>
<td>Polynyas, estuaries, kelps areas</td>
</tr>
<tr>
<td></td>
<td>Areas of high species and/or habitat diversity</td>
<td>Sea pens areas, deep sea coral gardens, sponge distribution areas, Zostera communities, multiyear ice</td>
</tr>
<tr>
<td></td>
<td>Key habitats of species with high biomass and special importance for the Arctic ecosystem and their geographic and genetic variations (diversity)</td>
<td>Spawning, breeding areas, feeding grounds of populations and geographical forms of key Arctic species of fish, seabirds and marine mammals</td>
</tr>
<tr>
<td></td>
<td>Ranges and key habitats of rare species or group of species (communities) and their geographic and genetic variations (diversity)</td>
<td>Spawning, breeding areas, feeding grounds of populations and geographical forms of rare, unique Arctic species or communities of fish, seabirds and marine mammals</td>
</tr>
<tr>
<td></td>
<td>Vulnerable, fragile, sensitive, or slow recovery biotopes, habitats /biotopes, areas</td>
<td>Vulnerable Marine Ecosystems, glacial fjords</td>
</tr>
<tr>
<td></td>
<td>Biotopes with high rates of C sequestration</td>
<td>Kelp areas, sea grass communities, salt marshes</td>
</tr>
<tr>
<td><strong>Refugia for Arctic marine species /communities/ ecosystems</strong></td>
<td></td>
<td>Resilient Arctic habitats/biotopes/features expected to be persistent for the coming decades (e.g. zones of persistent multiyear sea-ice, glacier termini)</td>
</tr>
<tr>
<td><strong>Special importance for coastal renewable resource communities, including indigenous communities</strong></td>
<td>Key subsistence species for indigenous communities, and their habitats</td>
<td>Spawning, breeding areas, feeding grounds of populations and geographical forms of species of fish, seabirds and marine mammals important for coastal communities, including indigenous communities</td>
</tr>
</tbody>
</table>

### 1.4. Marine conservation features that bridge land and sea

In general, we include into the analysis habitats and biotopes located below the high tide mark. However, we also included important habitats of marine mammals and seabirds (bird cliffs, haul out and denning sites) even though they are located above sea level. We also included salt marshes, estuaries, brackish lagoons, and other semi-closed water areas that are connected to the sea. This means, for example, that anadromous and semi-anadromous fish species and their habitats in water areas directly
adjacent to the sea are included on the list of Conservation Features, but not their potential upstream reproduction habitats.

1.5. Ecological (trophic) connectivity

The planned network is supposed to consider and reflect the ecological (trophic) connectivity for the protected Arctic ecosystems.

To ensure that all important trophic components are included in the CF list, we carried out a pre-analysis expert review. Before we started Marxan runs, we asked Dr. HR. Skjoldal as an expert of Arctic marine ecosystem structure to go through the list and identify, and point out to the thematic leads, possible gaps in the CF list. Dr. Skjoldal confirmed that the list of CFs is comprehensive with regard to trophic connectivity.

Dr. Skjoldal’s comments are available (1.5.1).

1.6. Geographic connectivity

The connectivity between habitats of free-swimming organisms (marine mammals, adult life stages of fishes) was addressed by identifying important spatially restricted migration bottlenecks (see chapter 6, section “Migration bottlenecks” for the description).

The connectivity between different habitats of free-swimming and free-ranging organisms was also examined during the post-Marxan review by the thematic teams (see chapter 5, section “Post-Marxan review” for the description).

It was agreed that the geographic connectivity for drifters (larvae) will be studied during the post-analysis. The role of oceanographic currents and advection for drifters (drifting life stages of Arctic marine species/species represented in the CF list) in the Arctic Ocean should be explored and described first to give biological meaning to the existing oceanography models. This step is a prerequisite for further work improving the connectivity of the network of PACs for these organisms.

1.7. Data-deficient conservation features

Spatial data for species and biological communities are often not comprehensive or lack the desired level of detail. While this is a general issue, it is also particularly true for species and communities of the Central Arctic Ocean LME. This paucity can potentially cause the underrepresentation of typical (notably incl. high-Arctic) species or communities in the analysis (e.g. Arctic cod, compared to Atlantic salmon).

To mitigate this situation, we defined typical habitats / biotopes for data-deficient Arctic species/communities based on sea ice and geomorphic variables and included these surrogates as CFs even where we don’t have direct data on these species’ distribution. We also used geomorphic, sea ice and zoogeographic regionalization units as surrogates for communities and species with data-sparse or data-deficient distribution records.

1.8. Time Period

Which Arctic should a Pan-Artic MPA network protect? The Arctic is already changing fast in many places, so constraining, and documenting the time period and collecting data accordingly is an important component of representing the spatial distribution of CFs. Specifying a specific timeframe affects both conservation feature selection and identifying surrogate spatial datasets. We suggested defining the timeframe as 1990-2020 for pragmatic reasons, as most of the data sets for the analysis were collected during this period and represent the diversity, structure and function of Arctic marine ecosystems at the present time and the most recent past.
1.9. Introduced species and non-Arctic species

We did not include invasive species, non-native (alien) or introduced species as CFs. We did, however, include some boreal elements that already inhabit the ArcNet study area in case they are seen as having an important role for the Arctic marine ecosystems, food webs, or for the local population, or have a high conservation status.

To guide the species inclusion/exclusion decision process and to make it transparent and uniform we developed the following flowchart (see Box 1).

It interprets the objectives and criteria for selecting conservation features chapter and table. As the criteria listed in the table apply both to the species’ habitats and communities’ biotopes, first the criteria relevant to the species and habitats should be selected:

a) Key habitats of species with high biomass and special importance for the Arctic ecosystem and their geographic and genetic variations (diversity)

b) Ranges and key habitats of rare species or group of species (communities) and their geographic and genetic variations (diversity)

c) Key subsistence species for indigenous communities and renewable resource economies, and their habitats and trophic linkages.

Box 1. Species inclusion/exclusion decision process flowchart

The goal of ArcNet:

“...to identify and map an ecologically representative and well-connected Pan-Arctic network of marine areas specially-managed for the conservation and protection of Arctic biodiversity that operate cooperatively to support the resilience of biological diversity and ecological processes across the Arctic marine environment with associated ecosystem services and cultural values”. Thus even there are species which inhabit ArcNet area not all of them are part of the Arctic biodiversity/ecosystem. Remember that ArcNet has a Pan-Arctic scale of analysis. That means that criteria a, b, c (above) should be interpreted from the Pan-Arctic prospective (e.g. IUCN Red List instead of national lists).

1. Is the species an Arctic endemic - inhabits Arctic only and lives exclusively in the Arctic ecosystem – interacts with / dependents on other Arctic species?

   Yes
   No
   Go to question #5

2. Is it rare, vulnerable or species in the IUCN Red List?

   Yes
   No

3. Is it species with high biomass and special importance for the Arctic ecosystem?

   Yes
   No

4. Is it key subsistence species for indigenous
Communities and renewable resource economies?

Yes ☐ No ☐

5. Does the species have populations / stocks that are Arctic endemics – inhabiting Arctic a year round and dependent on the Arctic ecosystem – other species Arctic endemics?

Yes ☐ No ☐

Go to question #2 replacing “species” with “population/stock”

6. Is this species a seasonal migrant to the Arctic – it spends a part of year in the Arctic interacting with other species of the Arctic ecosystem? This seasonal migration to the Arctic is a vital part of life history of the species or some of its populations.

Yes ☐ No ☐

Go to question #2 replacing “species” with “population/stock” if needed

7. Is this species cosmopolitan or boreal and some of its individuals or even populations present in the Arctic and sporadically interact with other species of the Arctic ecosystem? This presence in the Arctic and interaction with other species of the Arctic ecosystem is not a vital part of life history of the species or some of its populations.

Yes ☐ No ☐

Go to question # 4 Check questions # 1, 5 or 6. If not - it’ doesn’t have anything to do with the Arctic at all - OUT

Once the list of taxa (species, subspecies, stocks and populations) is compiled there is another question:

Does this species biology make it a target species for area based conservation measures? Does it have spatially constrained, locally restricted habitats?

Yes ☐ No ☐

IN ☐ OUT

for the Marxan analysis but distribution ranges of these taxa should be used in a post-analysis for the selected areas description

1.10. Dynamic features

Dynamic features are a part of the Arctic system and in a changing Arctic many of them may become even more dynamic. Some of these features, such as the sea ice marginal zone, have huge dynamic ranges over time, both within and across years. To capture these dynamic CFs in the analysis we:
- Adopted their maximum recorded spatial amplitude in the analysis (e.g. for polynyas we included the maximum extent of inter-annual variability),

- Identified and assigned representation priority for the core part(s) of dynamic features where that was possible and applicable (e.g. the most persistent and stable parts can be identified and considered as a part of a polynya CF with high confidence and importance or in Marxan terminology “high amount”),

- Set certain requirement for Marxan analysis, e.g. “to represent each CF in at least 3 sites” or as part of a post-Marxan analyses focusing on redundancy /replication,

1.11. Features supporting ecosystem resilience to a changing environment

In a time of rapid change persistent marine features that are identified as exceptionally diverse and /or exceptionally productive are also recognized to support ecosystem resilience to climate change independent of the very species that are currently present (Christie & Sommerkorn, 2012). At the present stage, ArcNet did not comprise or carry out a comprehensive analysis using this approach, but we recognized that doing so at a later stage would further improve the effectiveness of the network of PACs to strengthen ecosystem resilience to changing conditions. It should be stressed that both criteria for such an analysis, productivity and diversity, are included inter alia in the current CF selection criteria.

1.12. Other considerations

Other considerations for MPA network planning in a changing Arctic environment that are mentioned in the literature (for a summary see Arctic Council, 2017) and that were included in the ArcNet analysis are:

- To ensure that the design of PACs incorporates multiple marine ecosystems within individual sites and across the entire network. To address this consideration, we selected a high Boundary Length Modifier value (see section 5.2) to make the PACs relatively large, and also incorporated criteria of representativeness. This allowed us to track how various types of marine ecosystems are represented in the network.

- To use projected areas of multiyear ice zones and other refugia as conservation features. To address this consideration, we adopted a separate refuge criterion for CF selection (see section 1.3). Work to systematically identify refugia for CFs still needs to be carried out and success depends on the quality of coupled ocean climate models and interdisciplinary activities between modelers and biological experts. To the degree possible, we consider refugia during the post-Marxan review of the outputs (see section 5.7)

- Replication – to buffer from localized random and catastrophic events a number of replicated sites (e.g. 3-5) should be specified for each CF within each biogeographical region. Instead of a-priori specifying number of replicated sites for each CF we made sure that each CF is represented in several PACs (if possible) during the expert post-Marxan review of the outputs (see section 5.7).

- Replication – to assist biodiversity adaptation to changing conditions sites can be replicated along identified gradients of geophysical parameters or features, such as a current or a South-North coastline. Establishing suitable conservation measures for PACs identified in this way would serve as stepping stones for populations changing their range. For most of CFs we addressed this during the expert post-Marxan review of the outputs (see section 5.7).

- To select as CFs biotopes with regionally high rates of C sequestration, e.g. salt marshes, seagrasses and to a lesser extent kelp community. While protecting C sequestration is an often-
stated objective of MPA networks, process rates are comparatively small in the Arctic. To address this consideration, we adopted a dedicated criterion for CF selection (see section 1.3).

2. Conservation Features

We used the following process for creating the list of CFs:

The scientific analysis team, the project management team, the thematic leads and invited experts discussed and agreed on the set of objectives and criteria (see chapter 1, section “Objectives and criteria for selecting conservation features”).

Working with their respective teams, thematic leads developed lists of CFs for their taxonomic groups meeting these criteria. They then presented the CFs to the scientific analysis team, the project management team and invited experts and discussed them together during a workshop (Oslo, June 2018).

Once the CF list was finalized and data was collected, the thematic leads compiled reports describing and justifying the selection of CFs. The reports, the data and the CF lists (2.1) were reviewed by reviewers/independent experts (except for some coastal and sea ice features) who also advised us if any important CFs were missed. The potential reviewers were identified through recommendations from both the thematic leads and the Steering Committee and approached by the Steering Committee (2.2).

Thematic leads adjusted the CF list following the reviewers’ advice accordingly.

3. Spatial data collection

3.1. Systematic approach to data collection
Data was collected following the systematic approach we employed when we compiled the list of CFs: each thematic group was tasked to collect and produce spatial data layers and metadata for the respective CFs (Fig. 3). It was the task of thematic leads to organize work of their respective group and identify and instill missing data to amend datasets for particular CFs or geographies, for example by contacting colleagues.
3.2. Instructions
The scientific analysis and GIS groups provided the thematic leads with detailed instructions for data collection, templates and examples of data layers (3.2.1). Following the instruction thematic groups collected data and submitted it to the scientific analysis and GIS groups.

3.3. Priority of observation (field) data
Thematic teams were instructed to give priority to published observation (field) data. In case field data was missing for a certain CF, results of data-based modelling was used instead. In case neither observation data nor modelling were available, experts could use surrogate data layers (e.g. a certain sea-ice type data instead of data on a seal distribution). In a few cases raw unpublished field data as provided by the members of the thematic teams was also used.

3.4. Data processing
Data was collected by the thematic teams and submitted by the thematic leads.

The submitted data was first checked for structure and consistency by the scientific analysis team.

Then the data and the metadata were checked by the GIS expert W. Merritt. His task was to assign each data set with a unique ID, ensure that the spatial data were in the proper projection, and had an attributes table filled in (e.g. for benthic data). A GIS expert also made sure that the metadata tables were complete.

Data booklets representing each CF as a map and metadata were created from the data files and uploaded to the Google Drive (3.6.1) and are available also through the specially developed online tool Chikory.

The final check was done by a Marxan expert N. Platonov. Where necessary, corrections were made and notes and comments were incorporated into the documents for the experts (3.2.1).
N. Platonov then prepared files for the Marxan runs using purpose-made scripts (https://github.com/nplatonov/accenter/) and initiated Marxan tests. The scripts were written in R programming language (version 3.6) (R Core Team, 2020) and used for:

- Creating the grid of planning units for the agreed study area and in the selected projection (Lambert Equal Area Polar Projection);
- preparing the bound.dat file, consisting of information about planning units and their relation to each other in the created grid;
- transforming GIS data (shp-files) into the grid format;
- assigning “cost” and “status” attributes to planning units as required for a particular scenario;
- running Marxan;
- transforming Marxan outputs into GIS and graphic formats (export) and producing a range of statistics describing each particular scenario;
- producing Marxan outputs in HTML format for interactive visualization and reviewing of results.

3.5. Software

Geographic Information Systems (GIS) software ArcGIS (10.6 and other versions) (Environmental Systems Research Institute, 2018) and QGIS (versions 2.18, 3.4) (QGIS Development Team, 2018) were used for data layers’ preparation. ArgGIS was used for data organizing and processing by project managers, and for designing a data booklet. QGIS was used on its development stage for script prototyping and mapping design.

“ESRI Shapefile” (Environmental Systems Research Institute, 1998) with SRS ESRI WKT format was used for data exchange and applied for “points”, “lines” and “polygons” geometries. Polygonal layer was prepared for spatial linkage between Marxan units and GIS spatial grid.

R programming language (version 3.6) (R Core Team, 2020) was used for data management and batch scripting. R package “lwgeom” (Pebesma, 2018a) was used for validating and repairing data geometry. R package “sf” (Pebesma, 2018b, 2018c) was used for data regridding based on spatial intersection. R package “akima” (Akima and Gebhardt, 2016) was used for 2D-interpolation results of BLM/SPF parameters fluctuation. R package “ursa” (Platonov, 2020a) was used for spatial data management and visualization. GDAL utils (GDAL Development Team, 2018) were used in some cases only as an extended instrument for low-level spatial operations.

Base maps for mapping were provided with attributing information. The missing attribute information for “ursa” visualization (Platonov, 2020a) assumes using “OpenStreetMapData” (Topf and Hormann, 2018) under the Open Database License (ODbl). R Markdown (Xie et al., 2019) was used for reproducible reporting.

The decision support tool Marxan (Ball et al., 2009) was used to identify PACs. Binaries were compiled from sources v2.4.4 (Watts, 2017).
3.6. Spatial datasets

Datasets are available on the ArcNet Google Drive or through the specially developed online tool Chikory, an overview of the datasets is available in the Data Books (3.6.1).

The datasets statistics and spatial distribution are presented below (table 2 and Figure 4).

Table 2

<table>
<thead>
<tr>
<th>Group name</th>
<th>Number of species</th>
<th>Number of communities/biotopes/types of biotopes</th>
<th>Number of Conservation Features (CFs) (Distinctive-Representative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine mammal group</td>
<td>26</td>
<td>1</td>
<td>234 (234 – 0)</td>
</tr>
<tr>
<td>Birds group</td>
<td>19</td>
<td>-</td>
<td>106 (106 – 0)</td>
</tr>
<tr>
<td>Fish group</td>
<td>56</td>
<td>24</td>
<td>96 (72 - 24)</td>
</tr>
<tr>
<td>Ice habitats group</td>
<td>-</td>
<td>4</td>
<td>89 (89 - 0)</td>
</tr>
<tr>
<td>Benthic group</td>
<td>-</td>
<td>198</td>
<td>264 (54 – 190)</td>
</tr>
<tr>
<td>Coastal features</td>
<td>-</td>
<td>4</td>
<td>29 (29-0)</td>
</tr>
</tbody>
</table>
4. Quantitative conservation targets

Setting conservation targets is an essential and decisive component of the spatial analysis while it is at the same time not an absolute science but rather the result of a systematic expert-guided process using agreed criteria and approaches. Hence, these components need to be reflected in both process and documentation. In ArcNet, we focused on both achieving a consistent and knowledge-based set of quantitative targets and on carrying out and documenting a transparent and reproducible approach to target setting for MPA network planning. In this way, targets can be revisited and refined in the future, for example in national network planning.
Overall all CFs were divided into 2 groups: representative and distinctive features. Representative features include features that are representative of the system’s diversity, i.e. geomorphic features, biogeographic regionalisations.

4.1. Target-setting approach for representative features

The target-setting approach for representative features was described by Lieberknecht et al. (2010). The distribution of targets for features of the same general kind (e.g., one zoogeographic regionalisation dividing a study area into several sub-areas) falls within a continuum roughly proportional to the square root of their respective total areas:

\[
\frac{x_p}{y_p} \approx \left( \frac{x_t}{y_t} \right)^{0.5}
\]

Where the subscript:

- p represents the protected area of a given CF,
- t represents the total area of a given CF in the network.
- x is the conservation feature to which a protection target is sought,
- y is the conservation feature to which a protection target is known.

There are three sets of representative features in the dataset used for Marxan analysis 4.0:

1) Geomorphic regionalisation based on the Blue Habitats data by P. Harris et al. (2014)
2) Biogeographic regionalisation based on the benthic fauna distribution developed by V. Spiridonov
3) Biogeographic regionalisation based on the fish fauna distribution developed by N. Chernova

There is a general consensus to the target setting approach for representative features described above but there is no common understanding how to determine and justify an initial target for a CF with the highest amount because the formula above provides guidance for the balance between targets for various CFs but does not say anything about any particular numbers. There is no solid scientific basis for any minimal or initial target and, thus, the choice is often either politically-driven (e.g. 10% - Aichi target) or based on an expert advice (“the output seems to be correct”). We decided to use a different approach and take the following into consideration:

The targets for representative CFs should be relevant to the targets for distinctive CFs. For Marxan analysis version 3.0 (see section 5.1) we suggested the median target for a set of all representative CFs be similar or slightly lower than the median target for a set of all distinctive CFs in a relevant scenario, e.g. if a median target for distinctive CFs is 40%, a median target for representative CFs should be 30-40%. This conceptual justification allowed us to calculate and select an initial target for a range of representative CFs keeping in mind the balance between representative and distinctive features.

At the next step of the analysis after the post-Marxan self-review and following the external expert advice (see section 5.7), we agreed that a median target for representative features should be 2 times lower than a median target for the distinctive features. The exception is the geomorphic features for the Central Arctic Ocean Large Marine Ecosystem (except the abyssal plains). As we don’t have data for many of the
distinctive features distribution their representative features diversity serves as an important surrogate for distinctive features in the Central Arctic Ocean, justifying a comparatively higher target.

Following this logic, we calculated the median target for the distinctive features for each subset for each run of Marxan (scenario) and selected the target ranges for each of the three representative features subsets accordingly.

4.2. Target-setting approach for distinctive features

An approach to target setting for distinctive features was developed by Boris Solovyev (Scientific Analysis Team) as part of this project. The approach is based on the assumption that a target is a derivate from the following summons:

- Criteria for selection of Conservation Features identified by the ArcNet team (see Table 1).
- Suitability for area-based conservation. We take into account that there are other methods of conservation and area-based conservation is more effective for some features rather than others (e.g. a bird cliff versus an Arctic cod range, for details see below).

Distinctive features include features that are rare, unusual, or unique. They are represented by key habitats of species with high biomass and high importance for the Arctic ecosystem species, ranges and key habitats of rare species (or species having a certain IUCN Conservation Status) or group of species and distinctive communities.

The formula for target setting is:

\[
\text{Target (X)} = \frac{J(x)*(A(x) + B(x) + C(x) + D(x) + E(x) + F(x) + G(x) + H(x) + I(x) + J(x))}{L(x)}
\]

where:

- A(x)...D(x) and J(x) are relevant to the species and their habitats and ranges, and
- E(x)...I(x) are relevant to the communities and their biotopes,
- L(x) and J(x) are multipliers relevant to all the features.
- X is a given CF,
- A(x) – demonstrates the level of Arctic endemism or Arctic residency of a given CF (species).

The criterion of endemism was applied to fish and bird species and the residency criterion – to marine mammals. The reason for this is ecology of these groups – for instance, even Arctic endemic birds overwinter outside of the Arctic, at the same time some autochthonous and permanent resident Arctic marine mammal species are not Arctic endemics (e.g. beluga whale).

- B(x) – demonstrates whether a given CF (species) is a species with high biomass and special importance for the Arctic ecosystem.
C(x) – demonstrates whether a given CF (species) is a rare or likely to extinct according to IUCN Red List species. This category for birds and marine mammals was defined according to the IUCN Red List. As there are no IUCN assessments for most of the fish species, N. Chernova assessed species according to their biological characteristics and selected several species as an equivalent to the IUCN vulnerable category.

Regional assessments, assessments for particular stocks or populations done by IUCN had a priority over a species assessment.

D(x) – demonstrates the importance of a given CF (species) as a key subsistence species for indigenous and coastal communities.

Assessment was made by WWF staff from the relevant Arctic countries on population and stock basis if possible. A regional specific was taken into account.

E(x) - Areas of high biomass or elevated biological productivity

F(x) - Areas of high species and/or habitat diversity

G(x) - Vulnerable, fragile, sensitive, or slow recovery biotopes, habitats /biotopes, areas

H(x) - Biotopes with high rates of C sequestration

I(x) - Refugia for Arctic marine species /communities/ ecosystems

J(x) – demonstrates that a given CF (species) represents a small, locally restricted, stable and very well defined habitat –i.e. coastal haul out sites for walruses and eared seals, bird cliffs and seasonal aggregation core areas for some philopatric cetaceans like beluga whales, narwhals and bowhead whales, or core foraging areas for Steller sea lions or sea otters. These locally restricted habitats are among the most appropriate for being protected using area-based conservation measures.

L(x) – demonstrates whether a given CF represents a key habitat of a given species, known biotope or a general distribution range. A few poorly known species were represented by a general range which shouldn’t have as high a target as more spatially restricted key habitats.

The A(x)....I(x) represent criteria for CF selection adopted for ArcNet, and, thus, a target for distinctive features is proportional to the number of the criteria they meet.

J(x) and L(x) represent the suitability of the particular method (MPAs and other area-based conservation measures) for each CF: we take into account that there are other methods of conservation, and an area-based conservation is more effective for some features rather than others (e.g. a bird cliff versus an Arctic cod range).

As we acknowledge that a target is a derivate from the listed summons (criteria and suitability for area-based conservation), the next task is to balance them between each other.

We suggested the following ratio:

\[
J(x)^*\sqrt{(2y)*(A(x)+2C(x)+E(x)+F(x)+G(x)) + \sqrt{y^2*(B(x)+D(x)+H(x)+I(x))}} \\

\text{Target (X) = } \frac{\text{-----------------------------}}{L(x)^2}.
\]
**y**- is an amplifier. It could have any value starting from 1. It allows us to change the entire target system in a coordinated manner keeping the ratios between different CFs by increasing or decreasing **y**.

Then **B(x)**, **C(x)**, **E(x)**, **F(x)**, **G(x)** – are criteria from IUCN list of criteria for creation of a new MPA and CBD list of criteria for EBSA (https://oaarchive.arctic-council.org/bitstream/handle/11374/417/MPA_final_web.pdf?sequence=1&isAllowed=y, page 16, table 1). We gave them a higher value (2**y**) over the criteria **B(x)**, **D(x)**, **H(x)** and **I(x)** suggested by the ArcNet team as additional criteria to the list adopted from IUCN.

We also gave a higher value to the criteria **A(x)** following our decision to focus the designed network on the Arctic species and the current state of the Arctic.

As some features are more suitable for conservation by area-based measures compared to others we used the multiplier **J(x)** varying from 1 to 3, where:

- 1 is a widely distributed dispersed feature (habitat) less suitable for the area-based conservation,
- 2 is a restricted habitat suitable for area-based conservation and
- 3 is a very restricted well-studied habitat which distribution is based on in situ long term data.

**L(x)** is a criterion representing the nature of a conservation feature: **L(x)** =1 for most of the features (habitats and biotopes) and **L(x)**=2 for the general ranges.

There is a criterion of uniqueness among the ArcNet/IUCN/CBD criteria and due to the nature of this criterion, we set a high target of 50-100% depending on the data quality and how cohesive and unique the feature is. This category includes CFs unique in the scale of the entire Arctic, well defined and stable in space: Gakkel Ridge, thermal vents, spectacled eider wintering site in the Bering Sea etc.

Once all the priorities were set and the values were assigned, we ran a several scenarios to test different **y** values to select one.

We also allowed a few CF targets to be manually changed following the external expert advice and the outputs of self-review (Scenarios_Marxan_20200306e.xlsx) (4.2.1).

We calculated targets based on this approach for **y**=4, 6, 8 in Marxan 3.0 scenarios (see section 5.1). We selected targets based on **y**=6 and 8 for Marxan 4 – 4.2 scenarios. After further discussions with external experts, the thematic leads and the steering committee we calculated targets based on **y**=6, 7, and 8 (Marxin 4.4 set of scenarios). Adjustments included some minor manual corrections for a few CFs and a target increase for the Central Arctic LME representative geomorphic features.

For the final set of scenarios (Marxin 4.5) we used a set of targets calculated with **y**=6. The targets for each CF are presented in the Scenarios table (Scenarios_Marxan_20200306e.xlsx, target setting 4 tab, BQ column) (4.2.1).

Target selection for the entire set of CFs and adjustment of the particular targets was done by the thematic leads, external experts and the steering committee using the outputs of the Marxan analysis (see section 5). Therefore, the choice was “result-based” instead of “theory-based” or “number-driven”. The choice of the **y**, and the overall target system was driven by the following considerations:

- The PACs network should provide sufficient coverage for each species considered in the analysis.
• The PACs network should provide sufficient coverage for the key biodiversity and productivity areas, unique and vulnerable areas.
• The PACs network coverage should not be excessive.

5. Marxan analysis

5.1. Marxan analysis is an iterative process
Marxan is a decision support tool and we used it to help experts decide over a process of meetings, analyses and reviews/adjustments. Therefore Marxan analysis is an iterative process that should be repeated after data and parameters are added or corrected (Fig.5).

![Marxan analysis process diagram]

*Figure 5. Marxan analysis as an iterative process*

Four full test cycles were conducted:

➢ Version 1.0 (January 2019) aimed to test the initial analysis parameters and spatial datasets;
➢ Version 2.0 (March 2019) aimed to test a full dataset and the initial conservation targets;
➢ Version 3.0 (August 2019) aimed to test the datasets updated according to the data reviewers comments;
➢ Version 4.0-4.5 (November 2019-March 2020) aimed to:
  • implement comments provided by external and internal commentators by using the updated data layers and conservation targets and
  • produce a set of final Marxan outputs representing configurations of a network of potential priority areas for conservation that fulfilled all criteria and satisfied involved experts.

The outputs of each cycle (table 3) along with the input files, the scenarios and other relevant information are available (5.1.1).

Table 3

<table>
<thead>
<tr>
<th>File name</th>
<th>Description</th>
</tr>
</thead>
</table>

21
coverage.webp  Visualisation of ‘coverage’ field of ‘freq.shp’


freq.shp.zip  ESRI Shapefile with fields in attribute table: ‘sum’ - cumulative sum of PU selection in each iteration; ‘best’ - Marxan best run, ‘coverage’ - number of input thematic layers for each planning units with normalization on fraction of spatial intersection PU and layer; ‘layers’ - number of input thematic layers for each planning units without normalization on fraction of spatial intersection PU and layer

freq.webp  Histogram of planning units selection by Marxan iterations.

input.dat  Marxan ‘input.dat’ file for scenario.

occurrence.webp  Visualisation of ‘sum’ field of ‘freq.shp’

output.zip  The rest Marxan output files

output_best.csv.gz  Marxan output ‘output_best.csv’ file

output_mvbest.csv.gz  Marxan output ‘output_mvbest.csv’ file

output_penalty.csv.gz  Marxan output ‘output_penalty.csv’ file

output_penalty_planning_units.csv.gz  Marxan output ‘output_penalty_planning_units.csv’ file

output_solutionsmatrix.csv.gz  Marxan output ‘output_solutionsmatrix.csv’ file

output_ssoln.csv.gz  Marxan output ‘output_ssoln.csv’ file

output_sum.csv.gz  Marxan output ‘output_sum.csv’ file

pu.dat.gz  Marxan input ‘pu.dat’ file. If missed, then cost is 1 and status is 0.

pu.webp  Visualisation of ‘pu.dat’. Missed for missed ‘pu.dat’.

puvspr-set.png  Visualisation of each input layer with overlapping of Marxan best run results with summary of target achievement.

scenario.txt  Short textual description of scenario derived from metadata

solution-set.png  Multipanel visualisation of each Marxan iteration with output summary.

spec.dat.gz  Marxan input ‘pu.dat’ file.
5.2. Calibration

The first two Marxan cycles included calibration of the analysis itself. Calibration was carried out to test and determine a range of technical parameters of the project: the number of iterations, boundary length modifier (BLM) and species penalty factor (SPF) (Ball & Possingham, 2000; Ardron et al., 2010). The calibration process is described in detail in a separate report (5.2.2).

The number of iterations was calibrated to identify the number sufficient for Marxan to provide an optimal solution. BLM regulates clumping of the solutions, while the SPF is used to determine the significance of CF individual weights in the analysis and help Marxan reach all project targets (Ardron et al., 2010).

The optimal number of iterations was determined as $32 \times 10^6$. Optimal BLM and SPF were identified through calibration and visual analysis by the scientific analysis team and set at 0.03 and 1.2 respectively.

We did not perform similar technical calibration after the Marxan 2.0 iteration since the input spatial datasets did not change much this.

5.3. Dataset weights

All datasets were weighted for Marxan analysis. Individual CF weights do not play a major role in the analysis. Weight distribution shows general importance of individual CFs and influences integral score of the Marxan output configuration. The algorithm assigns a higher score to a configuration of outputs (potential PACs) which has more CFs with higher weights. In our analysis weight parameter served as an additional to the conservation target parameters and showed relative importance of each CF for the designed network.

We used the following approach to weight the CFs for the final set of scenarios:

Weights for distinctive features vary:

- 100 – for Arctic species and communities,
- 50 – for sub-Arctic species and communities,
- 30 – for boreal species and communities.
- Weight =50 for all representative features.

5.4. Cost

For the final set of scenarios, we used a uniform cost layer where an area of a planning unit served as a surrogate for the cost.

5.5. Locked-in planning units

For most of the scenarios we used an existing protected areas layer as locked-in planning units. Each planning unit having at least 50% of an area covered by an existing protected area was locked-in into the outputs of the Marxan analysis which means that each area considered as an already existing area-based conservation measure contributes to reaching conservation targets for respective CFs represented in this area.

An existing protected areas layer was compiled from the layer provided by CAFF working group of the Arctic Council (2017) with protected areas for Canada and Russia updated in 2019 with the help of WWF Canada and WWF Russia respectively (Fig. 6).
5.6. Sensitivity tests

A number of sensitivity tests were done along with the technical calibration.

We ran scenarios testing various data subsets such as: marine mammals, cetaceans, pinnipeds, fish, seabirds, Arctic species only, Arctic and sub-Arctic species only, all CFs excluding sea ice, distinctive features only etc. Full sets of a subset sensitivity tests and their outputs are available (5.1.1). These tests allowed thematic leads to see how their data contribute to the outputs, how the changes they make in data change the outputs, and provides general understanding of why some PACs are selected and what role they play.

We also ran scenarios testing various conservation targets - from low to high increasing them proportionally to understand how the PACs grow as the targets increase and what new areas appear as potential PACs, where and at what threshold.

We also considered scenarios having higher targets for the multiyear ice in the Canadian Arctic Archipelago and the Central Arctic Ocean LMEs.

We also ran a scenario with PUs having a lower cost in the Last Ice Area but the Steering Committee made the decision not to use this approach in the final sets of scenarios.

The results of the sensitivity tests were presented to the Steering Committee by the scientific analysis group for their consideration and to the thematic leads to make the decisions on the data, the conservation targets and the other parameters updates.
Overall the sensitivity tests helped us to better understand the spatial datasets along with the analysis parameters (from technical like BLM or SPF to conservation like targets). The tests also allowed us to better understand our conservation principles and goals for the network we worked on.

5.7. Post-Marxan review

As shown at Fig.5 we carried out a post-Marxan review with correction of data and parameters after each Marxan cycle. Post-Marxan review included physical meetings of the thematic leads and scientific analysis group, discussions of the results and consultations with external experts. The most profound and extensive post-Marxan review was undertaken after Marxan Version 3.0. The outputs of the Marxan runs were reviewed and assessed systematically by both the external Arctic experts from different Arctic countries and regions and the ArcNet thematic leads and scientific analysis team (5.7.1).

An external assessment included:

- A face-to-face meeting with DCE Aarhus University staff (Denmark) in August.
- A Zoom meeting with the authors of Audubon atlas and a number of NGO representatives from Alaska (USA) in September 2019
- A dedicated session and discussion at MARESEDU Conference in Shirshov Institute of Oceanology in Moscow (Russia) in October 2019
- A Zoom meeting with Cecilie von Quillfeldt (Norway) in October 2019
- A face-to-face 2 day meeting with Hein Rune Skjoldal (Norway) in Moscow with a detailed discussion of each area preliminary selected by Marxan in October 2019

A written request for the reviewing or commenting on Marxan outputs had also been sent to the data reviewers and consultants. We received comments from: Anthony Gaston (Canada), Oleg Karamushko (Russia) and Jorgen Christiansen (Norway-Greenland) (5.7.1).

The reviewers were asked:

- Please let us know if there are some areas that should be among the PACs but they are not listed/shown.
- Please let us know if you see any areas that should not be among the PACs but are listed/shown.
- Please let us know if you believe that any PACs should have a different shape or size.

An independent review of the target setting approach was conducted by Jeff Ardron (PacMARA, Canada) (5.7.1).

In the meantime, the thematic teams conducted a self-review. Each team had to assess the representation of each CFs in PACs and across the network of PACs against the following criteria:

- Redundancy
- Adequacy
- Resilience to climate change
- Connectivity (seasonal habitats and migration routes for active swimmers)

The self-review was done for marine mammal, bird, fish and coastal features. The review of benthic features was done separately under a simpler scheme (5.7.1).

The specially developed Accent tool was widely used for both the external and internal reviews.
“Accenter” (Platonov, 2020b) is a Shiny application (RStudio, 2013), which applies web mini-GIS for project managers and external experts to analyse Marxan results (Ball et al., 2009; Watts and Possingham, 2013). The tool allows instant querying of the ArcNet database (CF spatial data and the Marxan output) from the map, and for any planning unit or groups of planning units.

5.8. Set of Marxan scenarios 4.5

After technical parameters such as BLM (Boundary Length Modifier), SPF (Species Penalty Factor) and the Number of Iterations were set and calibrated, the sensitivity analysis for various subsets, the conservation targets and others were done; the final set of the scenarios was initiated (table 3). For the full set of metadata and scenarios parameters, please see the table Scenarios_Marxan_20200306e.xlsx, target setting 4 tab, BQ column) (4.2.1).

Table 3

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### 5.9. Outputs

The outputs of all the scenarios are available as well as the relevant shape files (5.1.1).

We also prepared high-resolution maps illustrating both the “best output” and the “selection frequency” for each scenario in graphic PNG format as well as in an interactive html format. All the scenarios outputs are available for exploration and presentations via the Accenter online tool.

Below we explain the purpose of each scenario in the final set of the Marxan analysis, showing what parameters were used and demonstrating maps with the representation of the outputs for main scenarios as both the “best output” and “the selection frequency” (sum).

“There are two most widely used solution provided by Marxan. One is called “sum solution” that reports out on all of the runs or solutions from a given scenario. This keeps track of how often each unit was involved in any solution. So if the user chooses the program to run one hundred times in a particular scenario, then the output reports on how many times any specific assessment unit is selected out of a hundred. This information is a useful way to explore the irreplaceability of units…. The other output is called “best solution” which is the most optimal run in the scenario that best meets the defined parameters. The objective function states that the best or most efficient solution will be the selected sites at the lowest total cost.” (Marine Spatial Planning)

It should be noted that every Marxan run yields a “best solution”, but even with the same parameters these solutions are not necessarily identical.

### 5.10. Scenario 33 (4.5.1). Basic scenario (Fig. 7)

This scenario considers all the available CFs (CF subset “Basic (S)”), the final set of agreed and corrected targets set (targets set “y=6 2020-03-07_CA”). All the existing MPAs are locked-in.

The purpose of this scenario is to show how the optimal network of PACs should look like practically – including all the identified CFs for all seasons and considering existing MPAs. We ran Marxan 100 times for this scenario.
5.11. Scenario 34 (4.5.2). Basic scenario not counting existing MPAs (Fig. 8)

This scenario considers all the available CFs (CF subset “Basic (S)”), the final set of agreed and corrected targets set (targets set “y=6 2020-03-07_CA”). Existing MPAs are not locked-in.

The purpose of this scenario is to show how the optimal network of PACs would look like in case there are no existing protected areas in the Arctic. We ran Marxan 100 times for this scenario.

Figure 8. Priority areas for conservation as identified in Scenario 34 and represented as a) Selection Frequency and b) Best Output
5.12. **Scenario 35 (4.5.3). Distinctive Conservation Features Only (Fig. 9)**

This scenario considers distinctive CFs (CF subset “Distinctive”), the final set of agreed and corrected targets set (targets set “y=6 2020-03-07_CA”). Existing MPAs are locked-in.

The purpose of this scenario is to show how the optimal network of PACs would look like in case we do not consider the objective of representativeness and consider for conservation measures only features that are unique, rare, having certain conservation status according to IUCN Red List and unusual. It shows how representative conservation features affect the outputs and what areas are selected primarily because they are representative. We ran Marxan 50 times for this scenario.

![Figure 9. Priority areas for conservation as identified in Scenario 35 and represented as a) Selection Frequency and b) Best Output](image)

5.13. **Scenario 36 (4.5.4). Arctic species only (Fig. 10)**

This scenario considers Arctic only species and all the representative features (CF subset “AspeciesAndHabitats”), the final set of agreed and corrected targets set (targets set “y=6 2020-03-07_CA”). Existing MPAs are locked-in.

The purpose of this scenario is to show how the optimal network of PACs would look like in case we focus on the Arctic species only. We had a lot of discussions about the importance of focusing on the Arctic species in the ArcNet and, thus, we wanted to see what the areas of primary importance for the Arctic species are. We ran Marxan 50 times for this scenario.
Figure 10. Priority areas for conservation as identified in Scenario 36 and represented as a) Selection Frequency and b) Best Output

5.14. **Scenarios 37-48 (4.5.5-16). Seasonal scenarios (Fig. 10)**
This group of scenarios considers conservation features grouped by each month of the year. For each CF, thematic leads had to provide information on the seasonality and identify the months when a CF exists and requires conservation (e.g. walrus haul out site on land that occurs only from July to October would be considered for analysis in scenarios from July to October; spawning of Atlantic capelin that happens only from March to May would be considered for analysis in scenarios from March to May). We used the final set of agreed and corrected targets set (targets set “y=6 2020-03-07_CA”) for these scenarios. Existing MPAs are locked-in.

The purpose of these scenarios was to show how optimal network of PACs would be changing through the range of the seasons and identify the most persistent areas where conservation is required year-round and some dynamic areas requiring seasonal conservation efforts. We ran Marxan 20 times for each of these scenarios.

Fig. 11 shows the most stable areas through the range of the season as areas with high mean value and low standard deviation and the most dynamic (areas important only for a particular season) areas as areas with low mean value and high standard deviation value.
6. Interpretation the outputs of the analysis

6.1. Interpretation the outputs of the analysis

After approval by the thematic leads, each set of scenarios was presented to the Steering Committee. Thematic leads corrected data and some targets if necessary and the role of the Steering Committee was to make more strategic choices – whether targets for the Central Arctic should be higher than for the rest of the ArcNet Area, how large should the identified areas be in general (how high should the average target be), should the existing MPAs be locked-in for the final set of maps, etc.

Once the parameters were identified and final run done, the network of PACs was identified.

We identified PACs based on the selection frequency map for Scenario 33 (Fig. 7) selecting all the areas with selection frequency higher than 50. We preferred selection frequency over the best output map as the latter is more random and “best” is a technical term rather than objective definition of the best configuration of PACs.

To move from the outputs of the final basic scenario Scenario 33 (Scenario 4.5.1) to the configuration of a network of PACs, we took the following steps:

- We overlapped and included the resulting configuration of PUs (all PUs with selection frequency >50 out of 100 in Scenario 33 (4.5.1) with coastal CFs including a group of coastal features such as salt marches, intertidal zones, polar bear denning areas and other habitats and cut out all the other terrestrial parts of PUs. We also kept in (included) all the areas within the existing coastal protected areas.

- In a few areas we adjusted the configuration of PACs manually. The adjustments were necessary /advisable for few areas to improve the delineation of the PAC vis-à-vis how well particular planning units matched with the coastline. Overall manual correction did not exceed 1% of the total PACs area.
➢ After this we calculated “target achievement” for each CF to see if all conservation targets are met. According the calculated table some of the CF did not meet their targets in a network of PACs based on the selection frequency >50 out of 100 even they meet targets in the “best solution” output (see the table) (6.1.1). Because of this we checked each CF not meeting the targets to see what the reason is this and adjusted some of the PACs adding PUs selected in the “best solution” map and not selected in the “selection frequency” map. These were just minor adjustments resulting in 44 000 km² (<1%) increase in total area of the network (Fig. 12).

➢ We divided the resulting areas in 83 PACs cutting some large areas in two or three. While these separations were carried out following geomorphology or oceanography arguments, they were done solely to make description and further discussions and analysis for these PACs easier (e.g. area in the north-east of Greenland was divided in two – one along the northern coast of Greenland and another one – along the eastern coast of the island); they can be merged again for future analyses.

Fig. 12. Configuration of PACs before and after they were manually adjusted and divided

6.2. Migration bottlenecks

In a separate process thematic leads identified important migration bottlenecks for vertebrate species. It had been decided earlier that traditional area-based conservation measures should be focused on the
more static seasonal habitats like feeding and breeding areas and not extensive migration routes often lasting for thousands of kilometres. At the same time, we noted that there are some important spatially restricted areas where animals pass during their migrations. These areas are normally straits of critical importance as animals gather here in high density at certain time of the year and probably cannot avoid them. These migration bottlenecks are or could be important for shipping and, thus, are or become areas of potential conflict with economic use. It may be problematic to establish a conventional protected area in an important strait so we decided not to include migration bottlenecks as conservation features in the Marxan analysis to identify a network of PACs. Rather, we identify them as priority areas in a separate systematic process and dedicate them also to an envisaged separate follow-up process for establishing conservation measures.

Each thematic lead had to identify important bottlenecks and list species migrating throughout noting the months animals use them. The tables from each thematic lead were merged and the final table and the map was produced (6.2.1). Contours of the bottlenecks were approved by the thematic leads and overlaid with the PACs as a separate category of priority areas (Fig. 13).
Fig. 14. ArcNet – an Arctic Ocean Network of priority areas for conservation

Figure 14 shows final configuration of PACs and Migration Bottlenecks.

Below we present some statistics characterizing identified network (Tables 4-6).

Table 4

ArcNet PACs areas for each EEZ within the ArcNet Area
<table>
<thead>
<tr>
<th>Exclusive Economic Zone (EEZ)</th>
<th>Total area of EEZ within ArcNet, mln² km</th>
<th>ArcNet PACs, mln² km</th>
<th>ArcNet PACs, % of EEZ</th>
<th>Total area of existing PAs (marine parts) within ArcNet area, mln km²</th>
<th>% of EEZ within ArcNet covered by PAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russia</td>
<td>4.516</td>
<td>1.104</td>
<td>24.446</td>
<td>0.165212</td>
<td>3.658</td>
</tr>
<tr>
<td>Spitsbergen/Svalbard</td>
<td>0.706</td>
<td>0.339</td>
<td>48.017</td>
<td>0.074676</td>
<td>10.577</td>
</tr>
<tr>
<td>Norway (Continental)</td>
<td>0.293</td>
<td>0.098</td>
<td>33.447</td>
<td>0.001039</td>
<td>0.354</td>
</tr>
<tr>
<td>Norway (incl. Spitsbergen/Svalbard and Jan Mayen)</td>
<td>1.171</td>
<td>0.592</td>
<td>50.555</td>
<td>0.080</td>
<td>6.824</td>
</tr>
<tr>
<td>Jan Mayen</td>
<td>0.172</td>
<td>0.155</td>
<td>90.116</td>
<td>0.004199</td>
<td>2.441</td>
</tr>
<tr>
<td>Canada</td>
<td>3.961</td>
<td>1.611</td>
<td>40.672</td>
<td>0.556893</td>
<td>14.059</td>
</tr>
<tr>
<td>Denmark (Greenland)</td>
<td>1.795</td>
<td>0.799</td>
<td>44.513</td>
<td>0.078029</td>
<td>4.347</td>
</tr>
<tr>
<td>United States Exclusive Economic Zone (Alaska)</td>
<td>1.279</td>
<td>0.484</td>
<td>37.842</td>
<td>0.089944</td>
<td>7.032</td>
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<tr>
<td>Iceland</td>
<td>0.420</td>
<td>0.092</td>
<td>21.905</td>
<td>0.002749</td>
<td>0.654</td>
</tr>
<tr>
<td>Central Arctic Area Beyond National Jurisdiction</td>
<td>2.806</td>
<td>0.406</td>
<td>14.469</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total ArcNet Area (incl. land)</td>
<td>22.367</td>
<td>5.868</td>
<td>26.235</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Total ArcNet Area (marine)</td>
<td>16.392</td>
<td>5.087</td>
<td>31.033</td>
<td>0.972</td>
<td>5.929</td>
</tr>
<tr>
<td>ArcNet Marine Area within EEZ</td>
<td>13.088</td>
<td>4.682</td>
<td>35.773</td>
<td>0.972</td>
<td>7.426</td>
</tr>
</tbody>
</table>

Table 6

ArcNet PACs areas for each EEZ within the CAFF Area

<table>
<thead>
<tr>
<th>Exclusive Economic Zone (EEZ)</th>
<th>Total area of EEZ within CAFF. mln² km</th>
<th>ArcNet PACs. mln² km</th>
<th>ArcNet PACs. % of EEZ</th>
<th>Total area of existing PAs (marine parts) within CAFF area. mln km²</th>
<th>% of EEZ within CAFF covered by PAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spitsbergen/Svalbard</td>
<td>0.795</td>
<td>0.339</td>
<td>42.64</td>
<td>0.074676</td>
<td>9.393</td>
</tr>
<tr>
<td>Russia</td>
<td>5.007</td>
<td>1.104</td>
<td>22.05</td>
<td>0.199842</td>
<td>3.991</td>
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<tr>
<td>Norway (Continental)</td>
<td>0.549</td>
<td>0.098</td>
<td>17.85</td>
<td>0.001994</td>
<td>0.363</td>
</tr>
<tr>
<td>Norway (incl. Spitsbergen/Svalbard and Jan Mayen)</td>
<td>1.637</td>
<td>0.592</td>
<td>36.16</td>
<td>0.080869</td>
<td>4.940</td>
</tr>
<tr>
<td>Jan Mayen</td>
<td>0.293</td>
<td>0.155</td>
<td>52.90</td>
<td>0.004199</td>
<td>1.433</td>
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<tr>
<td>Canada</td>
<td>3.898</td>
<td>1.512</td>
<td>38.79</td>
<td>0.535727</td>
<td>13.744</td>
</tr>
<tr>
<td></td>
<td>Total area.</td>
<td>%</td>
<td>Average target.%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------</td>
<td>-------------</td>
<td>-------</td>
<td>-------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>mln. sq. km</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Scenario 33</td>
<td>6.458</td>
<td>31.6</td>
<td>30.74</td>
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<tr>
<td>Best Solution</td>
<td>5.647</td>
<td>17.45</td>
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</tr>
<tr>
<td>ArcNet PACs (incl. land)</td>
<td>5.868 out 22.367</td>
<td>26.23</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ArcNet PACs (marine)</td>
<td>5.087 out 16.392</td>
<td>31.03</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Best Solution (marine)</td>
<td>5.193 out 16.796</td>
<td>30.91</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Technical descriptions of each PAC are available [online](https://oaarchive.arctic-council.org/handle/11374/417).

**Bibliography**


Pebesma E. 2018c. sf: Simple Features for R. R package version 0.6-3. https://CRAN.R-project.org/package=sf


OUR MISSION IS TO CONSERVE NATURE AND REDUCE THE MOST PRESSING THREATS TO THE DIVERSITY OF LIFE ON EARTH.