Physical connectivity – Issues and possible approaches to mapping physical and habitat connectivity in the Arctic

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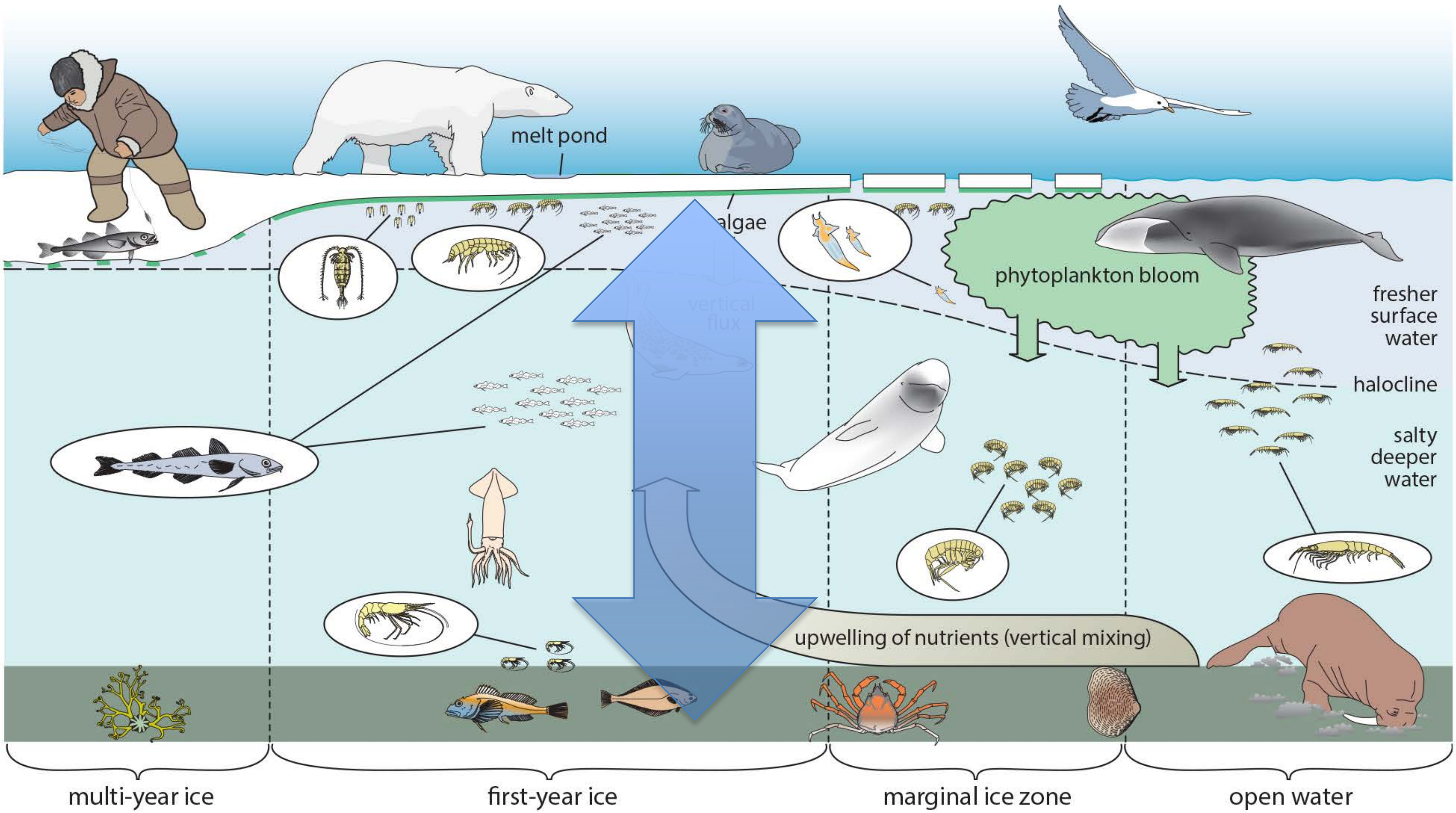
NICHOLAS SCHOOL OF THE ENVIRONMENT
DUKE UNIVERSITY MARINE LAB

POSTERA CRESCAM LAUDE
THE UNIVERSITY OF MELBOURNE

Topics:

- The Arctic context
- Connectivity modeling framework
- Arctic connectivity pilot studies
- Next steps

We tend to view Arctic marine ecosystems in terms of ***vertical connections*** across seasonal ice conditions…



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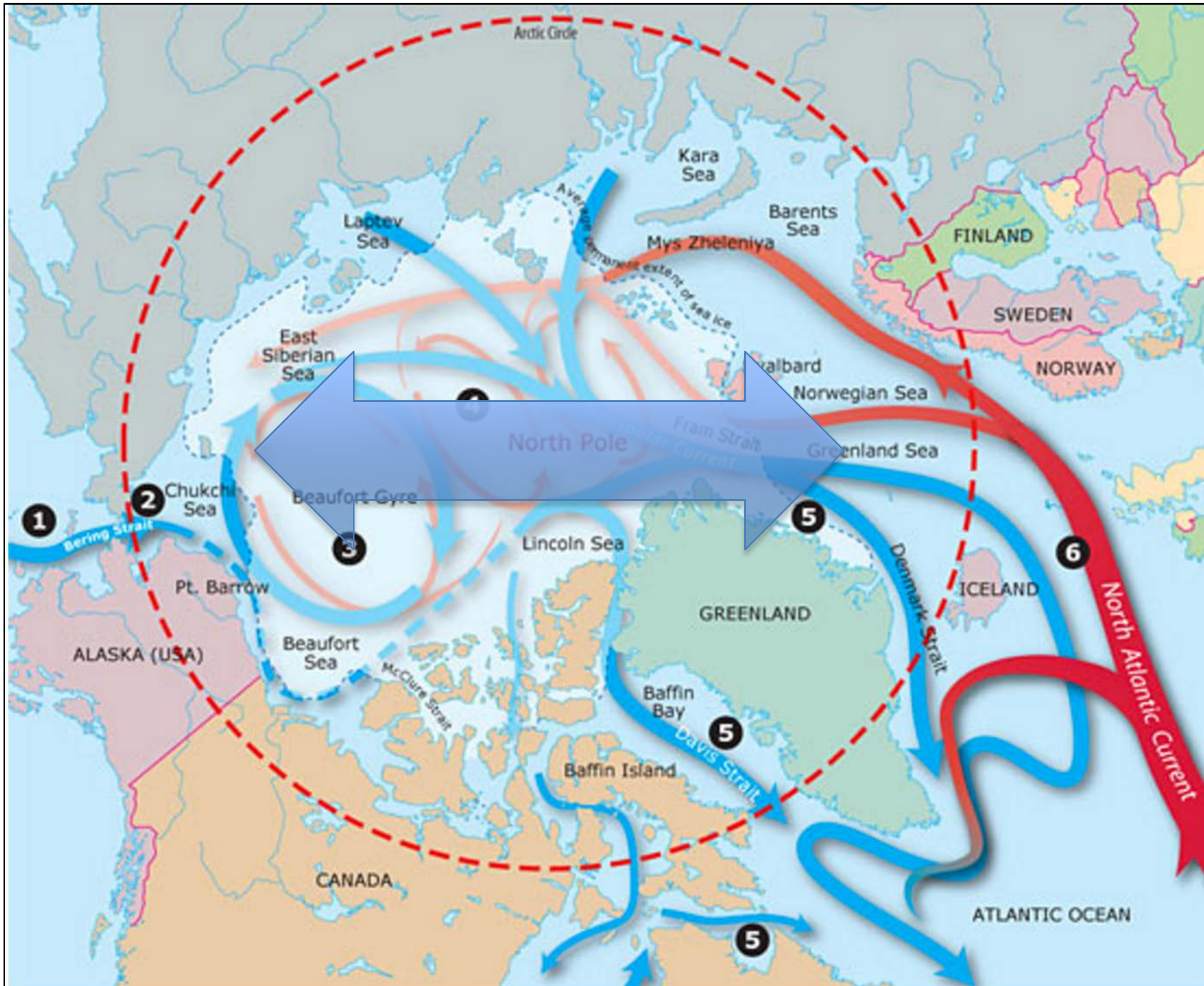
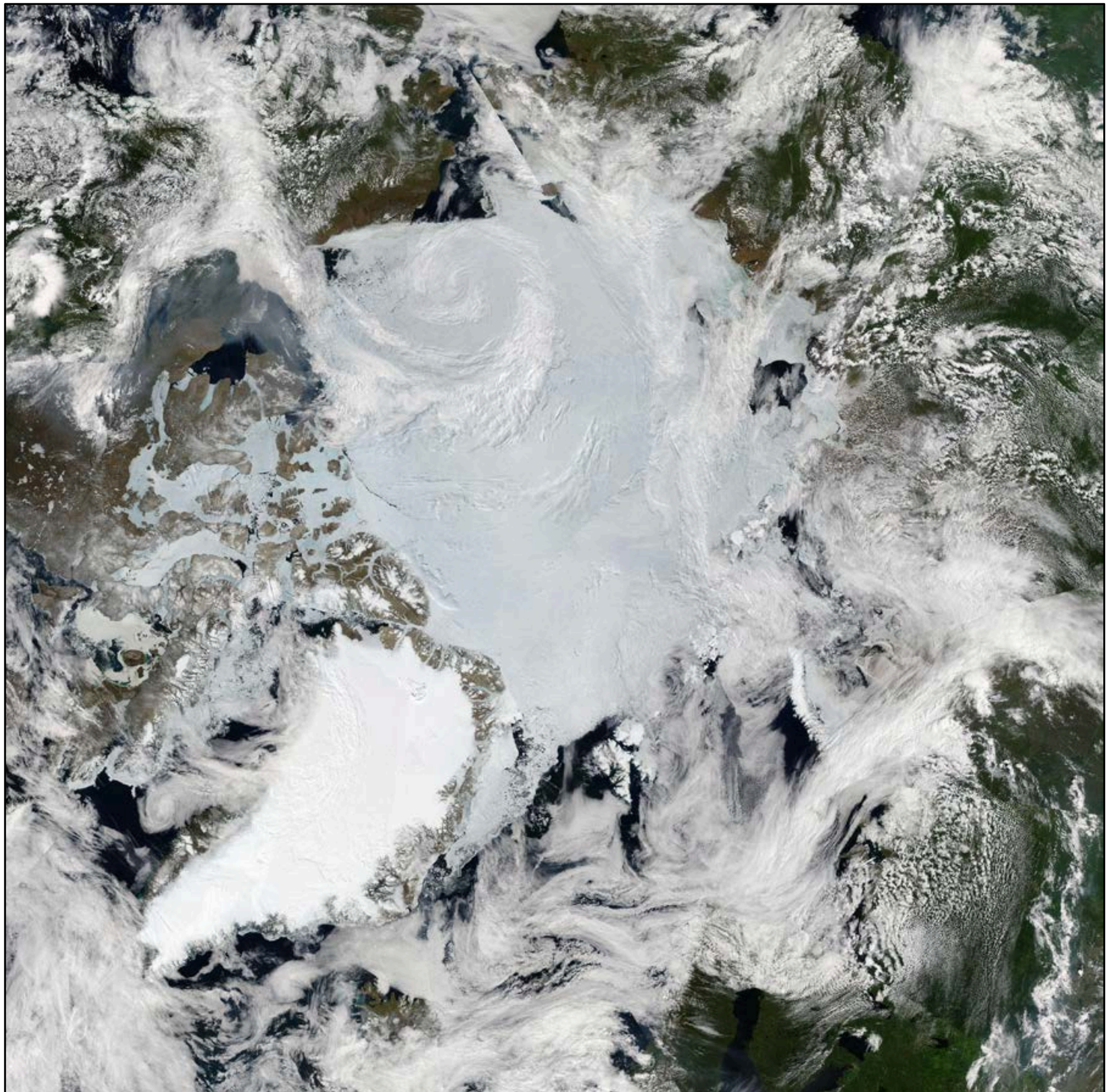
…but there is significant ***horizontal connectivity*** in the Arctic that controls the distribution of species, habitats and exchanges of resources

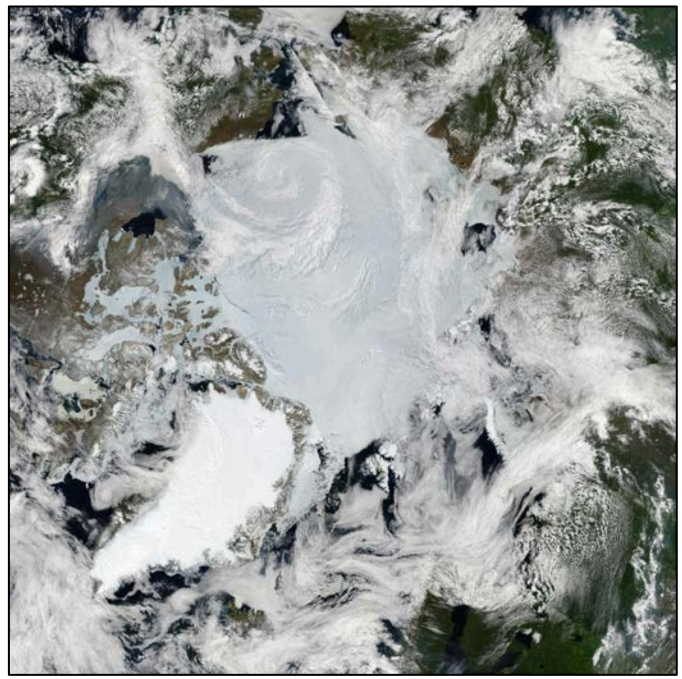


Movement and connectivity in the Arctic is highly dynamic at multiple spatial and temporal scales…



Physical factors effecting marine connectivity

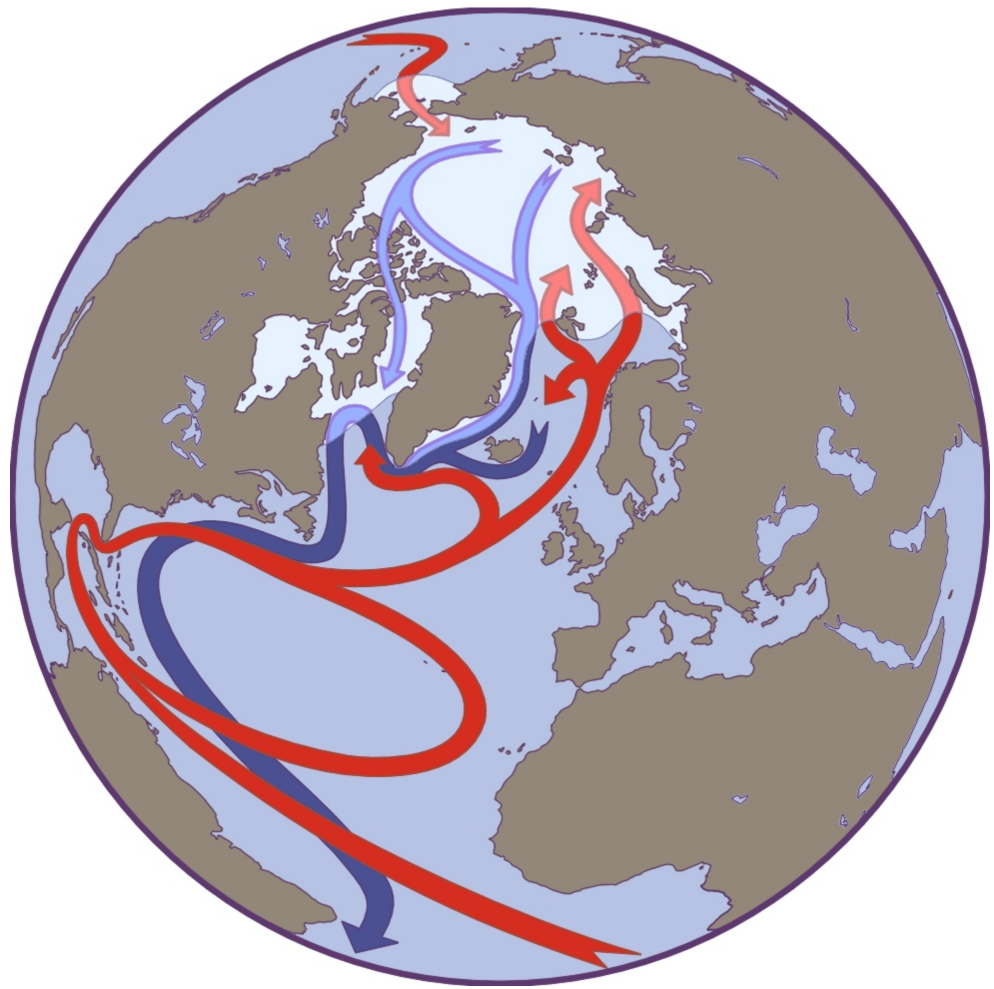
- Ocean currents (surface & sub-surface)
- Water mass properties (temperature, salinity…)
- Surface wind
- Sea ice
- Seasonality



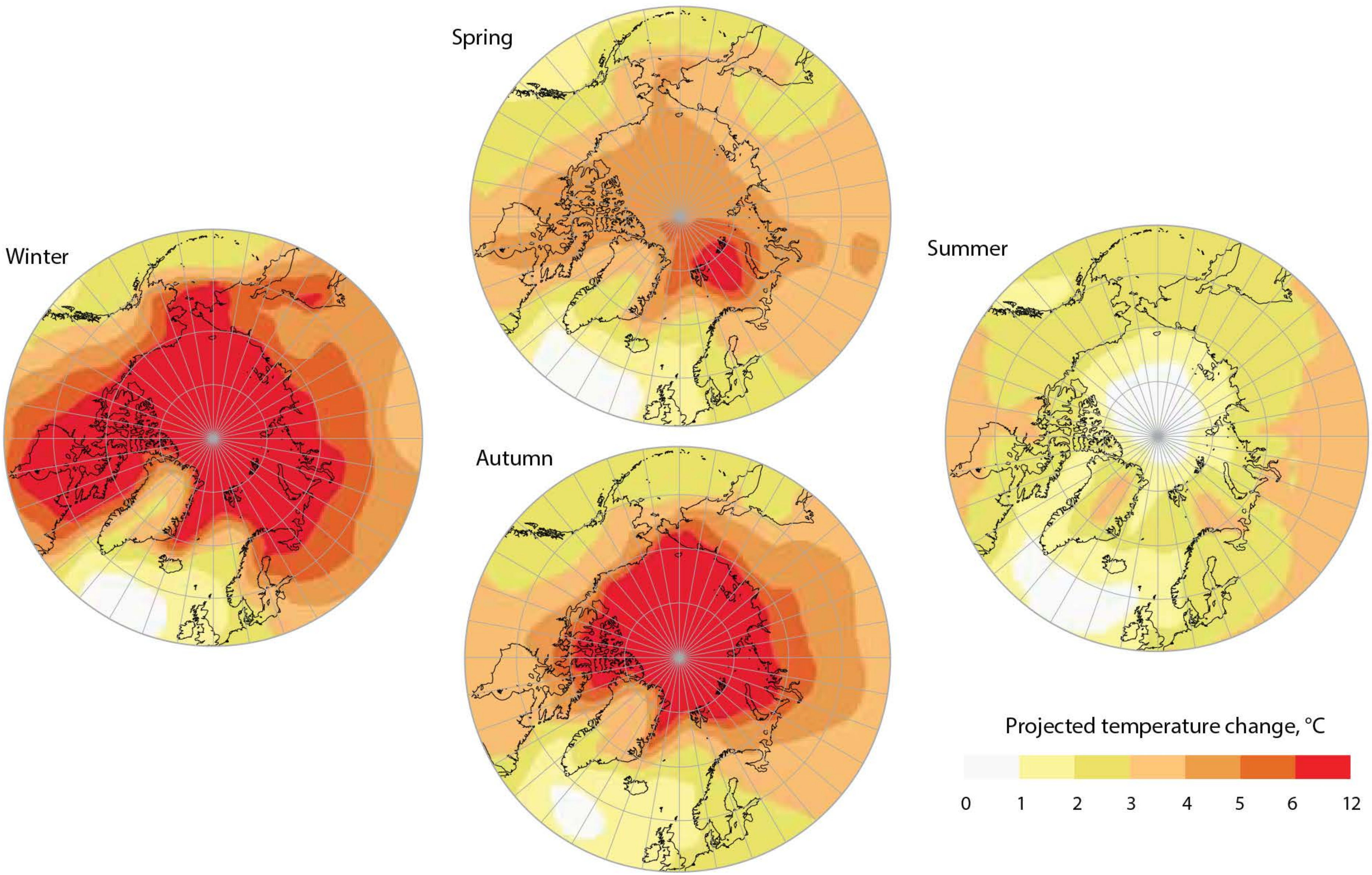
All of these factors are changing…

Changing currents

Potential changes to the oceanographic regimes at multiple depths

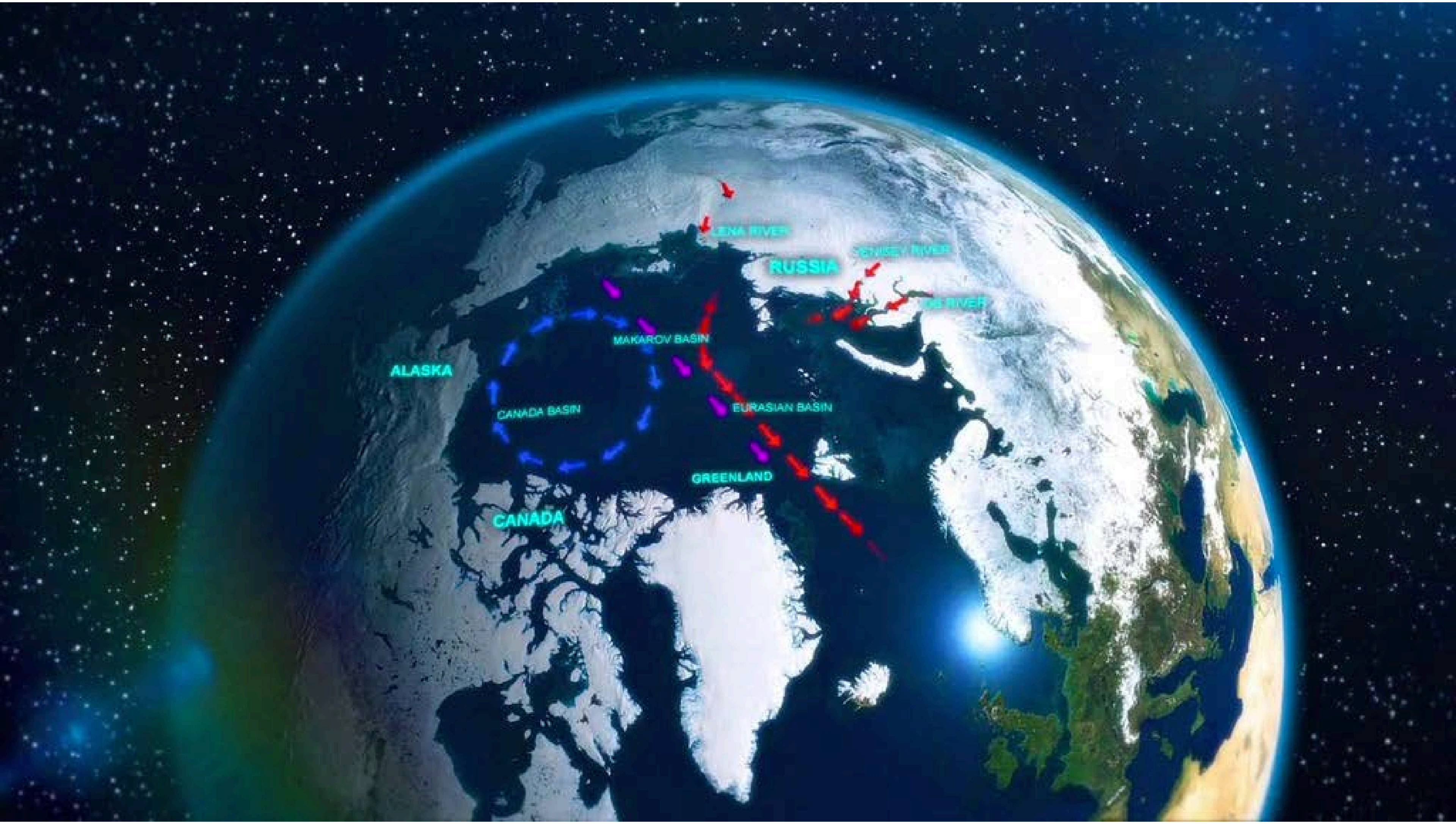


Changing surface temperature



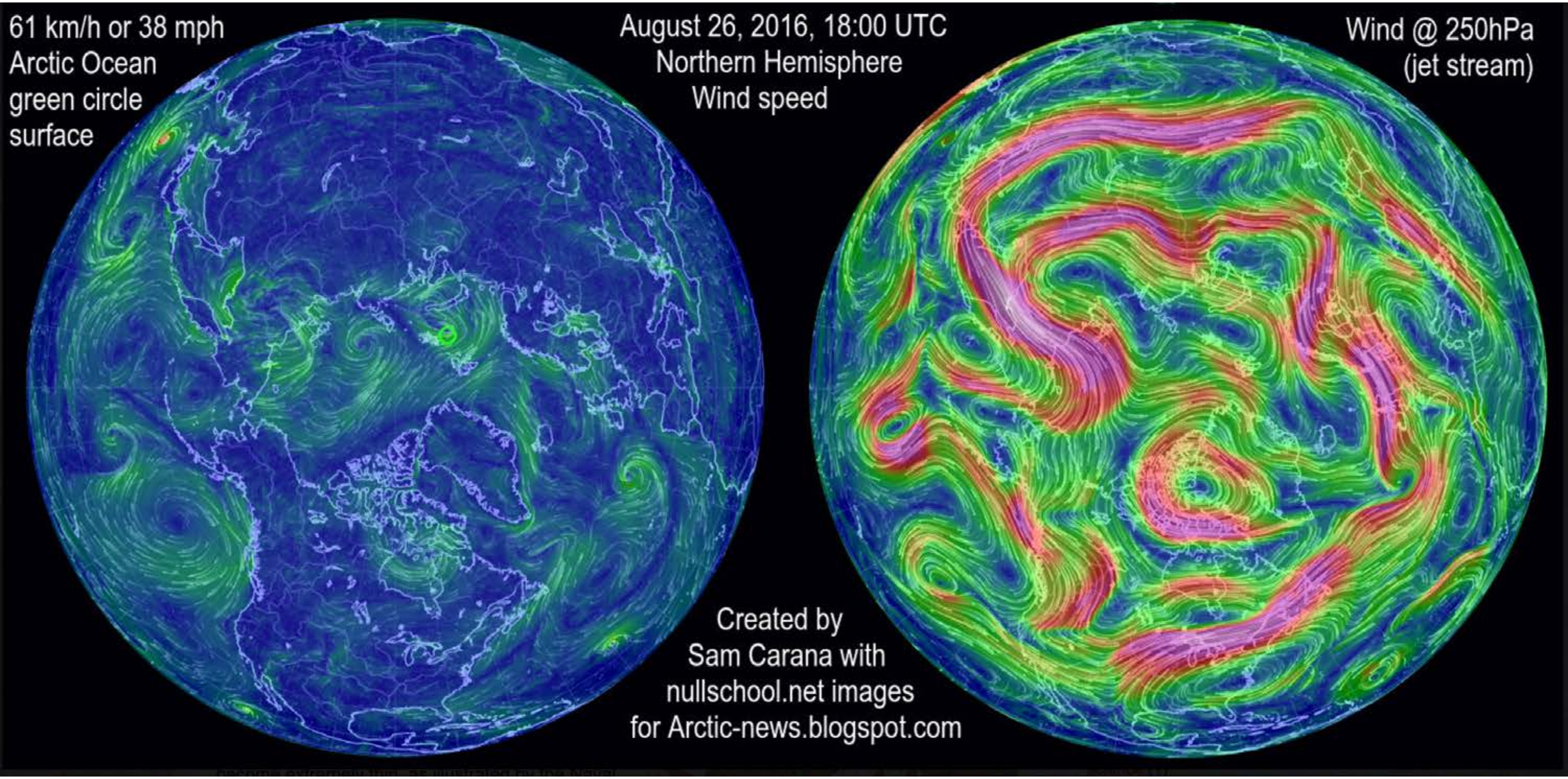
Changing freshwater circulation

Russian runoff “freshening” Canadian waters…

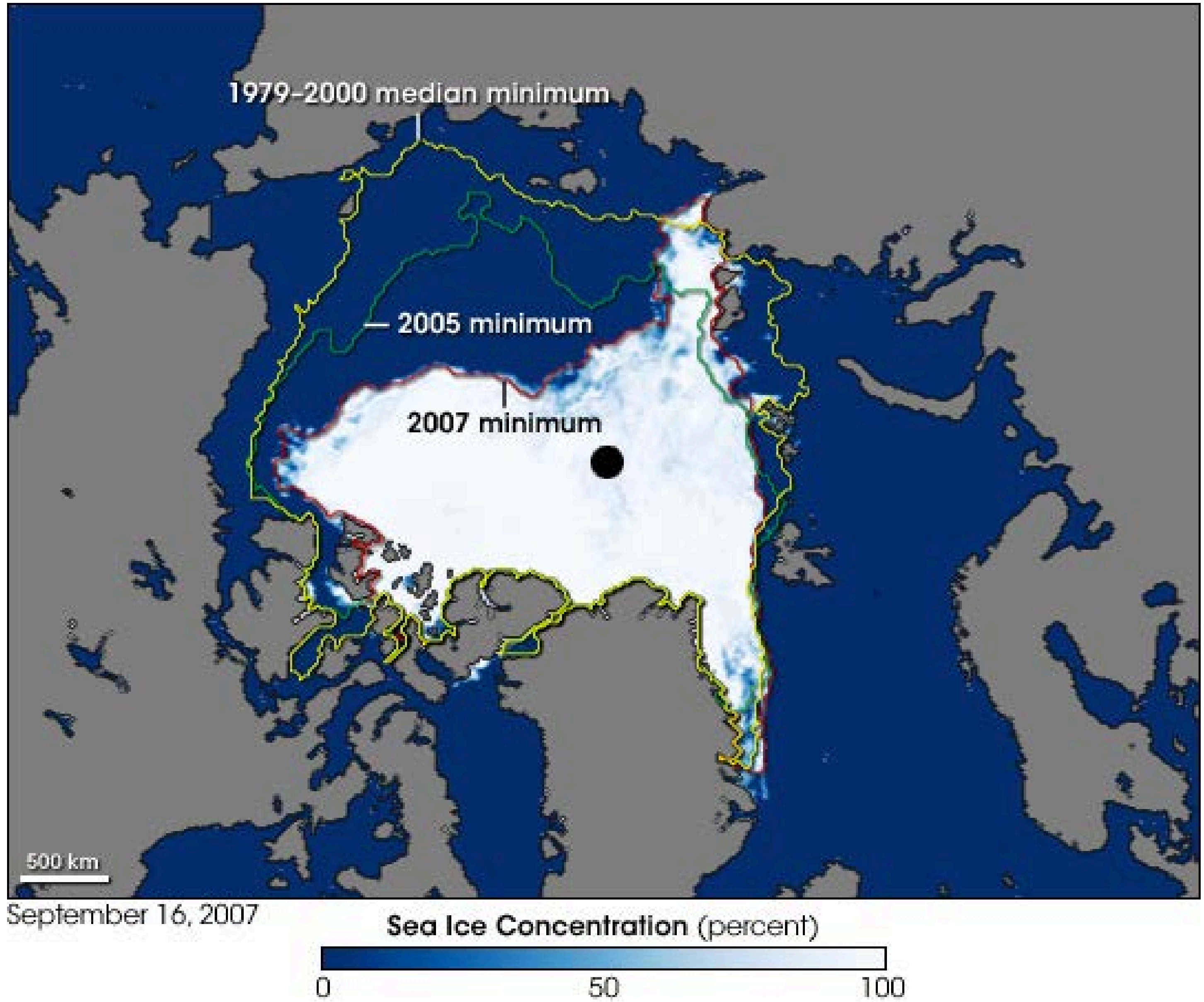


http://svs.gsfc.nasa.gov/vis/a010000/a010800/a010889/

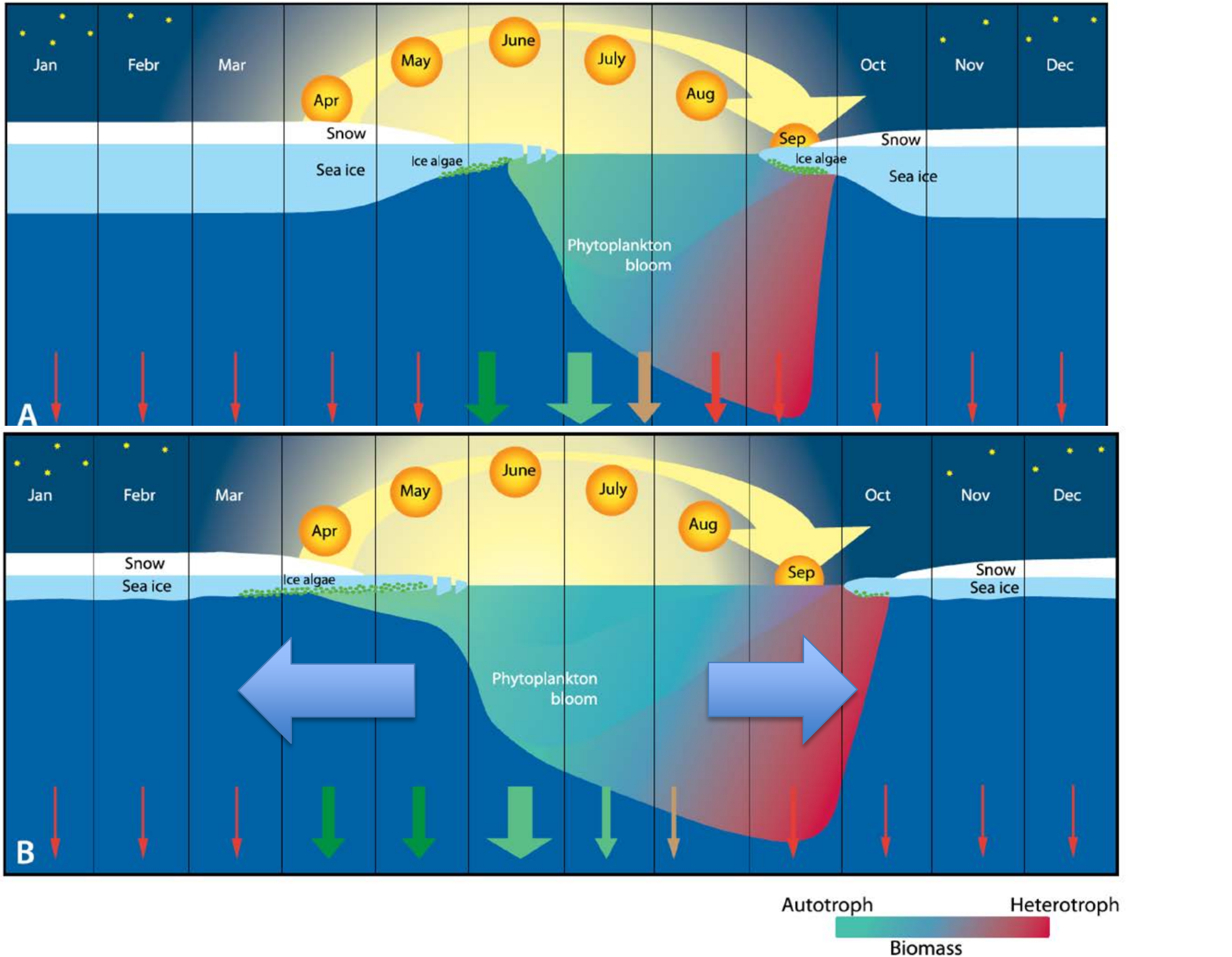
Changing wind regimes



Changing sea ice



Changing seasonality/phenology



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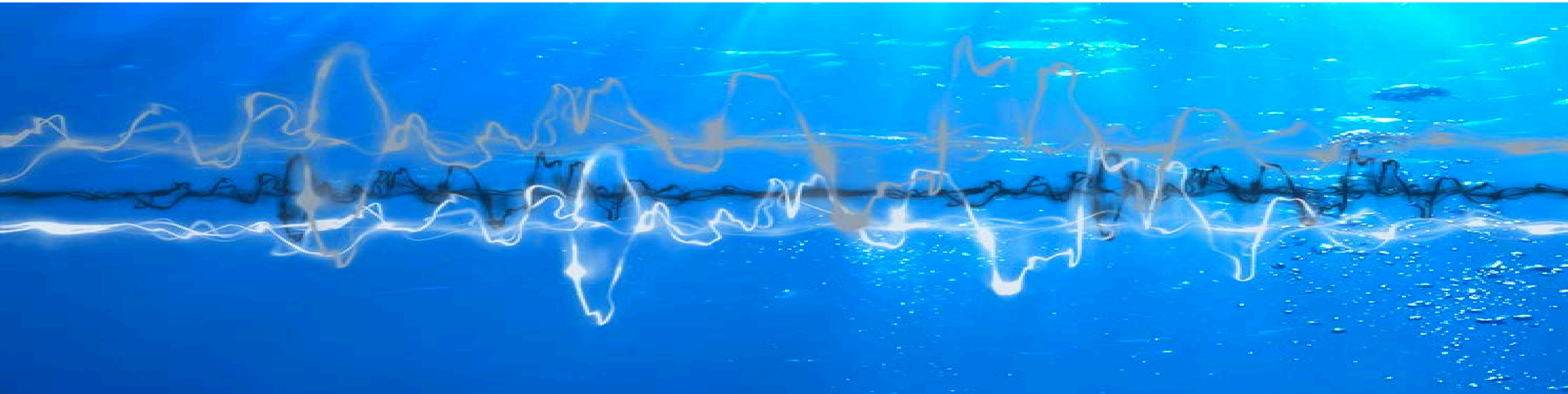
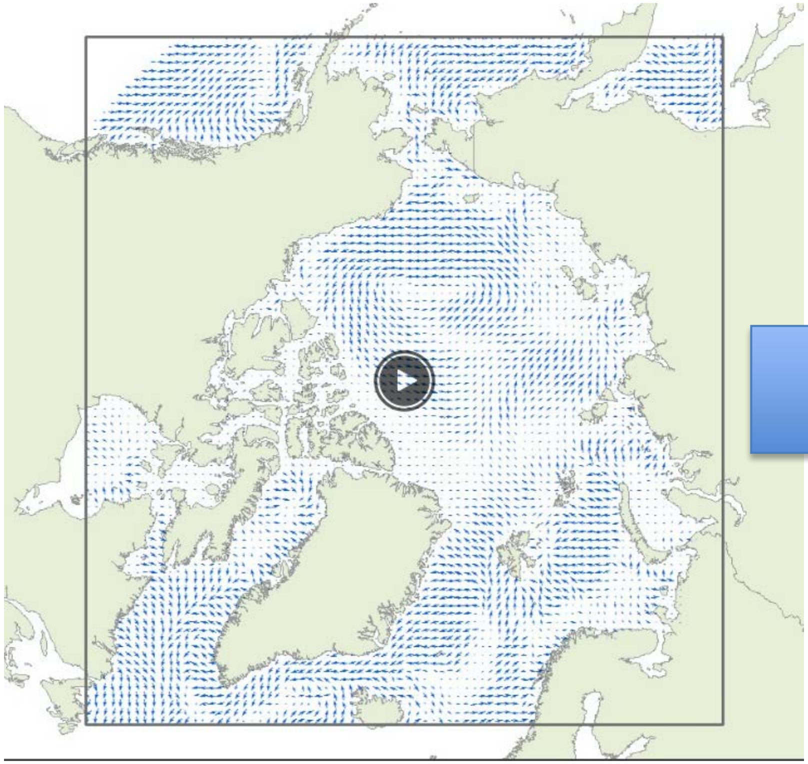
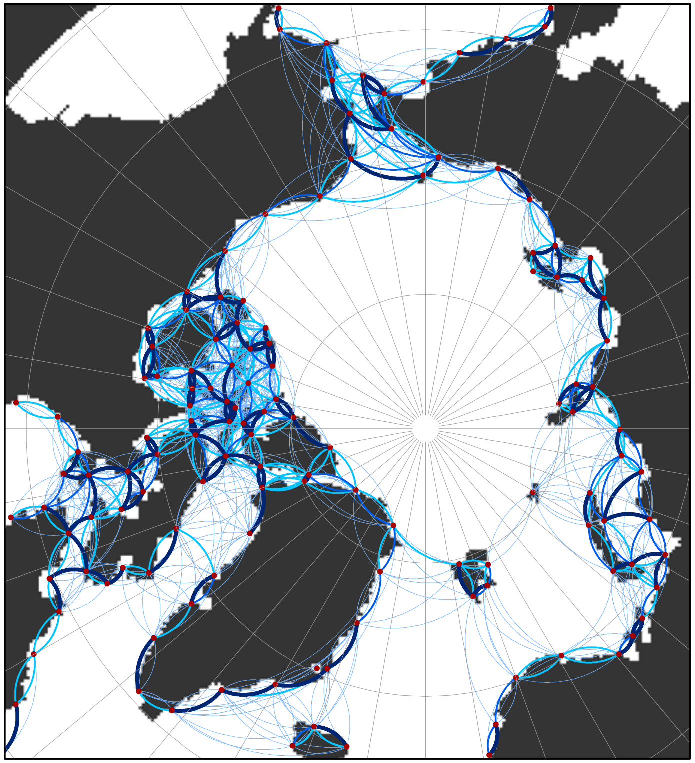


Arctic connectivity analysis framework

Models of surface currents



Network Models



How do we represent physical and ecological processes of connectivity…

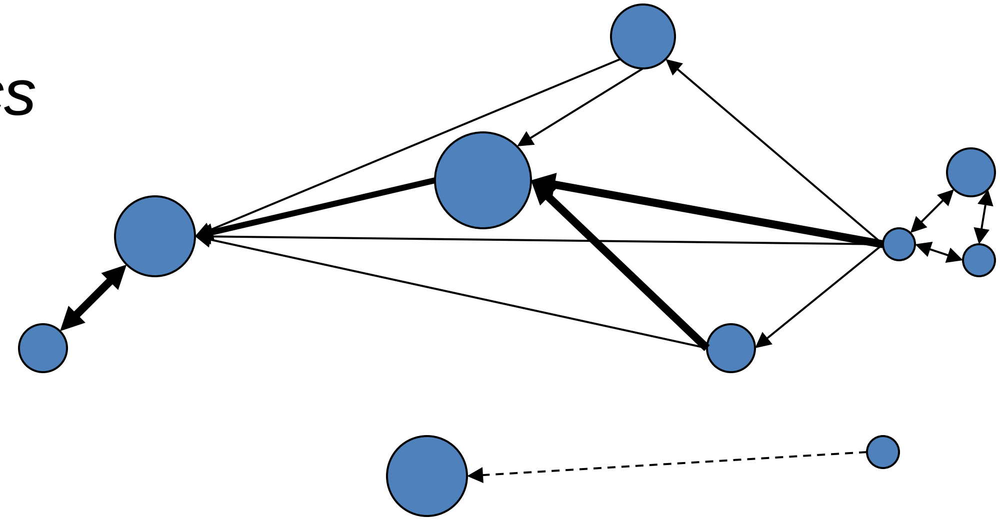
How do we ask questions about connectivity…

Marine Connectivity
via Larval dispersal

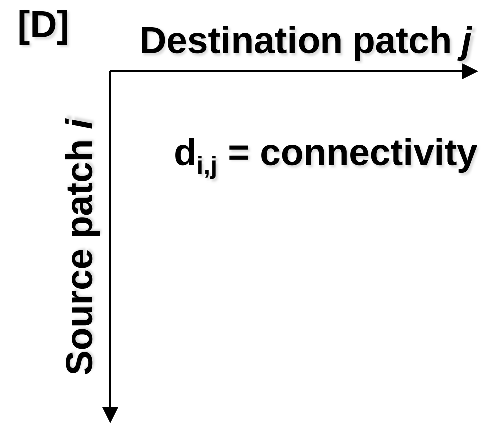
Connectivity (estimate of larval exchange)

- Recruitment/recovery from disturbances
- Source/sink implications
- Flow of genetic information
- Range expansion
- Biogeographic and phylogeographic patterns

Driven by hydrodynamics



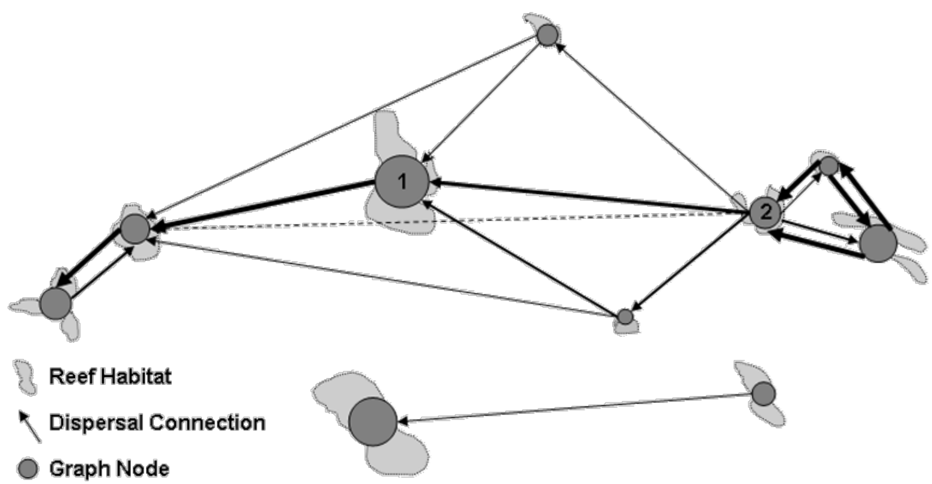
Modeling Connectivity
Data Structure



Data model

- Connectivity matrix [D]
  - Drifting days **
  - Probability
  - Geographic distance

- Location matrix (patch id, longitude, latitude)
- Reef properties (area, density, quality, etc)



connectivity

- Oceanographic models
- Larval transport models
- Graph-theory network models

PLOS | ONE

RESEARCH ARTICLE

No Reef Is an Island: Integrating Coral Reef Connectivity Data into the Design of Regional-Scale Marine Protected Area Networks

Steven R. Schill[1], George T. Raber[2]*, Jason J. Roberts[3], Eric A. Treml[4], Jorge Brenner[5], Patrick N. Halpin[3]

1 Caribbean Program, The Nature Conservancy, Coral Gables, Florida, United States of America, **2** Department of Geography and Geology, The University of Southern Mississippi, Hattiesburg, Mississippi, United States of America, **3** Marine Geospatial Ecology Lab, Nicholas School of the Environment, Duke University, Durham, North Carolina, United States of America, **4** School of BioSciences, University of Melbourne, Melbourne, Victoria, Australia, **5** Texas Chapter, The Nature Conservancy, Houston, Texas, United States of America

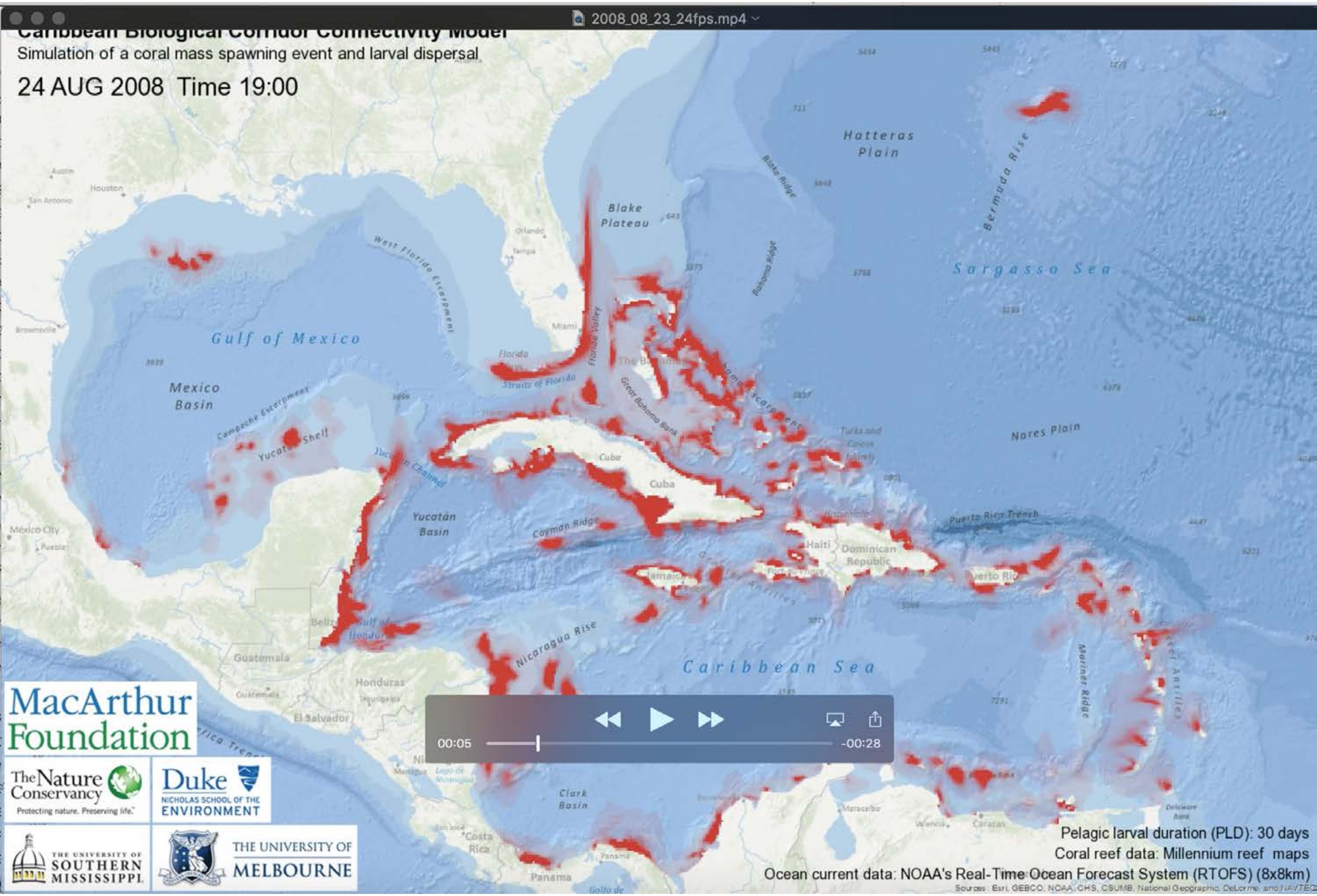
* george.raber@usm.edu

Abstract

We integrated coral reef connectivity data for the Caribbean and Gulf of Mexico into a conservation decision-making framework for designing a regional scale marine protected area (MPA) network that provides insight into ecological and political contexts. We used an ocean circulation model and regional coral reef data to simulate eight spawning events from 2008–2011, applying a maximum 30-day pelagic larval duration and 20% mortality rate. Coral larval dispersal patterns were analyzed between coral reefs across jurisdictional marine zones to identify spatial relationships between larval sources and destinations within countries and territories across the region. We applied our results in Marxan, a conservation planning software tool, to identify a regional coral reef MPA network design that meets conservation goals, minimizes underlying threats, and maintains coral reef connectivity. Our results suggest that approximately 77% of coral reefs identified as having a high regional connectivity value are not included in the existing MPA network. This research is unique because we quantify and report coral larval connectivity data by marine ecoregions and Exclusive Economic Zones (EZZ) and use this information to identify gaps in the current Caribbean-wide MPA network by integrating asymmetric connectivity information in Marxan to design a regional MPA network that includes important reef network connections. The identification of important reef connectivity metrics guides the selection of priority conservation areas and supports resilience at the whole system level into the future.

y.zip.

Funding: This project was funded by a grant from the John D. and Catherine T. MacArthur Foundation. The title of the grant was "A Vision for Protecting



2008_08_23_24fps.mp4
Simulation of a coral mass spawning event and larval dispersal
24 AUG 2008 Time 19:00
Gulf of Mexico
Mexico Basin
Yucatan Basin
Caribbean Sea
Sargasso Sea
Hatteras Plain
Blake Plateau
Nares Plain
Cuba
Haiti
Dominican Republic
Puerto Rico Trench
Nicaragua Rise
Cayman Ridge
Clark Basin
00:05
-00:28
MacArthur Foundation
The Nature Conservancy
Protecting nature. Preserving life.
Duke
NICHOLAS SCHOOL OF THE ENVIRONMENT
THE UNIVERSITY OF SOUTHERN MISSISSIPPI
THE UNIVERSITY OF MELBOURNE
Pelagic larval duration (PLD): 30 days
Coral reef data: Millennium reef maps
Ocean current data: NOAA's Real-Time Ocean Forecast System (RTOFS) (8x8km)

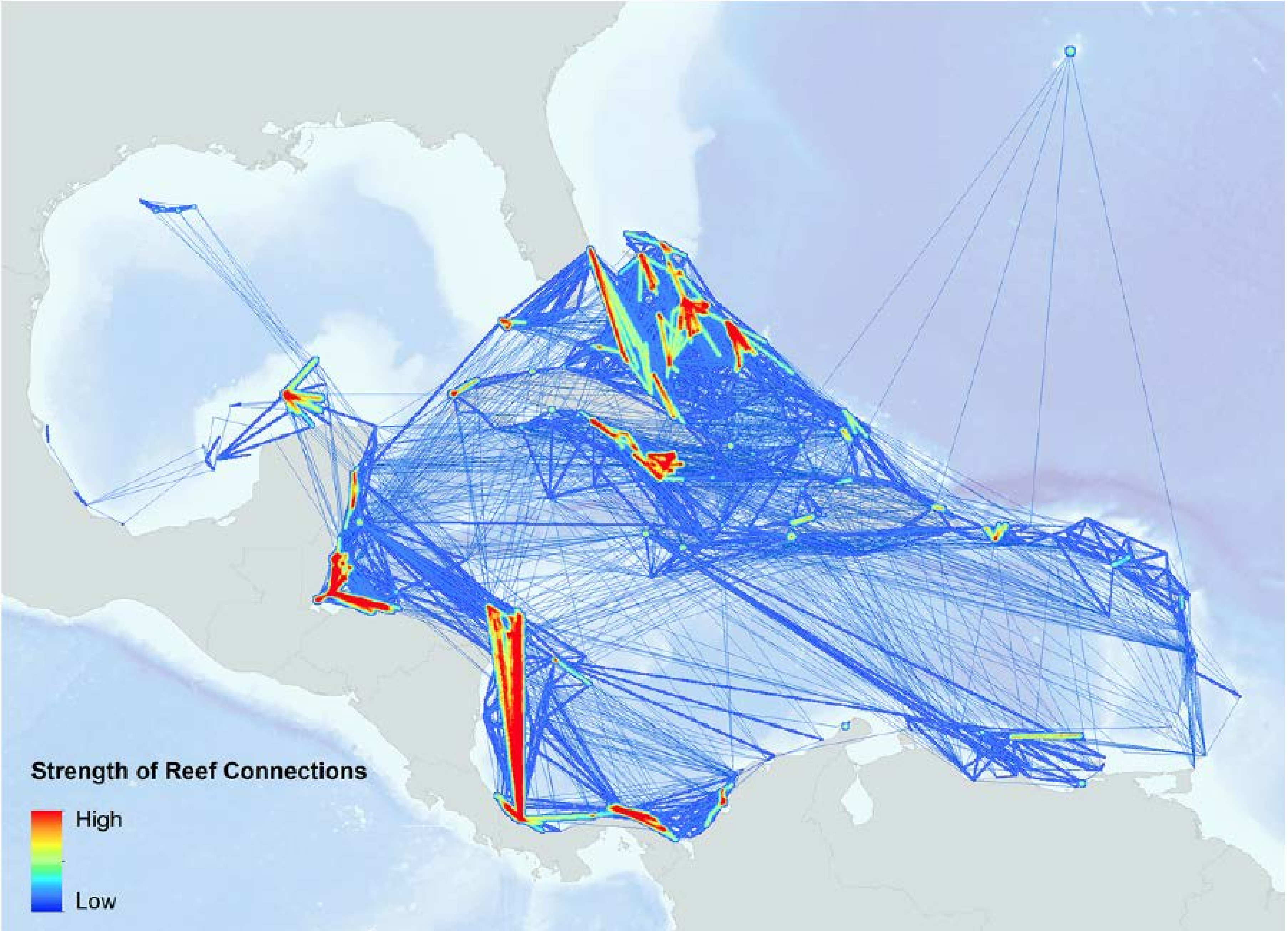


Fig 2. Strength of reef connections based on modeled transported coral larvae. These values represent an average of eight coral larvae dispersal simulations between 2008–2011. The width and color of the lines represent the strength of connection. The darker red and orange areas indicate high amounts of settled coral larvae transported along that connection, while the shades of blue represent smaller amounts of settled larvae.

Topics:

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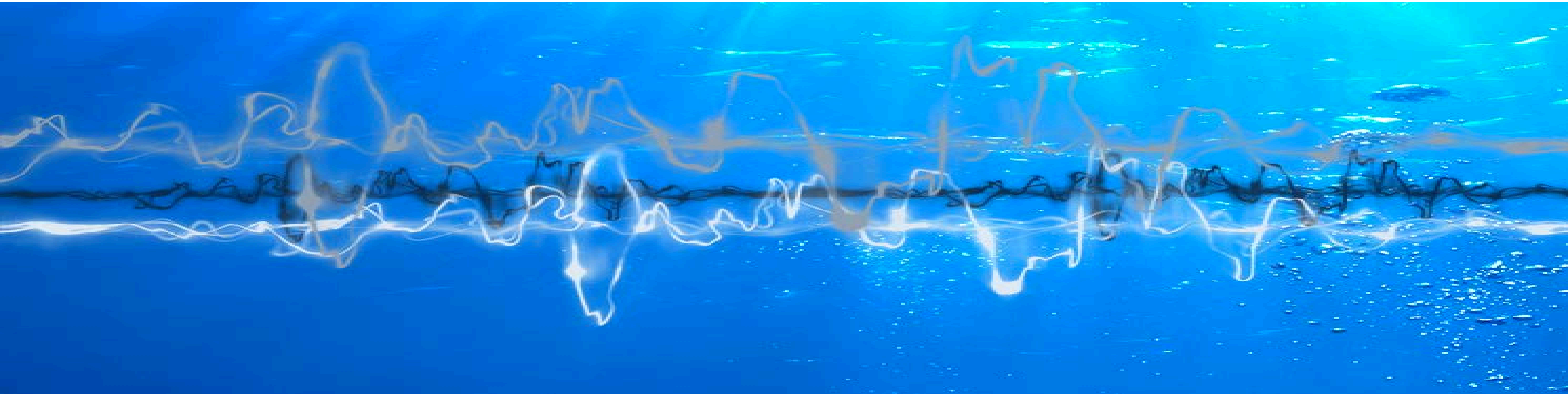
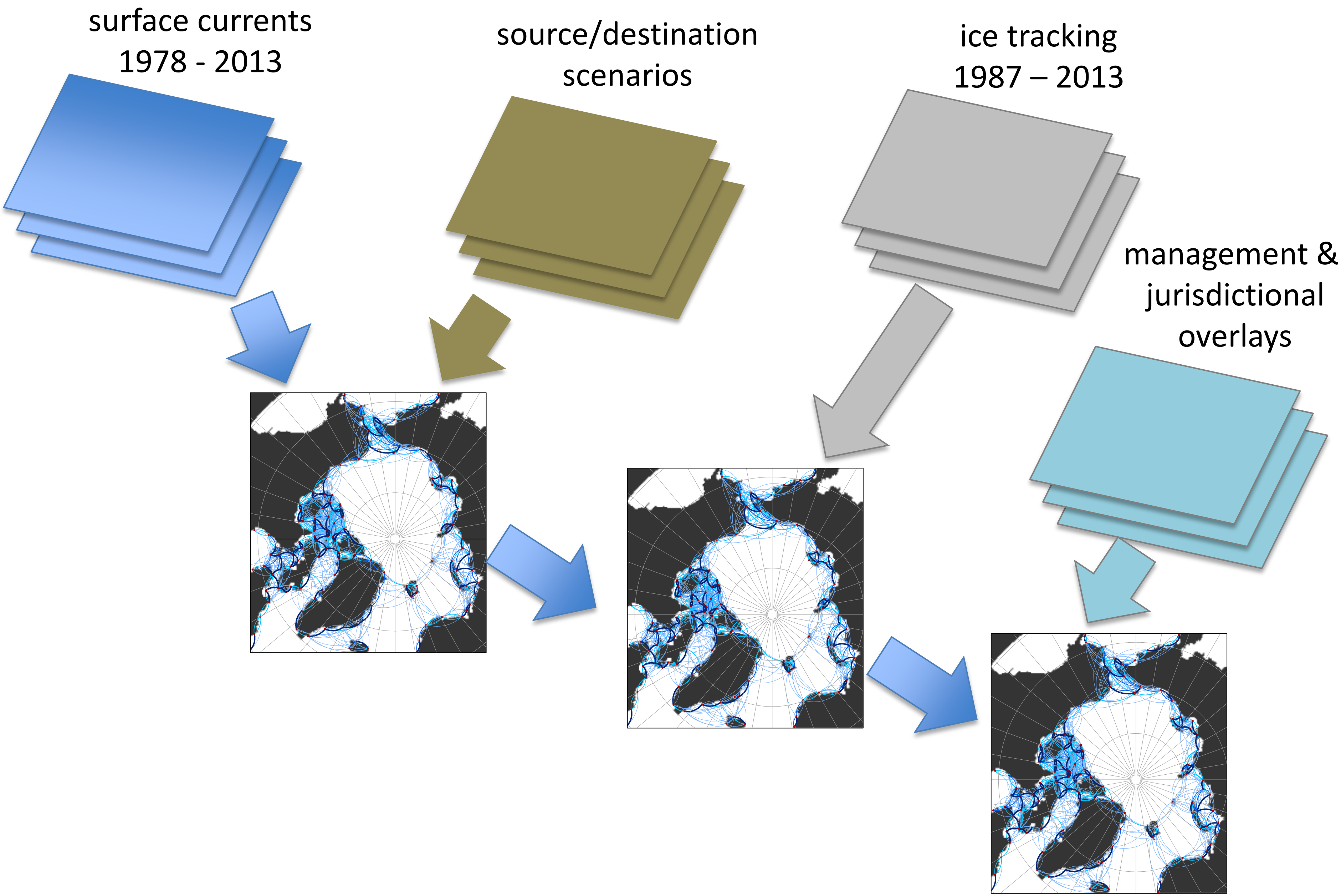


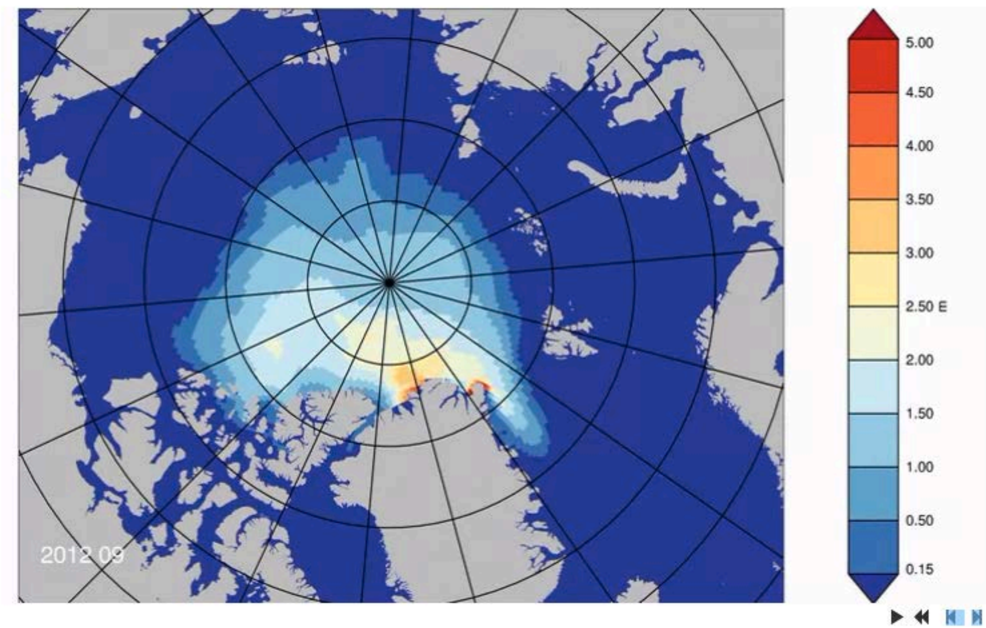
Arctic connectivity pilot analysis



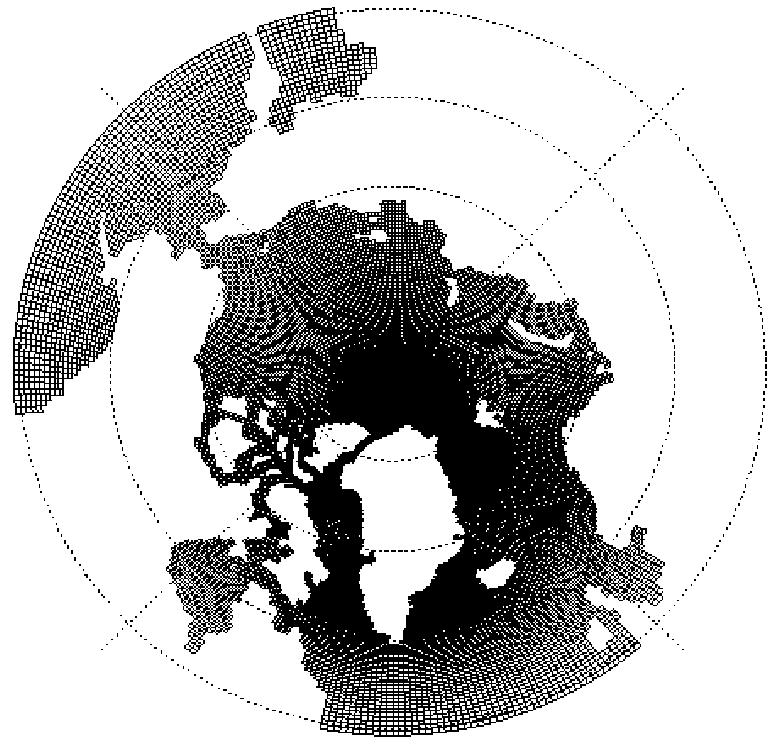
Arctic connectivity pilot analysis

Surface Currents:

Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS, version 2.1), Zhang and Rothrock (2003)



Monthly Ice Thickness from 1979-2015



Monthly data, 1978 – 2013
partially-coupled, data assimilative

Arctic connectivity pilot analysis

Potential pilot scenarios

Source / destination targets	"normal" ice year		"low" ice year	
Coastal areas (500km regions)	winter	summer	winter	summer
Fish spawning areas	winter	summer	winter	summer
Important feeding grounds	winter	summer	winter	summer

3 x 2 x 2 = 12 initial pilot scenarios

Arctic connectivity pilot analysis

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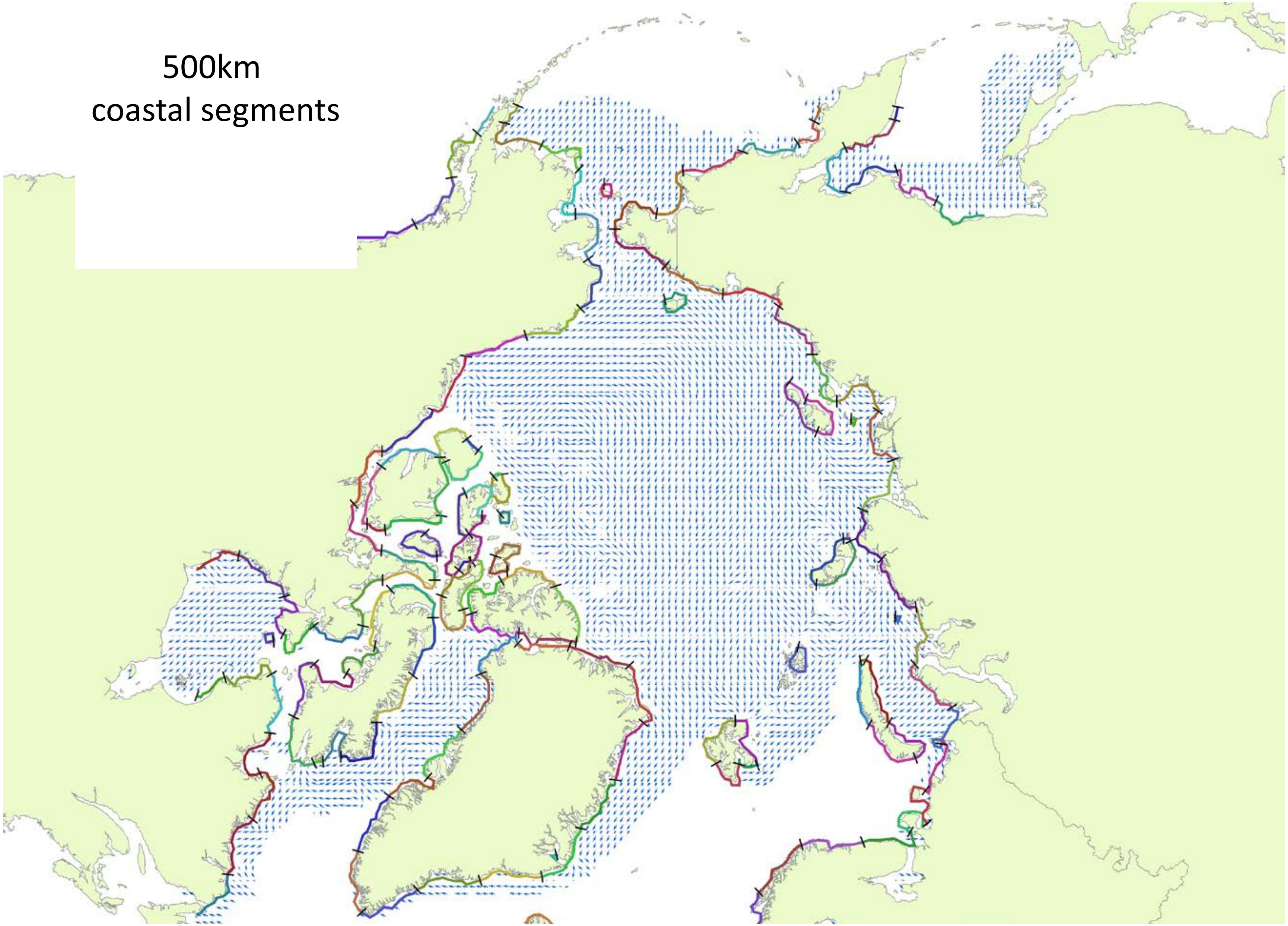
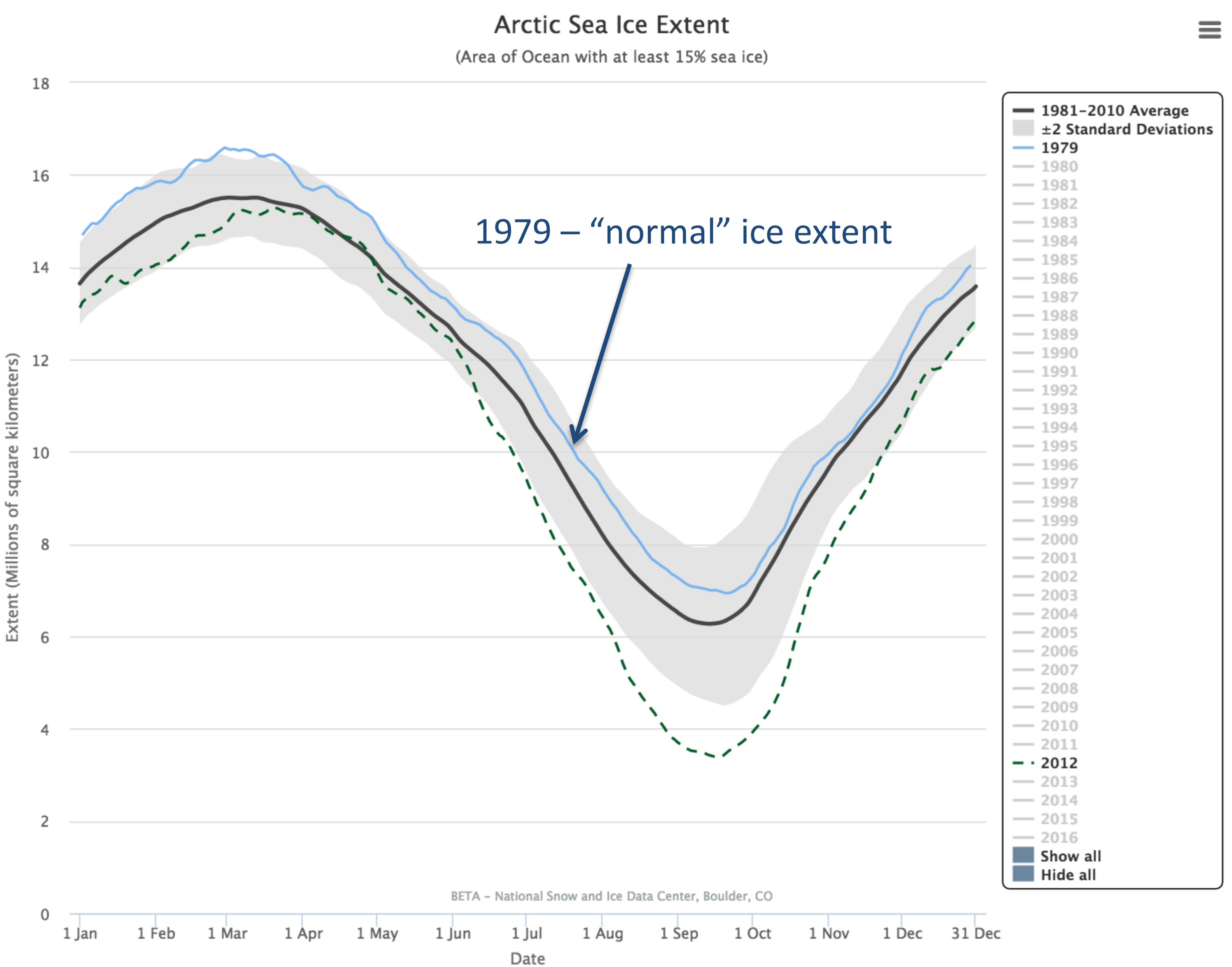
Arctic connectivity pilot analysis

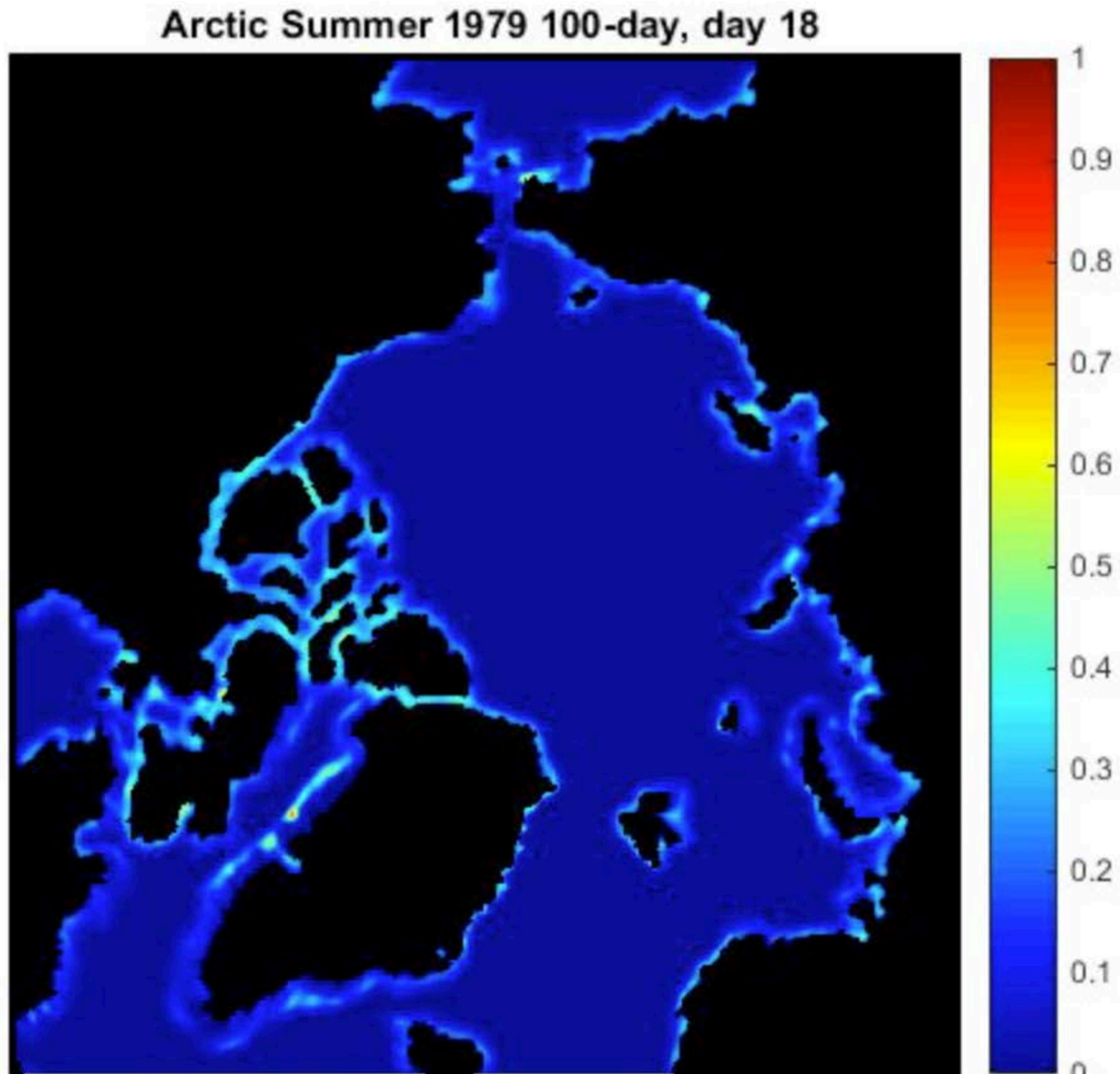


Arctic connectivity pilot analysis



Coastal water connectivity

summer normal year (1979)

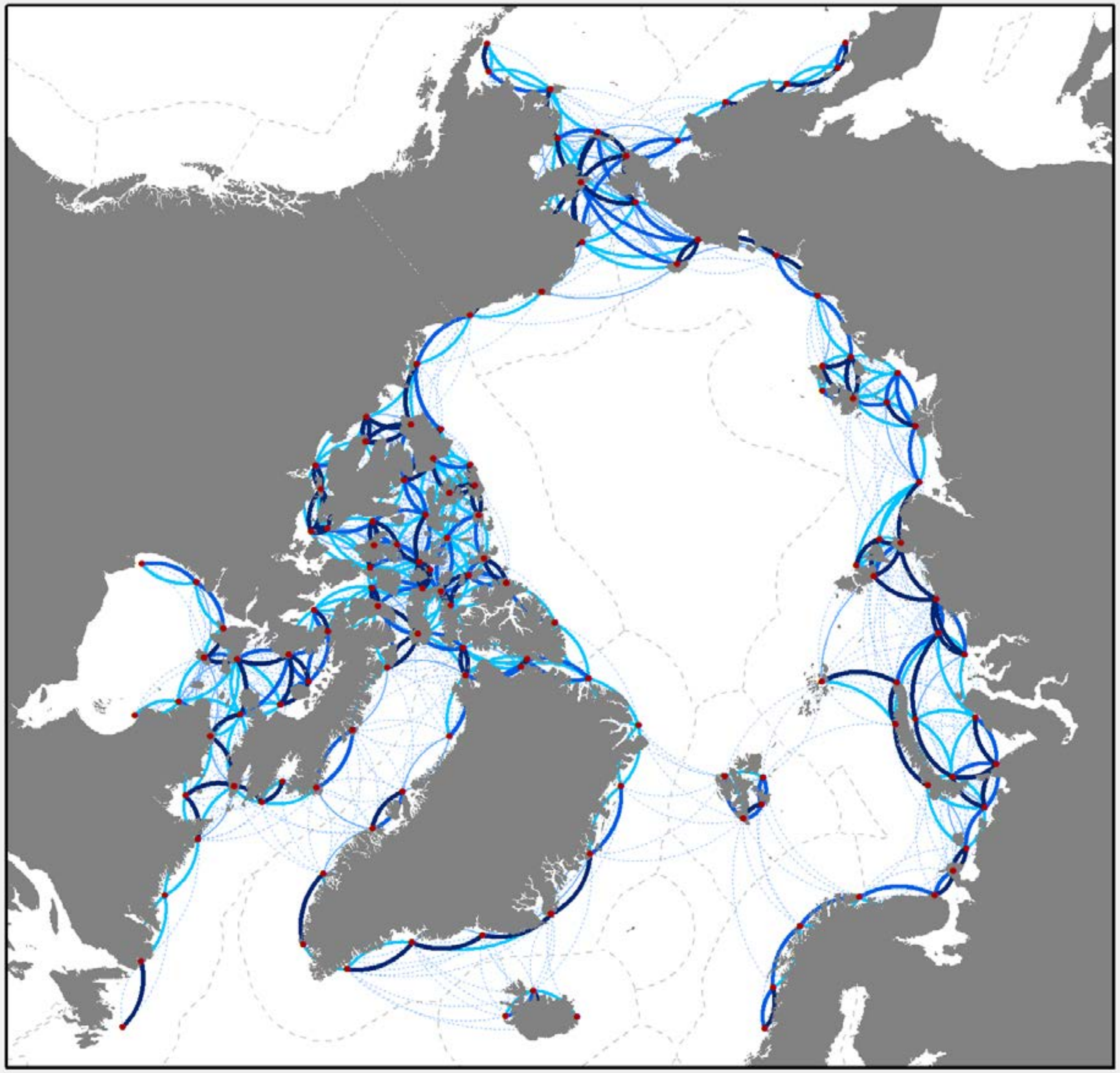


Treml, Fay *et al*. 2016

Arctic connectivity pilot analysis

Summer
September 1979 connectivity
500km coastline regions

Connectivity
What coastal areas are connected to other coastal areas on a 100 day period

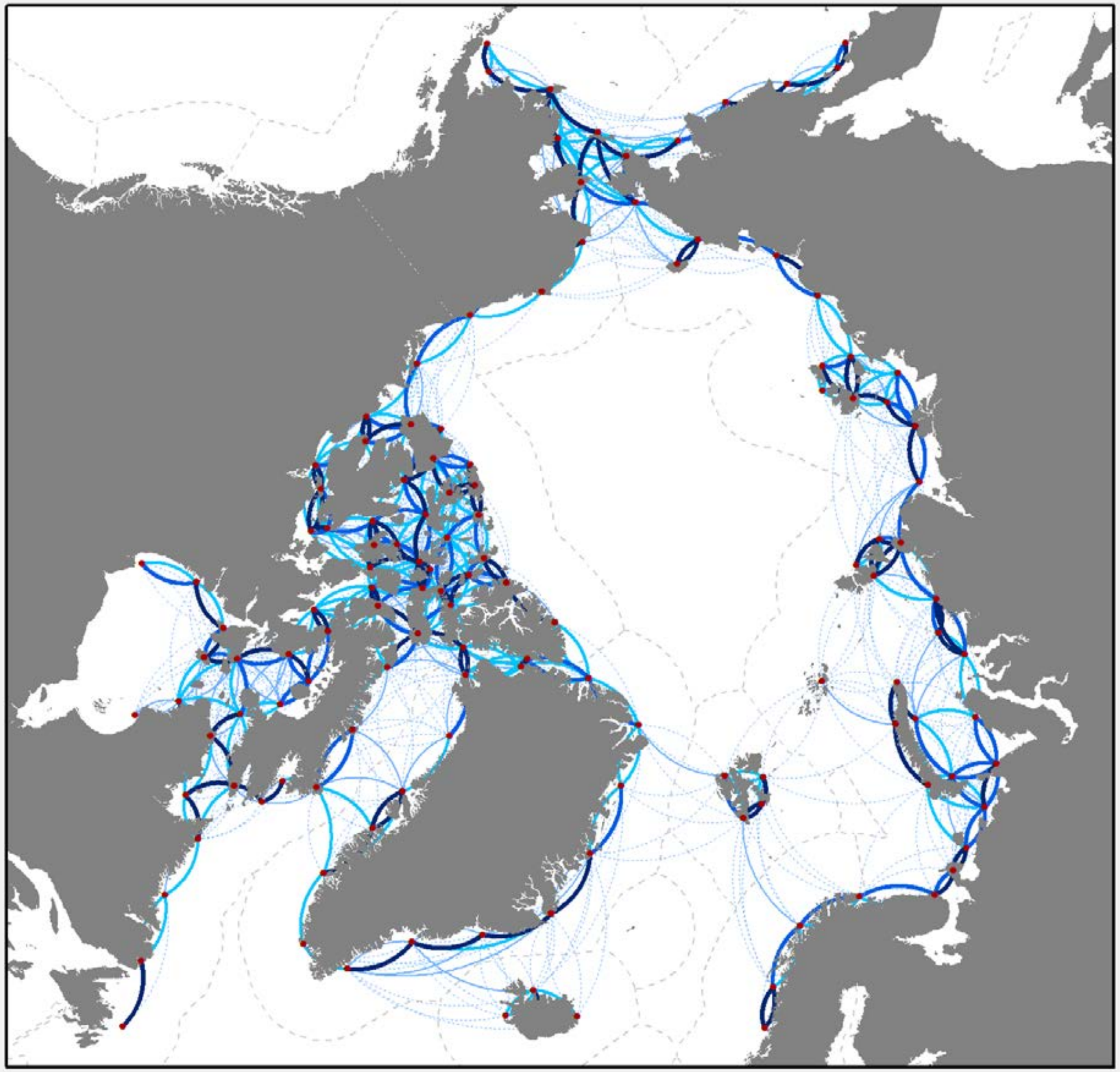


Summer 1979, 100 day connectivity

Arctic connectivity pilot analysis

Winter
February 1979 connectivity
500km coastline regions

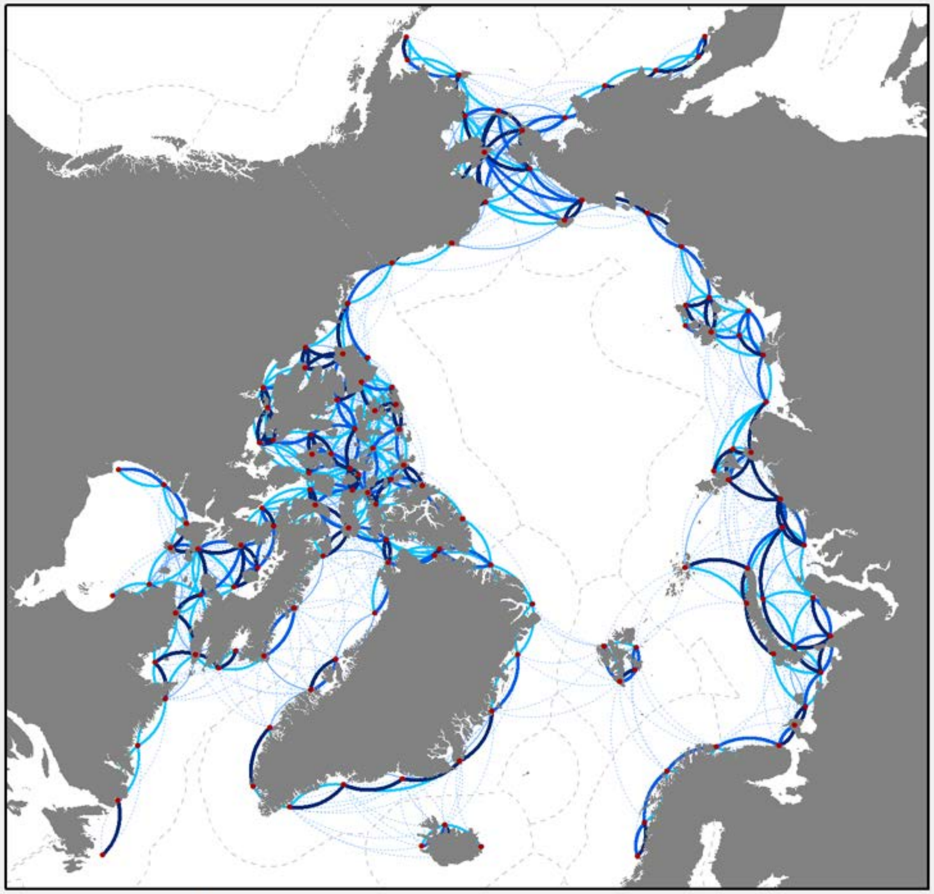
Connectivity
What coastal areas are connected to other coastal areas on a 100 day period



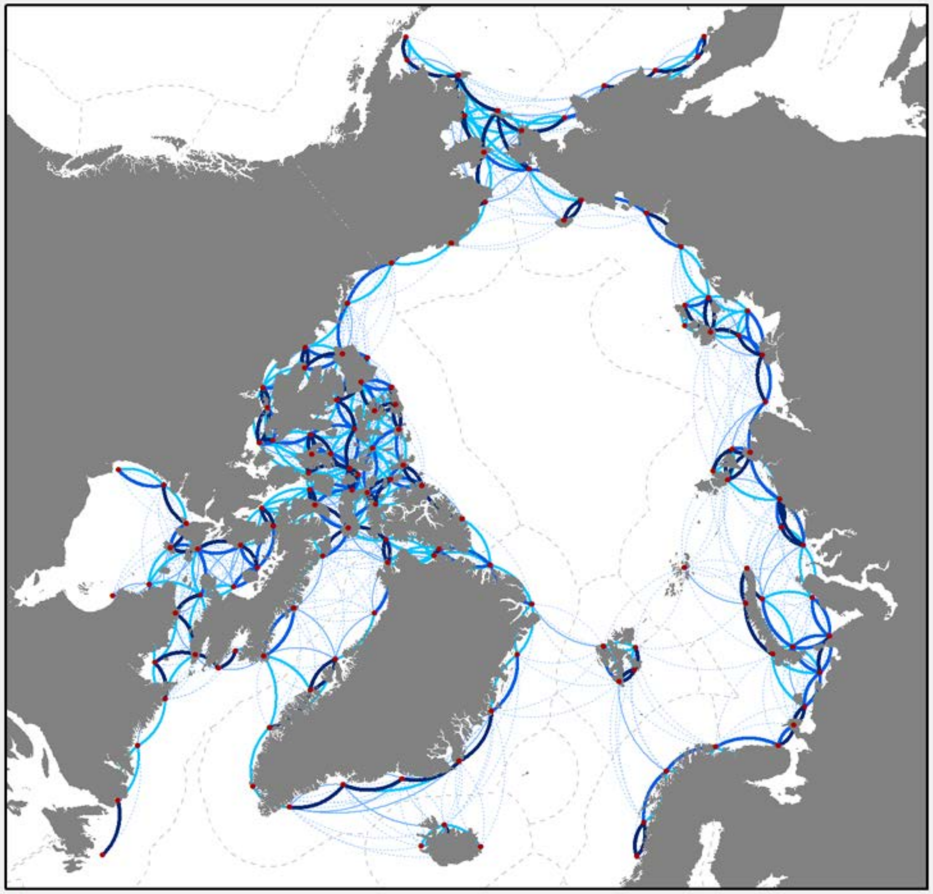
Winter 1979, 100 day connectivity

Coastal water connectivity

summer vs. winter normal year (1979)



Summer 1979, 100 day connectivity



Winter 1979, 100 day connectivity

Arctic connectivity pilot analysis

Potential pilot scenarios

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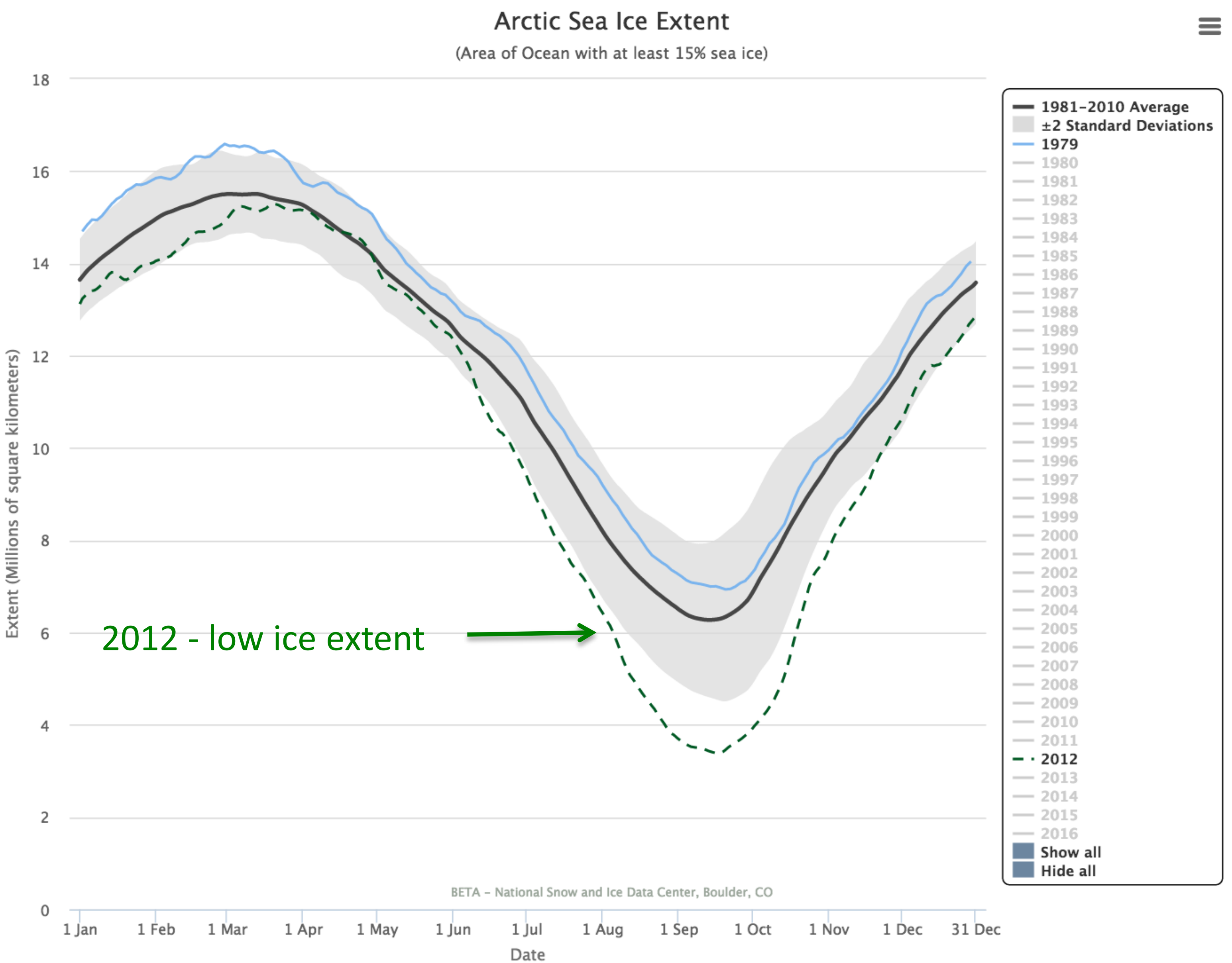
3 x 2 x 2 = 12 initial pilot scenarios

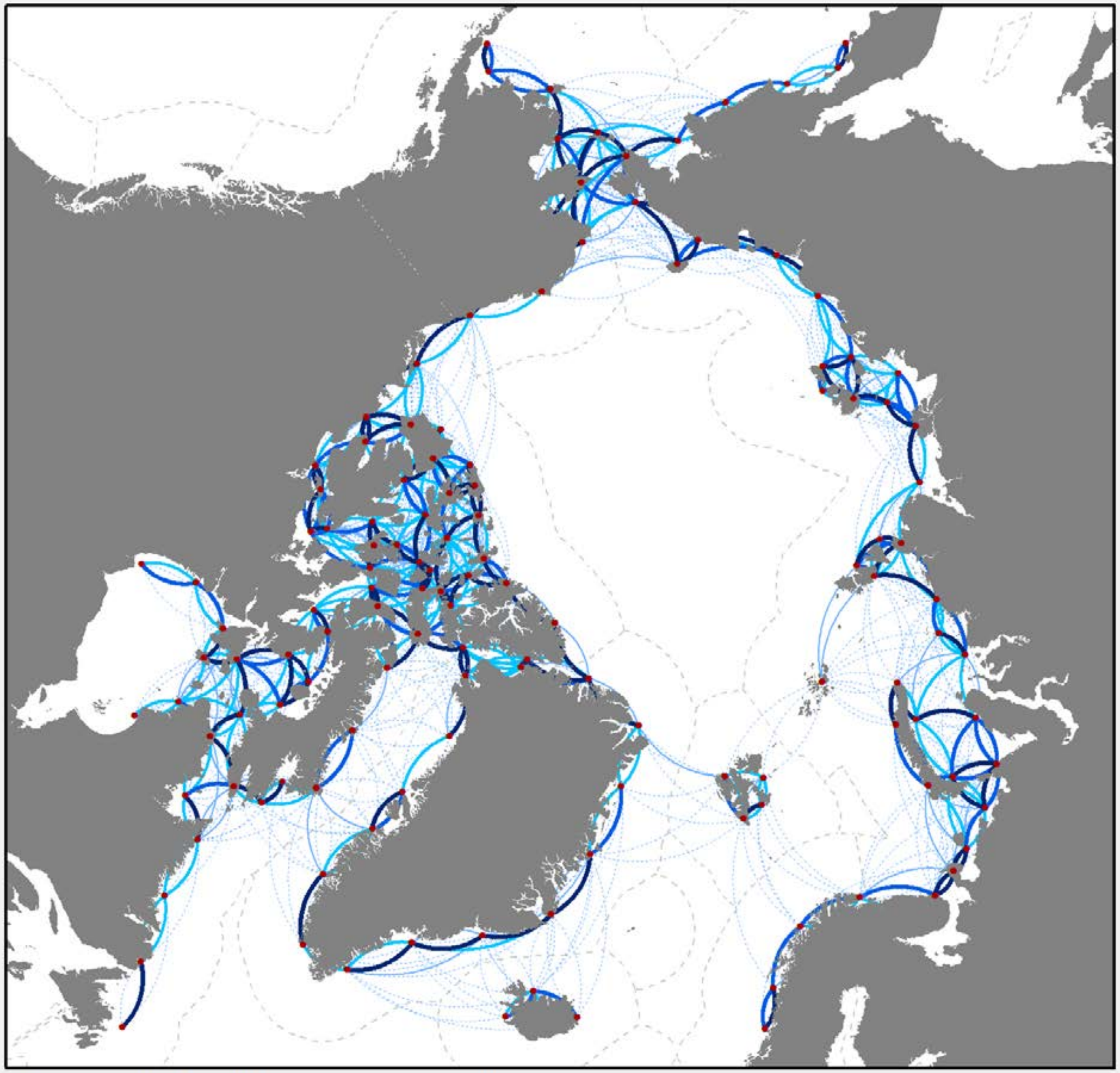
Arctic connectivity pilot analysis



Arctic connectivity pilot analysis

Connectivity
100 days
summer
2012

Low ice year

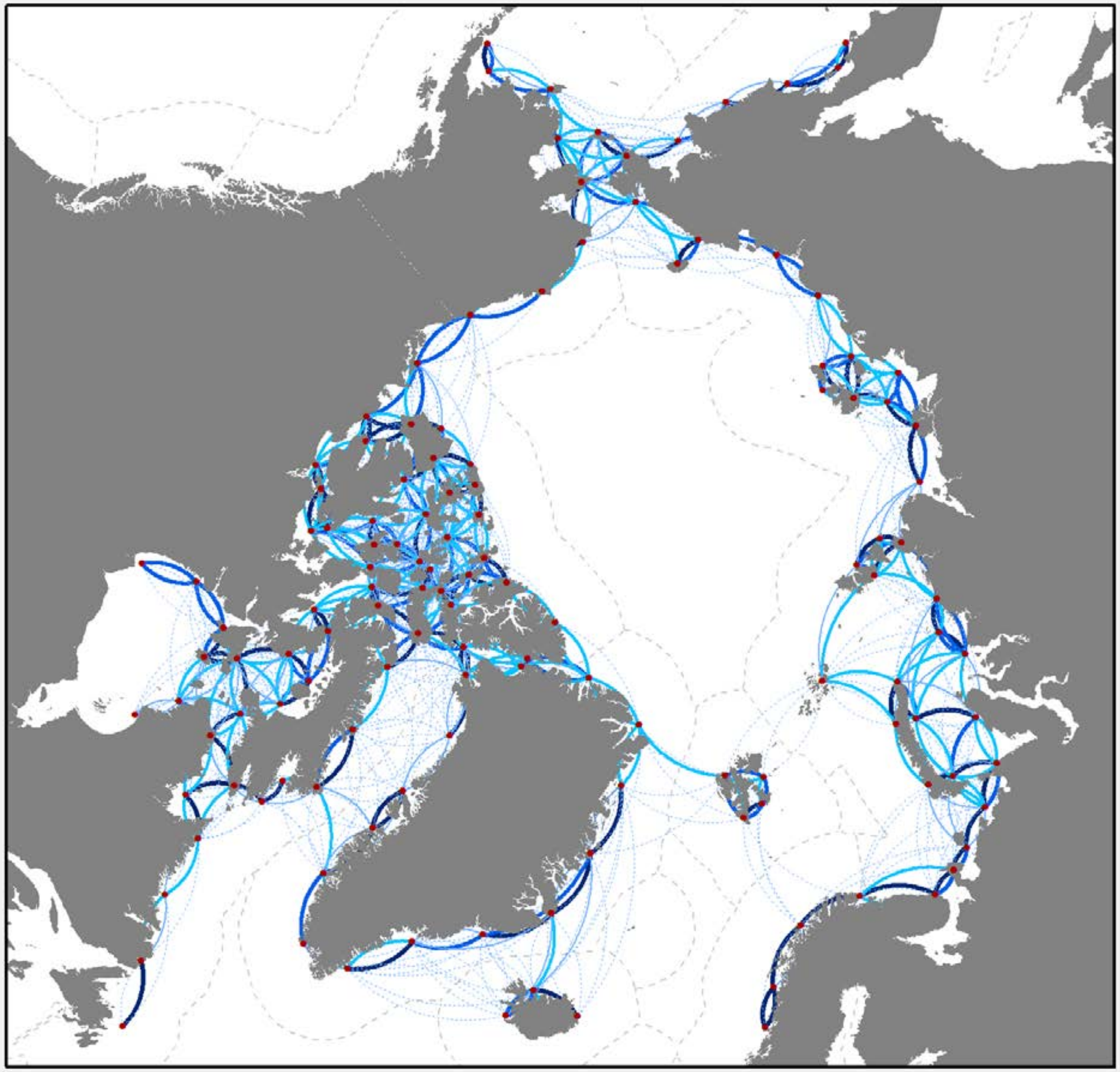


Summer 2012, 100 day connectivity

Arctic connectivity pilot analysis

Connectivity
100 days
winter
2012

Low ice year

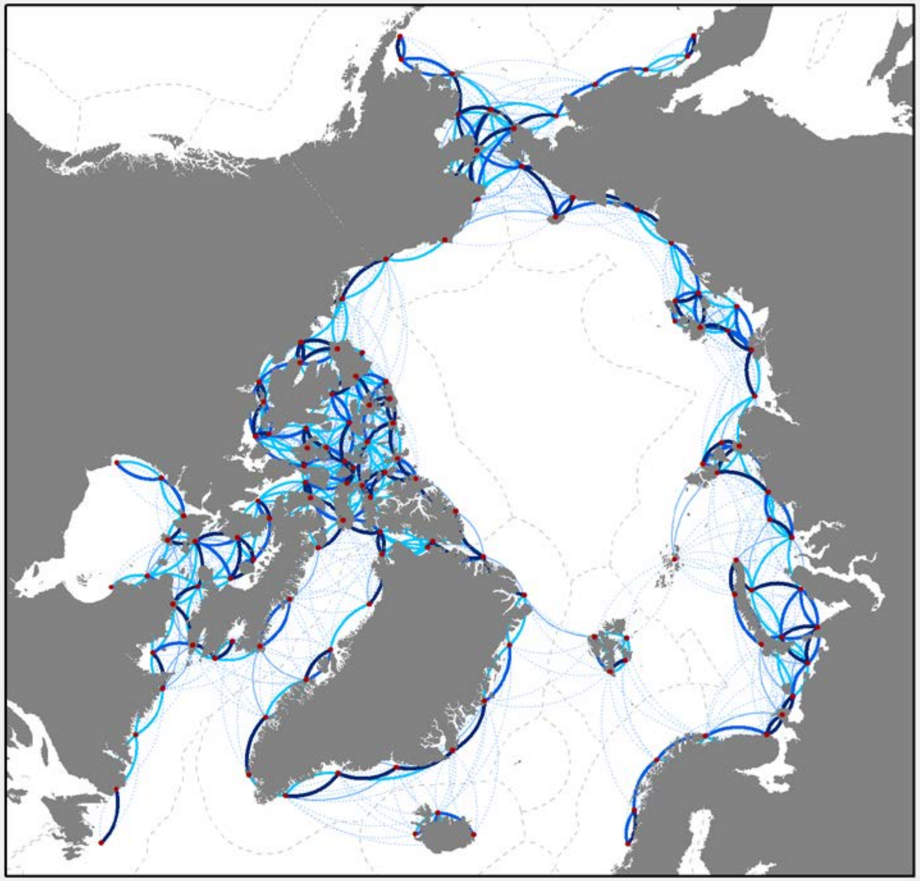


Winter 2012, 100 day connectivity

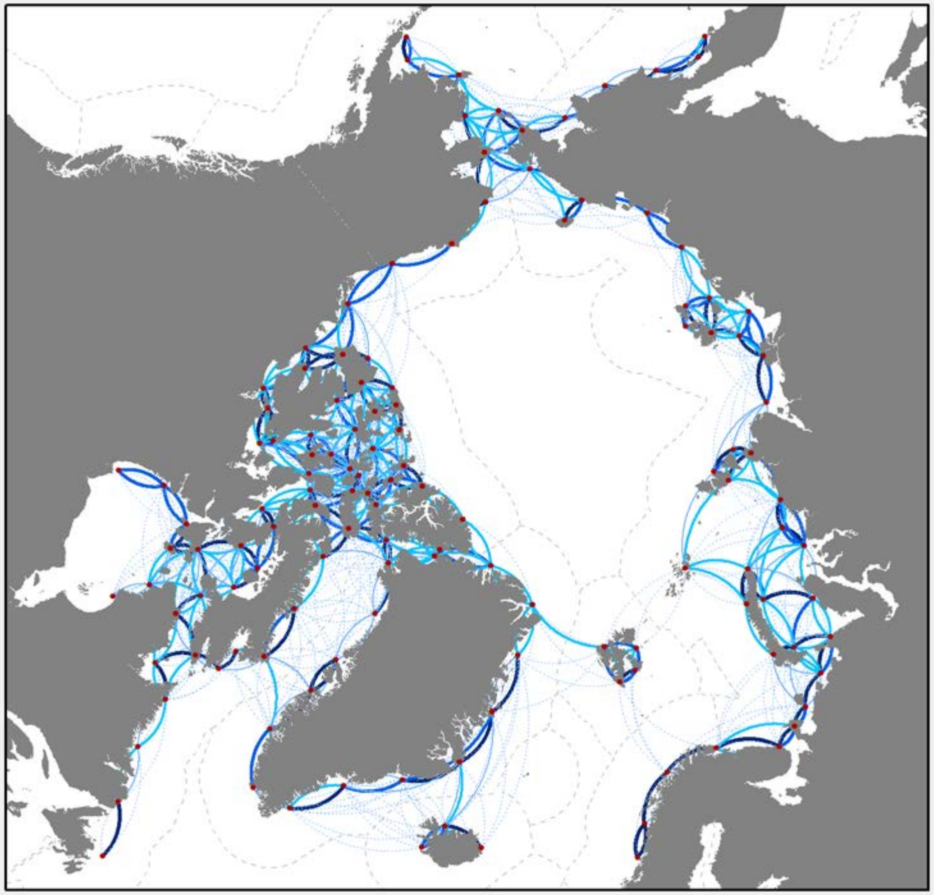
Arctic connectivity pilot analysis

summer / winter comparison

2012

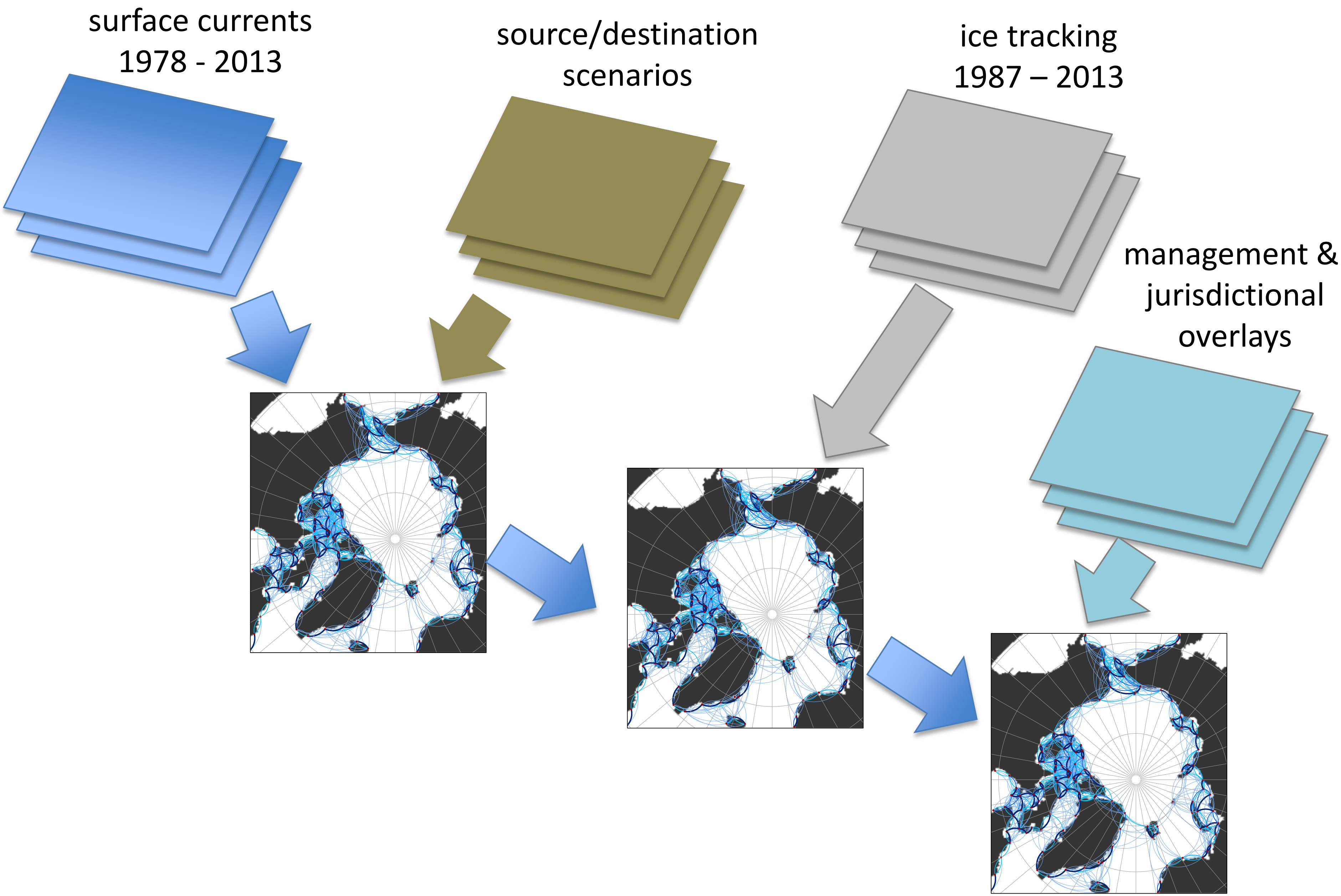


Summer 2012, 100 day connectivity



Winter 2012, 100 day connectivity

Arctic connectivity pilot analysis



Arctic connectivity pilot analysis

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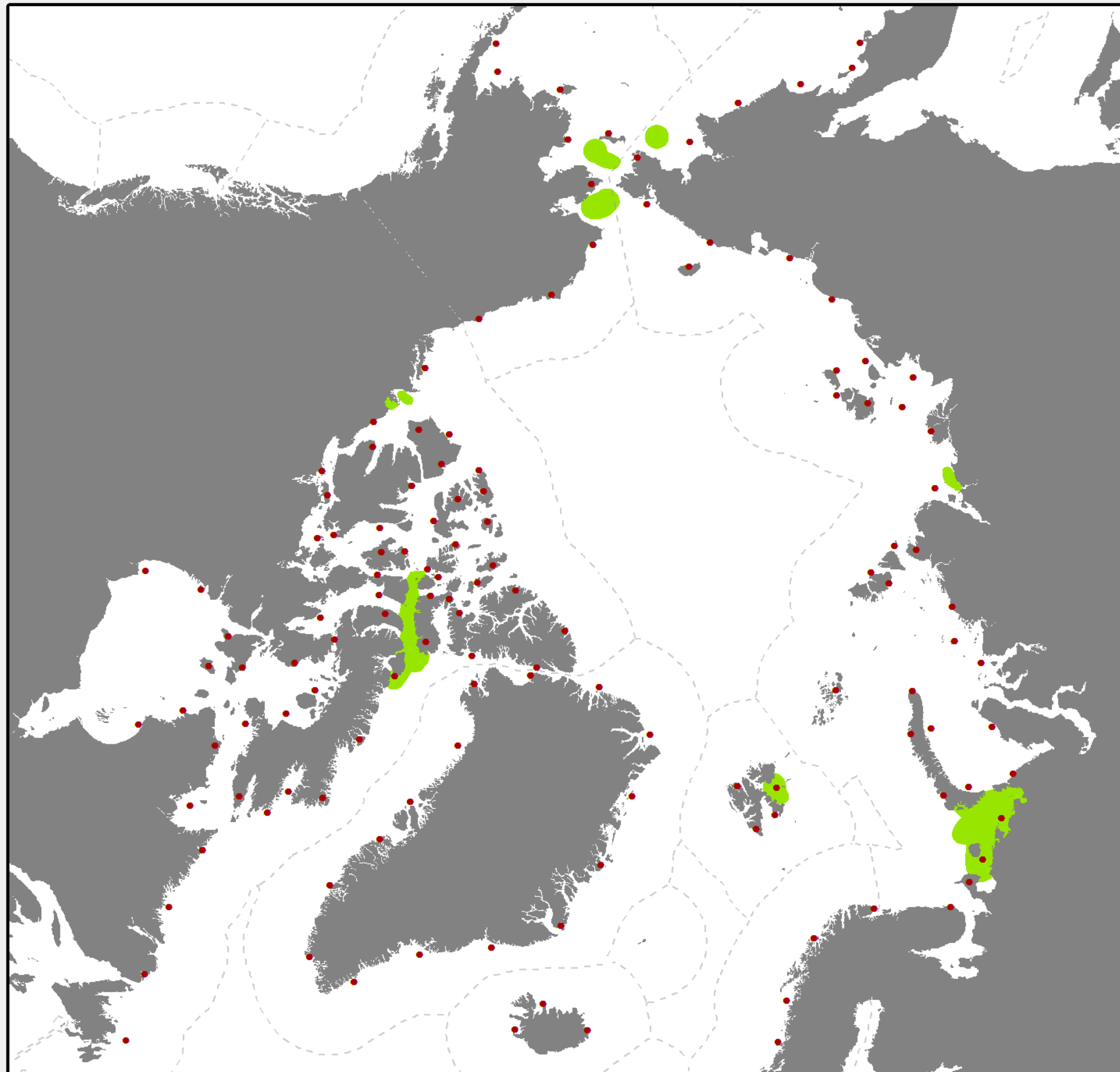
3 x 2 x 2 = 12 initial pilot scenarios

Arctic connectivity pilot analysis

Polar cod
Boreogadus saida
Spawning areas

From: AMSA-IIc



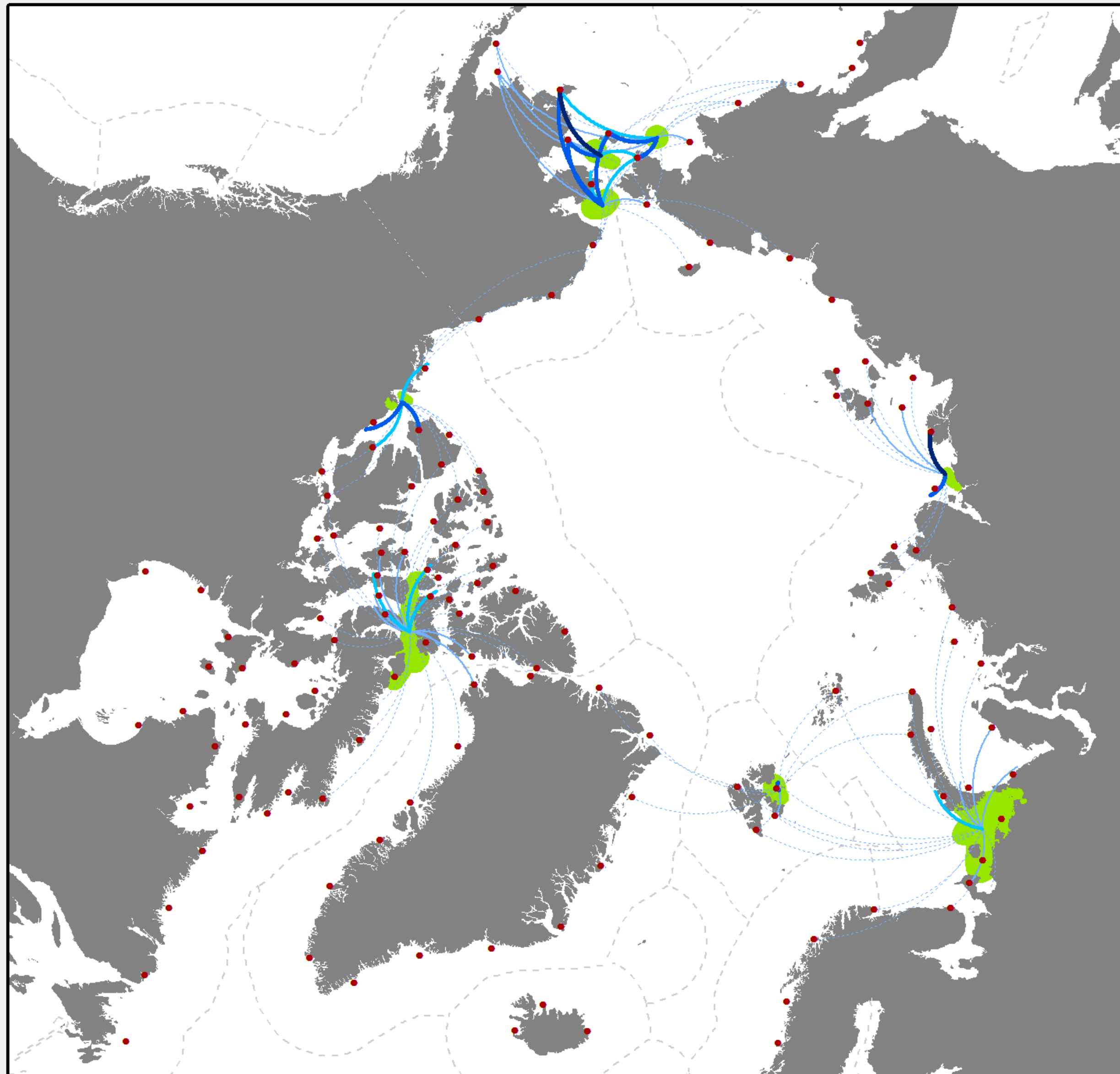
Polar Cod Spawning Areas (known and potential)

Arctic connectivity pilot analysis

Polar cod
Boreogadus saida
Spawning areas

From: AMSA-IIc

connectivity winter 1979



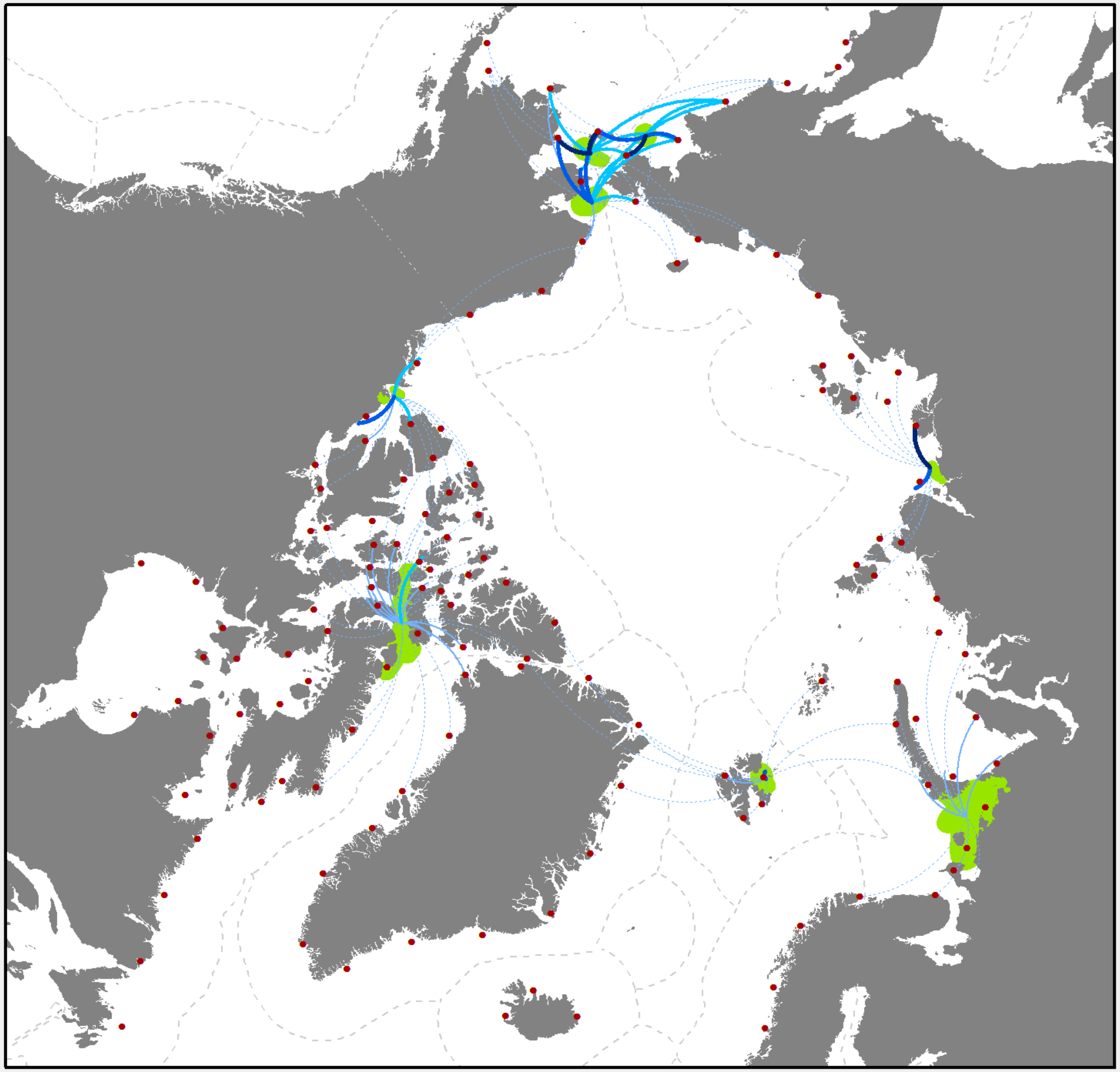
Polar Cod, Winter 1979, 275 day drift

Arctic connectivity pilot analysis

Polar cod
Boreogadus saida
Spawning areas

From: AMSA-IIc

connectivity winter 2012



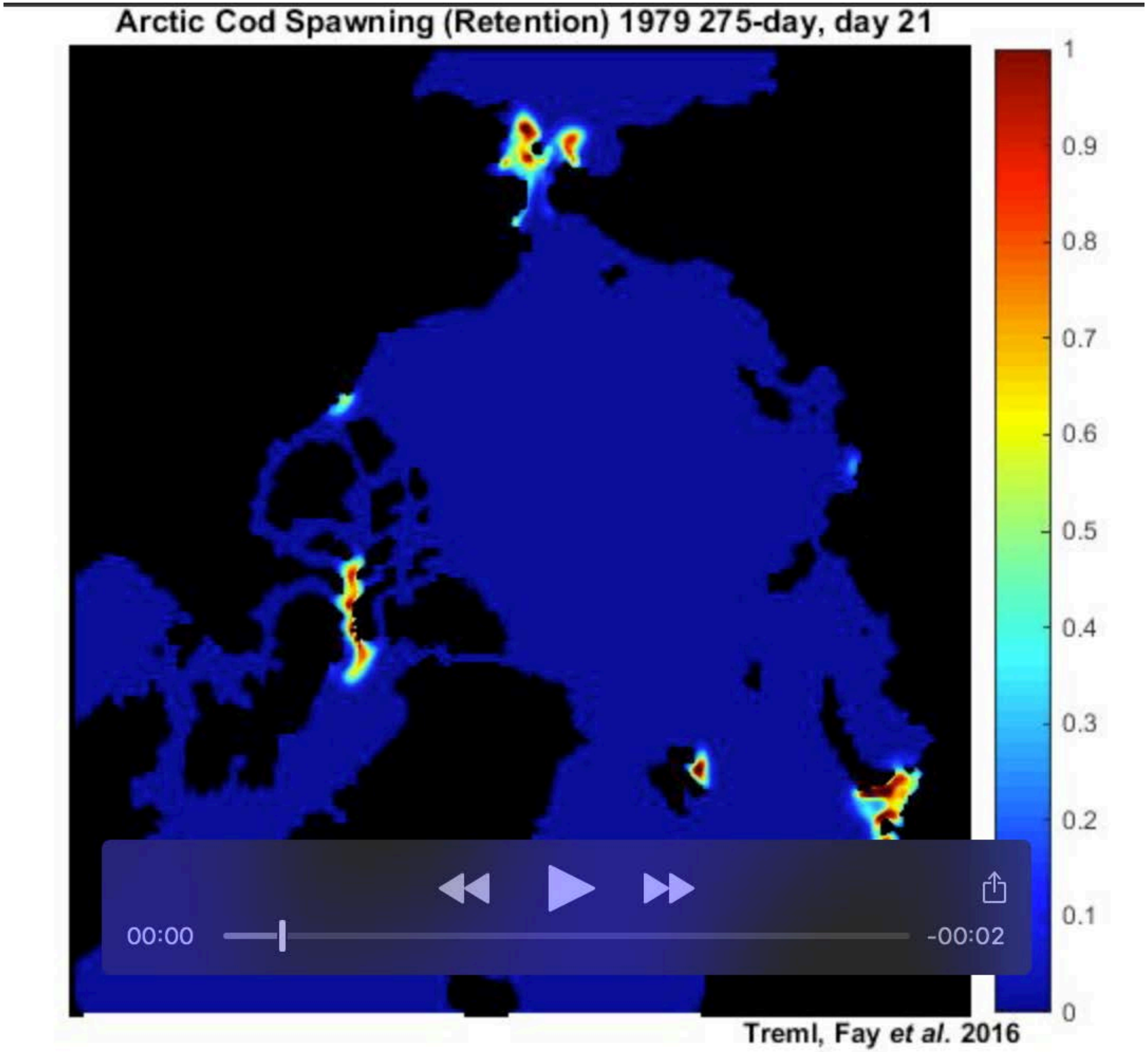
Polar Cod, Winter 2012, 275 day drift

Arctic connectivity pilot analysis

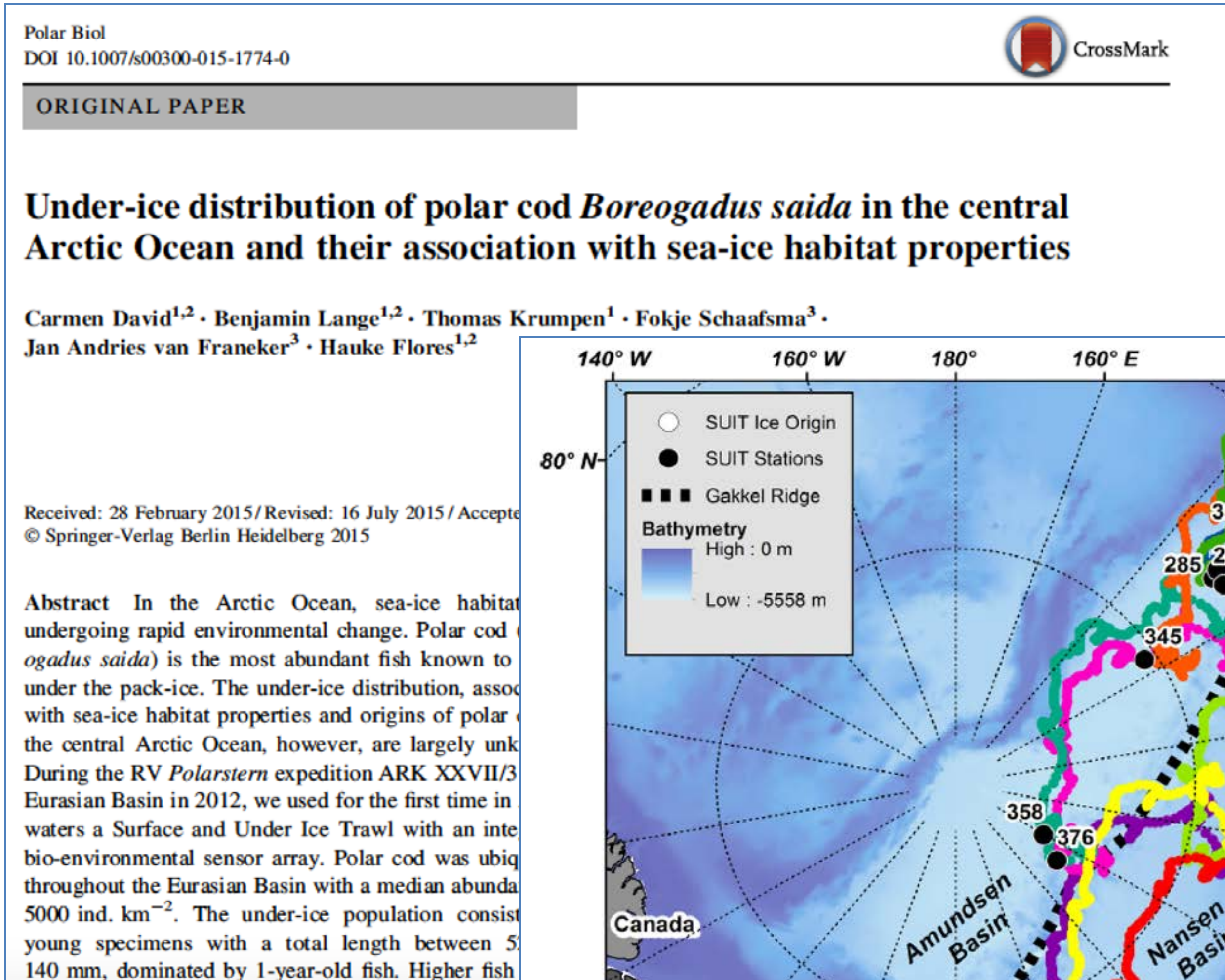
Polar cod
Boreogadus saida
Spawning areas

From: AMSA-IIc

Flow from spawning areas 1979



Arctic connectivity pilot analysis


Polar Biol
DOI 10.1007/s00300-015-1774-0

CrossMark

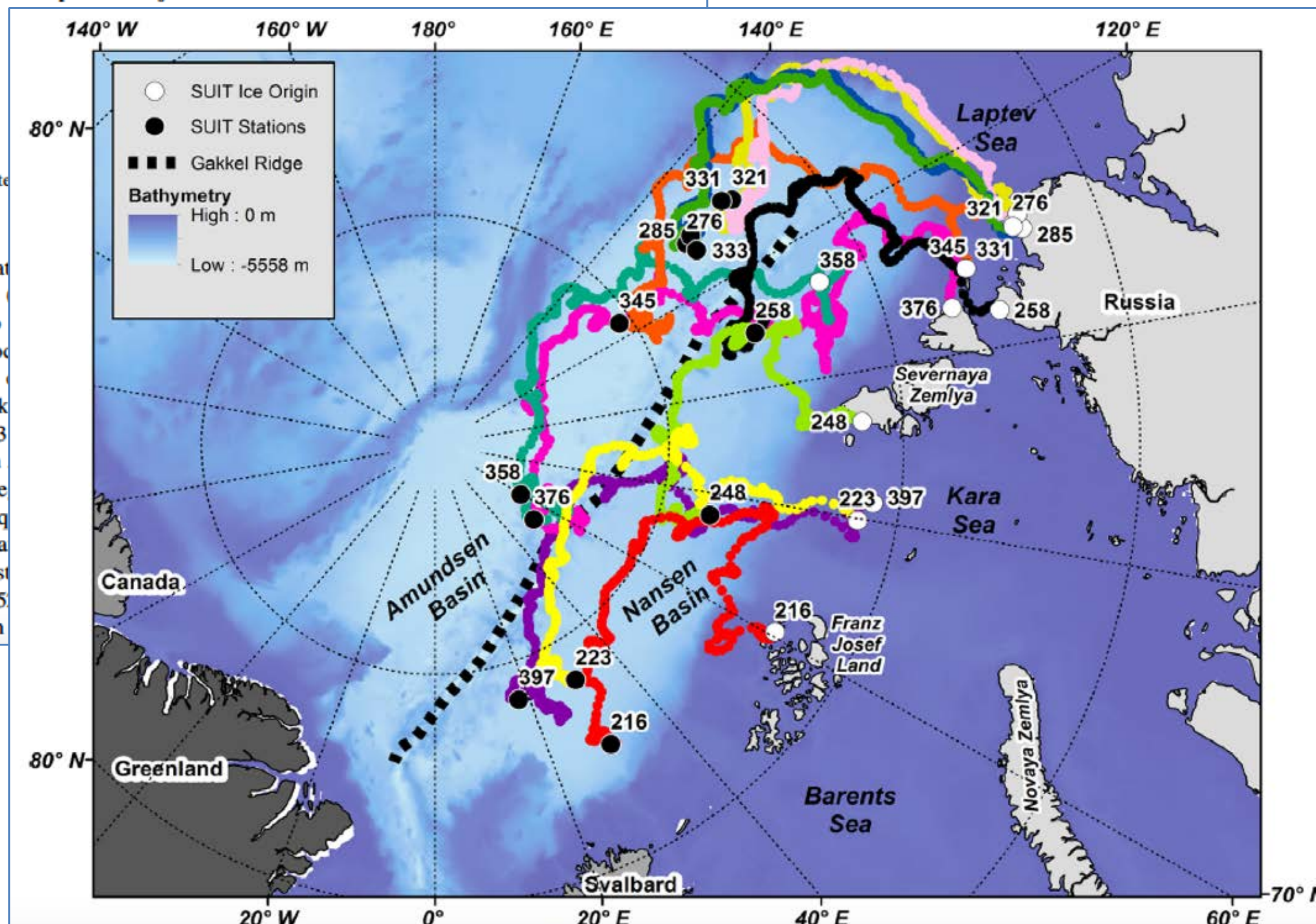
ORIGINAL PAPER

Under-ice distribution of polar cod *Boreogadus saida* in the central Arctic Ocean and their association with sea-ice habitat properties

Carmen David[1,2] · Benjamin Lange[1,2] · Thomas Krumpen[1] · Fokje Schaafsma[3] ·
Jan Andries van Franeker[3] · Hauke Flores[1,2]

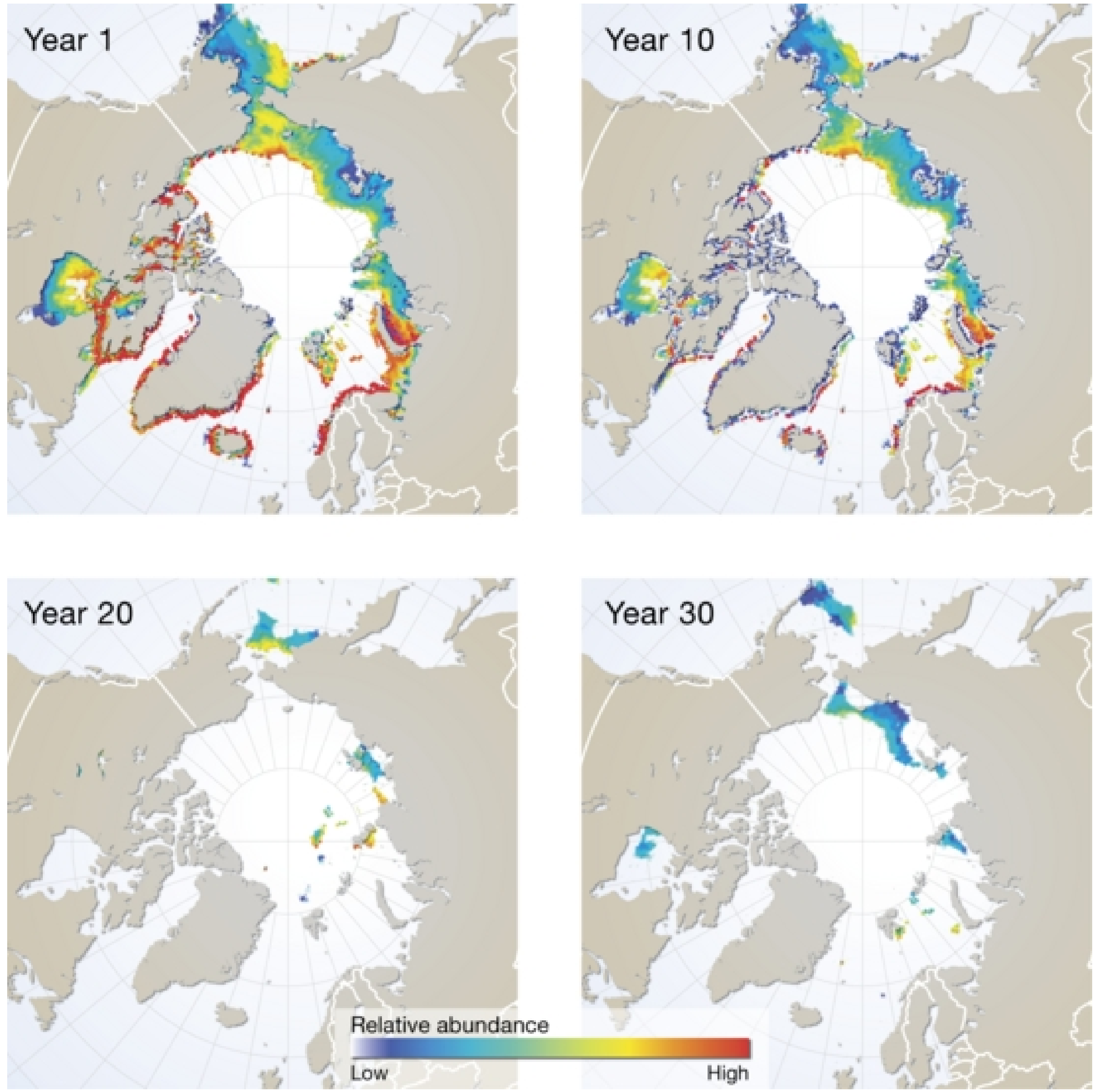
Received: 28 February 2015 / Revised: 16 July 2015 / Accepte

Abstract In the Arctic Ocean, sea-ice habitat
undergoing rapid environmental change. Polar cod (
ogadus saida) is the most abundant fish known to
under the pack-ice. The under-ice distribution, asso
with sea-ice habitat properties and origins of polar
the central Arctic Ocean, however, are largely unk
During the RV *Polarstern* expedition ARK XXVII/3
Eurasian Basin in 2012, we used for the first time in
waters a Surface and Under Ice Trawl with an inte
bio-environmental sensor array. Polar cod was ubiq
throughout the Eurasian Basin with a median abunda
5000 ind. km^{-2}. The under-ice population consist
young specimens with a total length between 5
140 mm, dominated by 1-year-old fish. Higher fish



Arctic connectivity pilot analysis

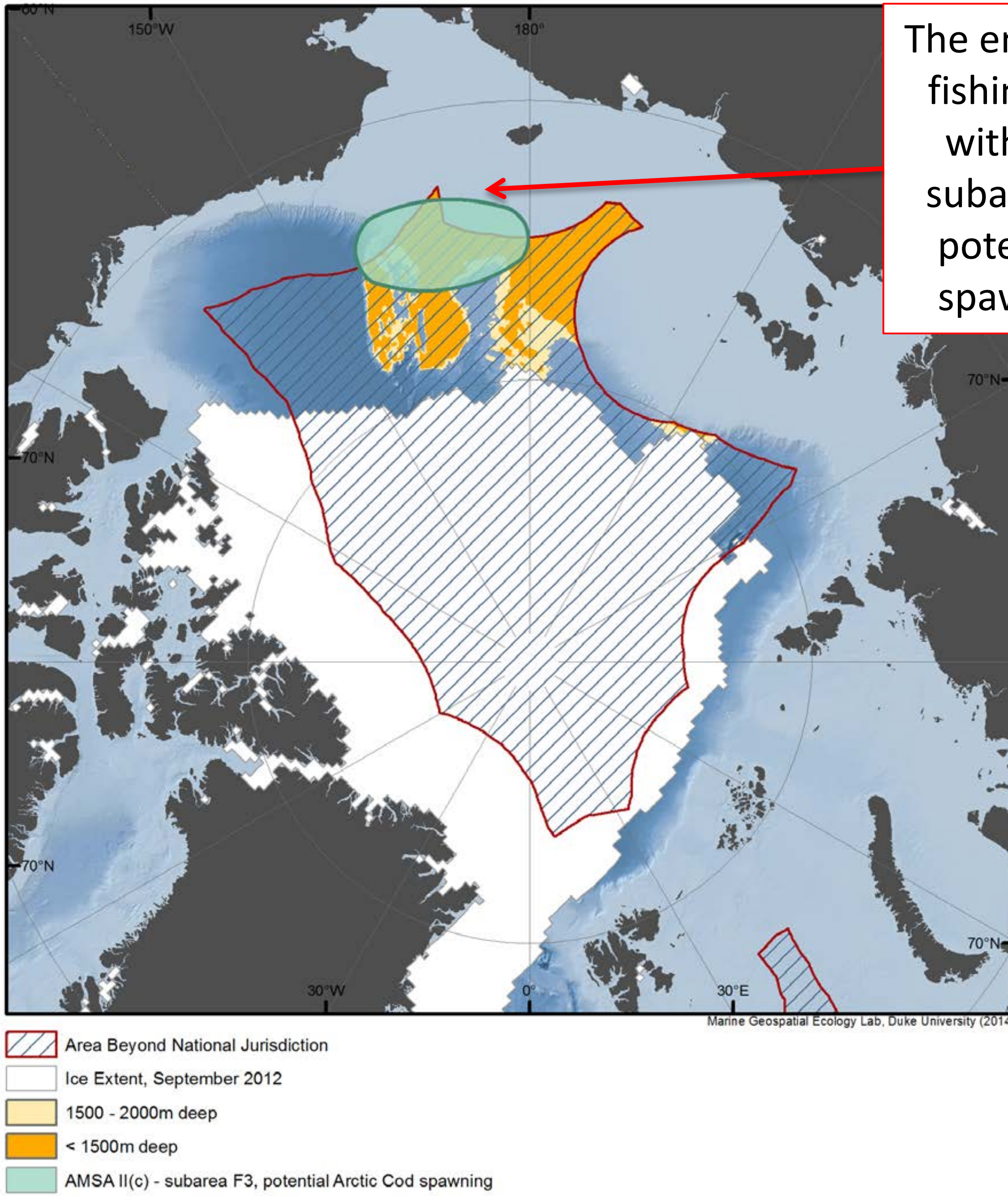
Simulated projections for Polar cod distribution with global warming



http://www.grida.no/graphicslib/detail/simulated-projections-for-polar-cod-distribution-with-global-warming_5c5a#

Potential deep sea fishing areas

Potential Arctic cod *(Arctogadus glacialis)* spawning area



The emerging deep sea fishing area overlaps with an AMSA-II(c) subarea identified as potential Arctic cod spawning habitat …

Arctic connectivity pilot analysis

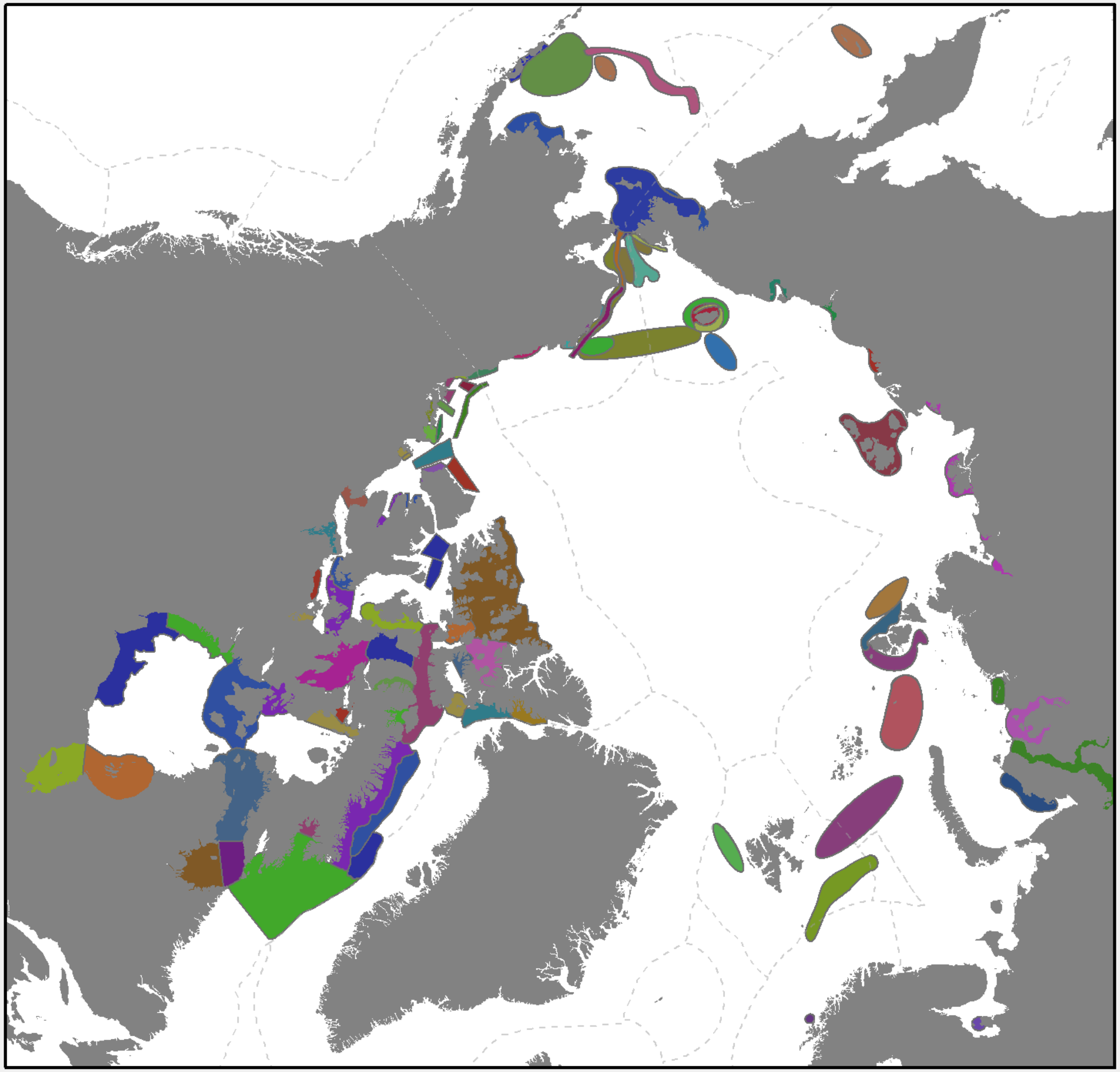
Potential pilot scenarios

Source / destination targets	"normal" ice year		"low" ice year	
Coastal areas (500km regions)	winter	summer	winter	summer
Fish spawning areas	winter	summer	winter	summer
Important feeding grounds	winter	summer	winter	summer

3 x 2 x 2 = 12 initial pilot scenarios

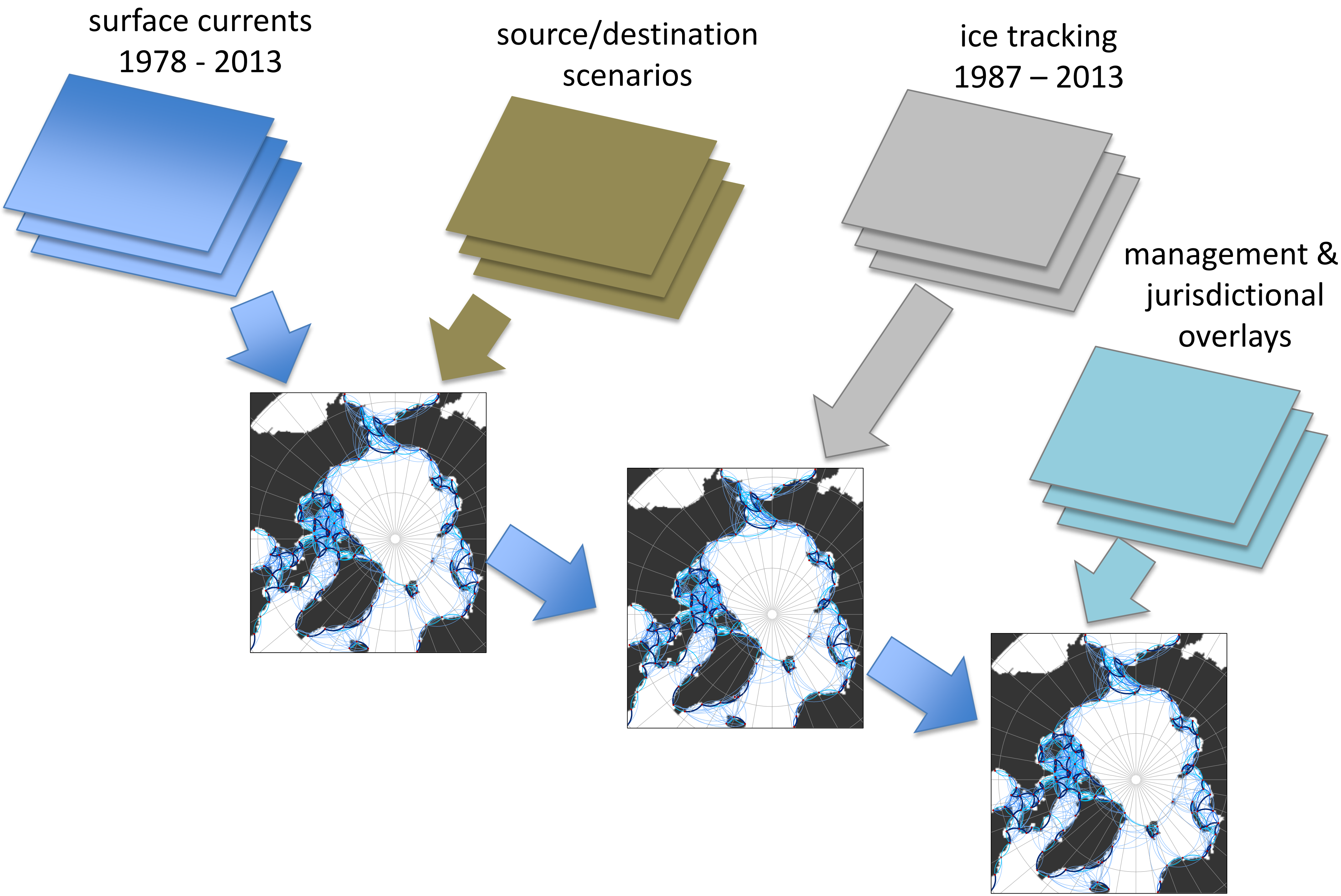
Arctic connectivity pilot analysis

Foraging areas
AMSA-IIc
(multiple types)



Feeding areas - AMSA IIC

Arctic connectivity pilot analysis



Topics:

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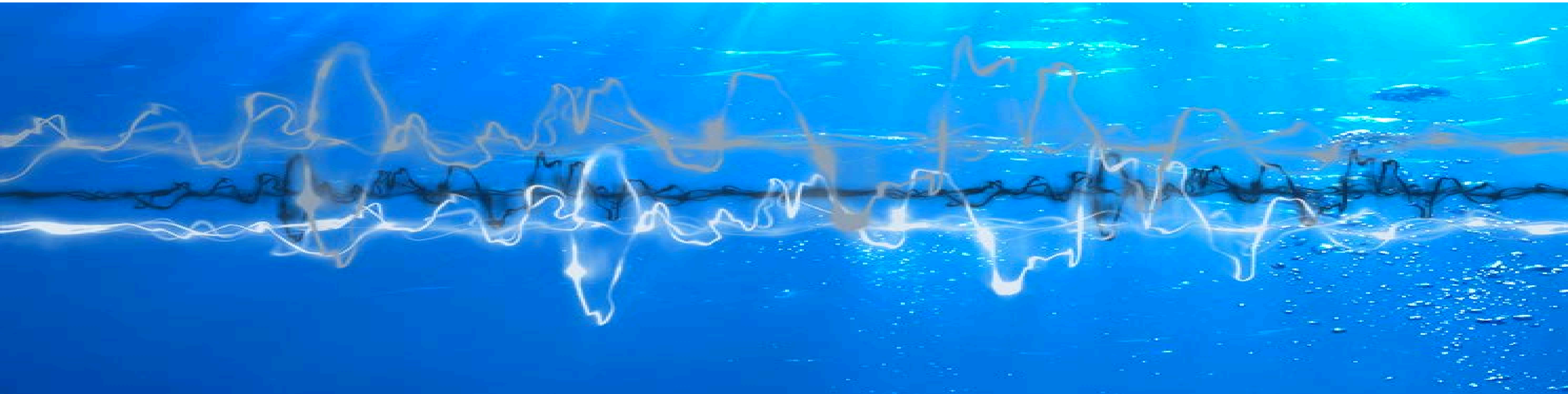
- Arctic connectivity pilot studies
- Next steps

Next steps

- Complete initial pilot study
  - Coastal connectivity
  - Fish spawning areas
  - Foraging areas
- Identify pan-arctic trends across ecoregions
- Identify further case studies / applications
- Further develop connectivity tools for use in the Arctic “toolbox”



Multi-target conservation network planning

Chukchi & Beaufort Sea Regions

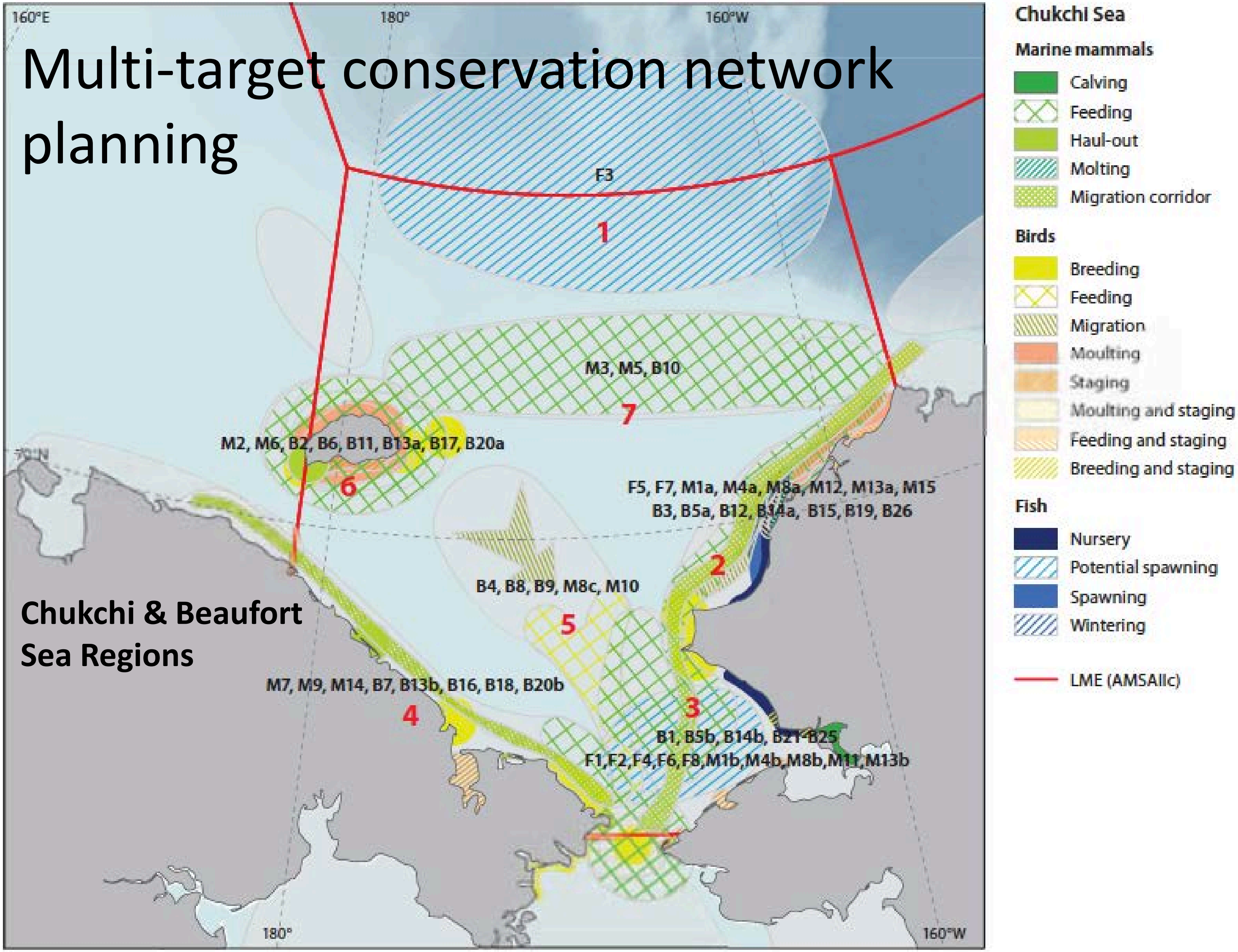
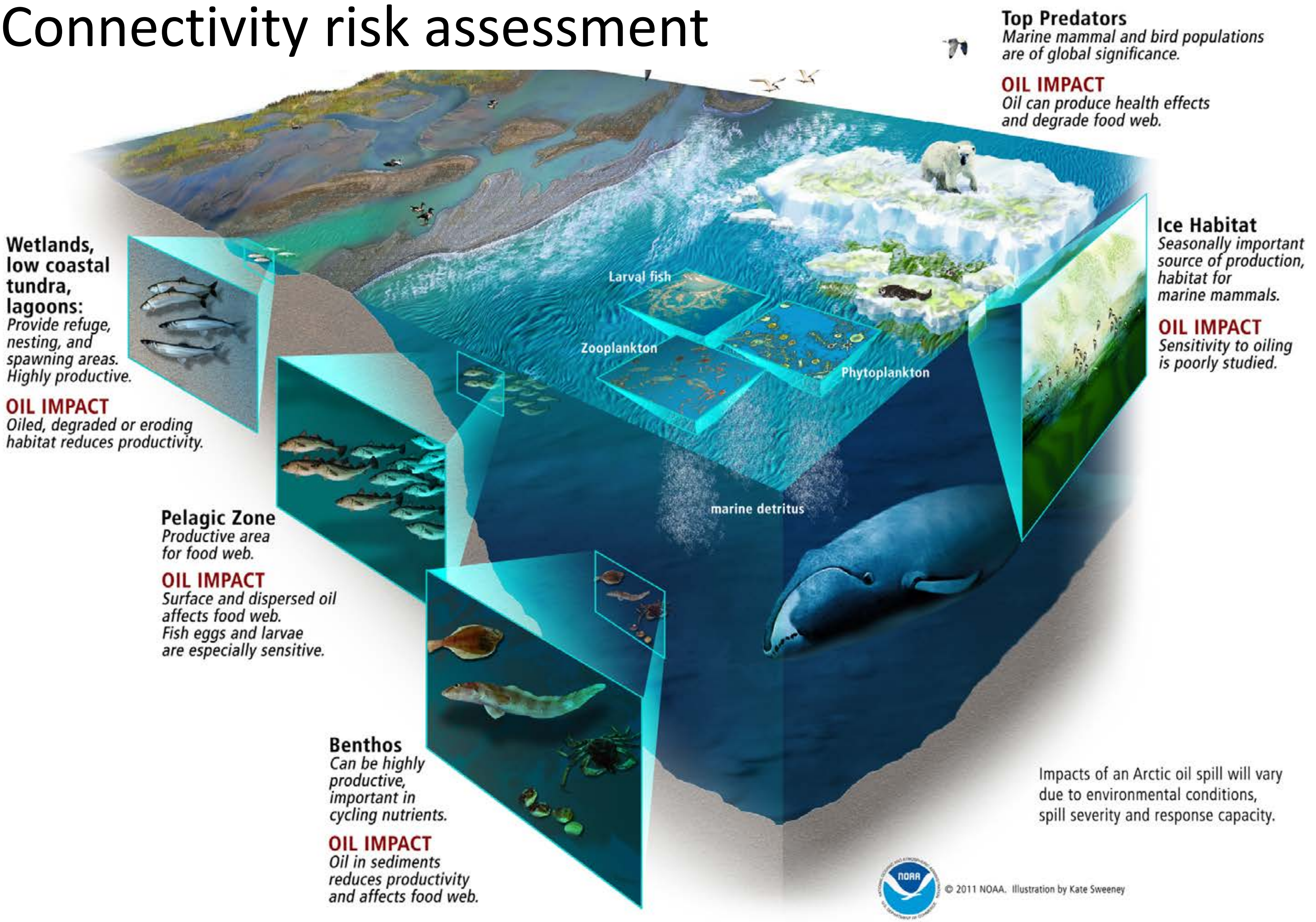


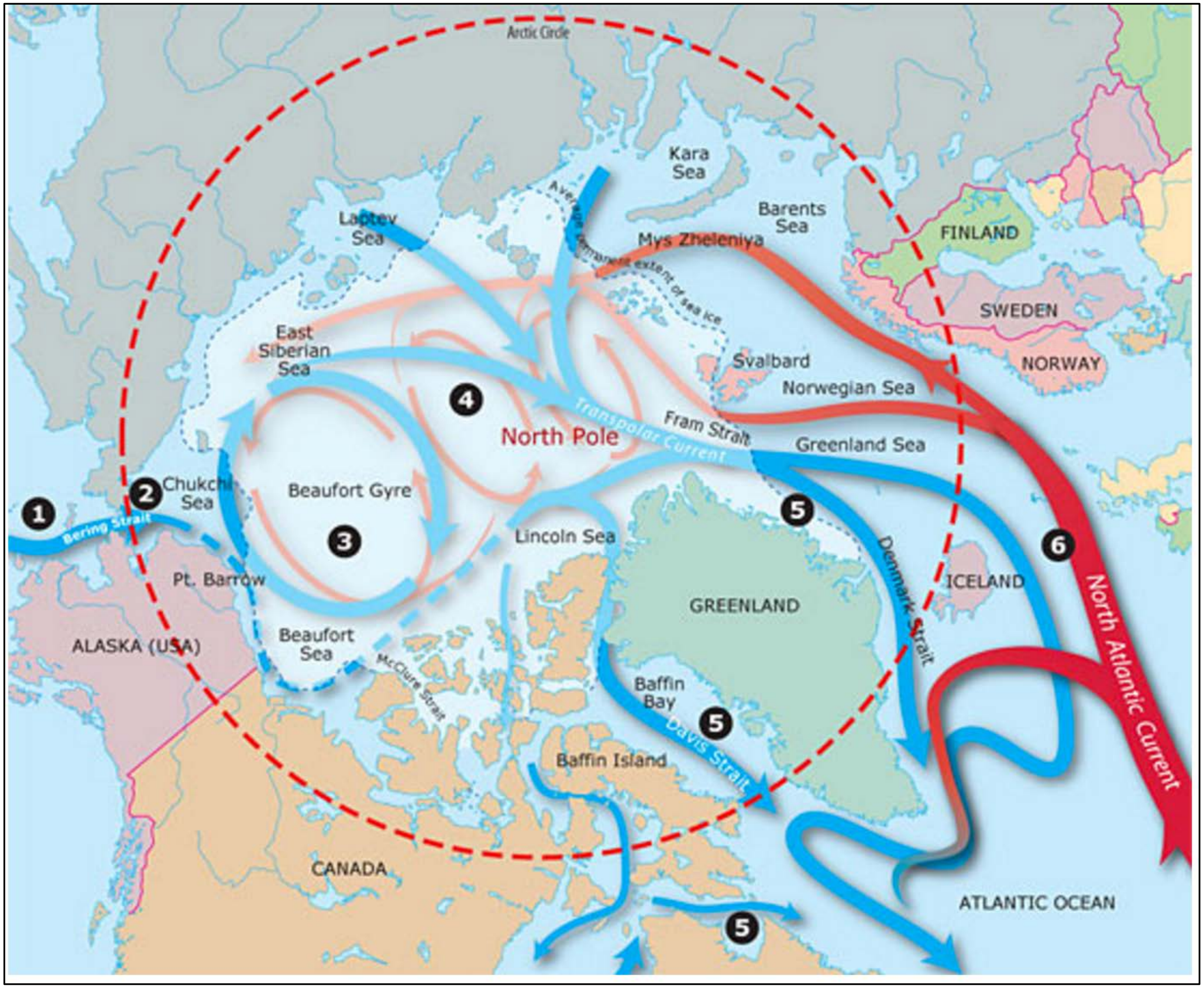
Figure A.11a. Areas of heightened ecological significance in the Chukchi Sea LME.

Connectivity risk assessment



http://usresponserestoration.files.wordpress.com/2011/05/arctic-food-webs-oil-impacts-illustration_noaa_katesweeney.jpg

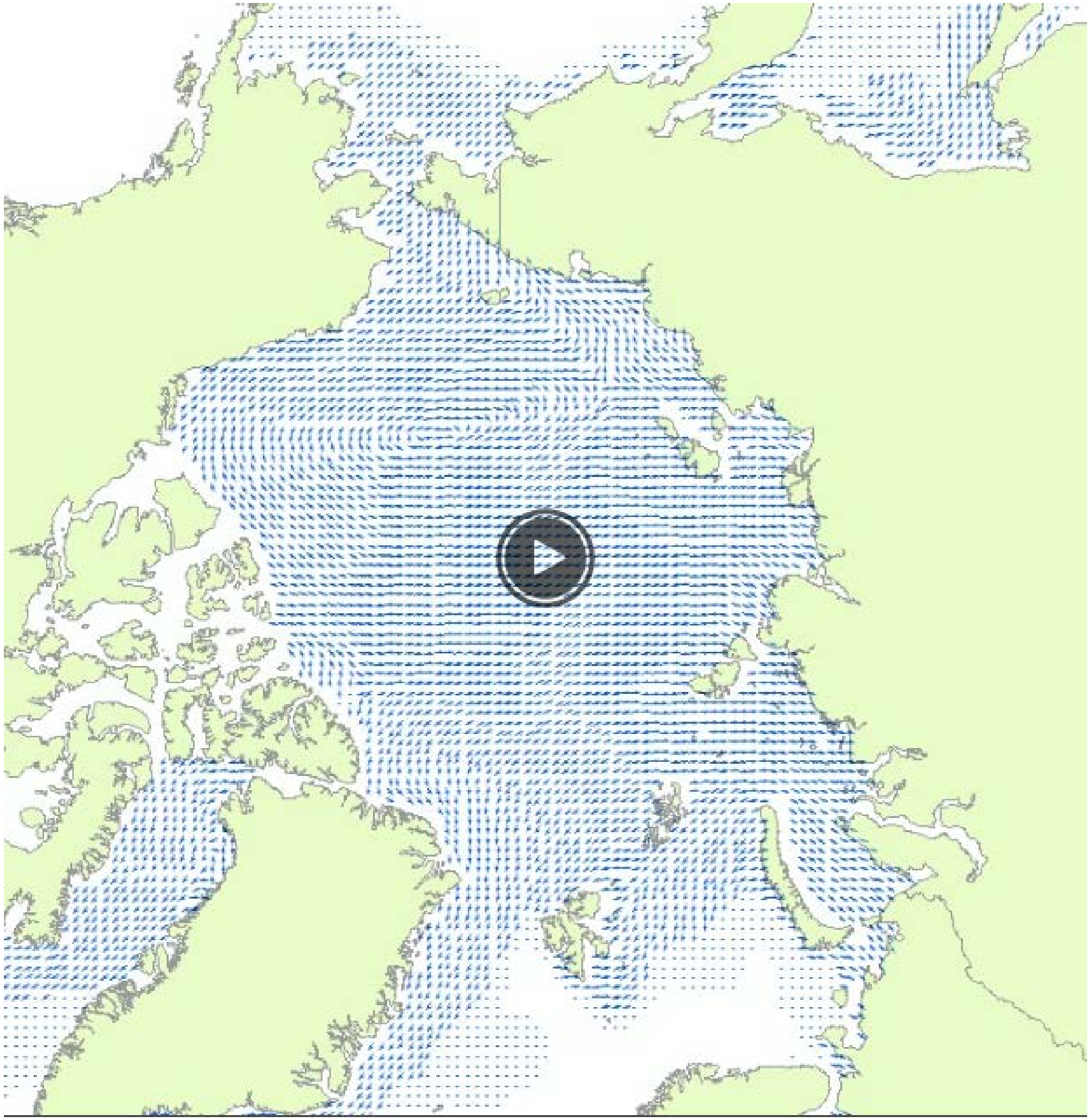
Discussion



Arctic Circle
Kara Sea
Barents Sea
Laptev Sea
Mys Zheleniya
FINLAND
SWEDEN
NORWAY
East Siberian Sea
Svalbard
Norwegian Sea
North Pole
Transpolar Current
Fram Strait
Greenland Sea
Beaufort Gyre
Chukchi Sea
Bering Strait
Lincoln Sea
Denmark Strait
ICELAND
North Atlantic Current
Pt. Barrow
GREENLAND
ALASKA (USA)
Beaufort Sea
McClure Strait
Baffin Bay
Davis Strait
Baffin Island
CANADA
ATLANTIC OCEAN
1
2
3
4
5
6

Arctic connectivity pilot analysis

Ice area/movement

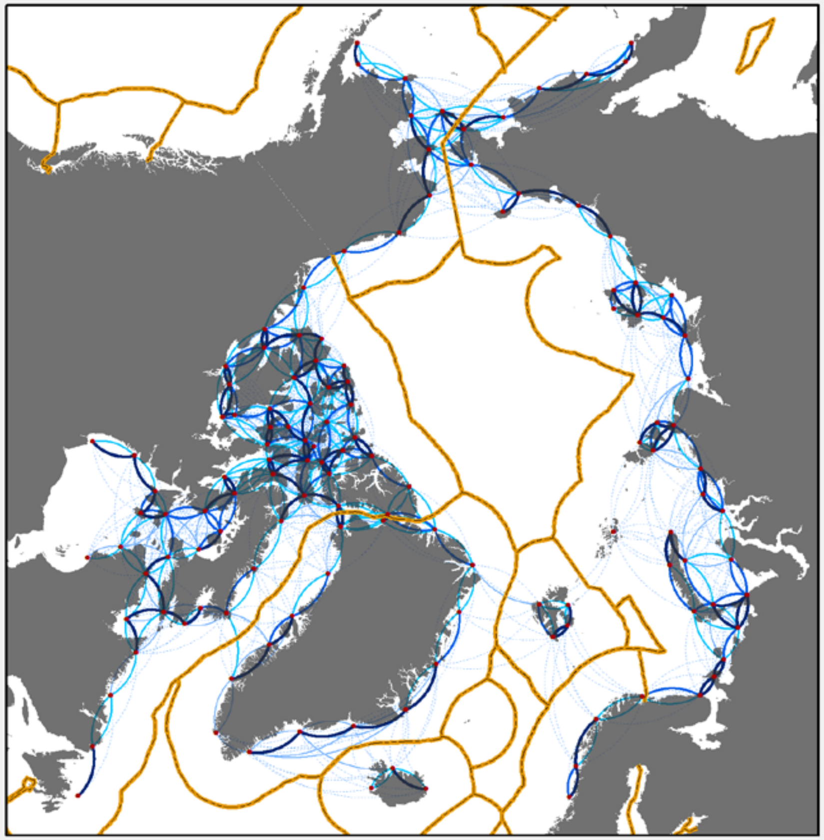


Monthly mean ice velocity circulation, NSIDC data:

Arctic connectivity pilot analysis

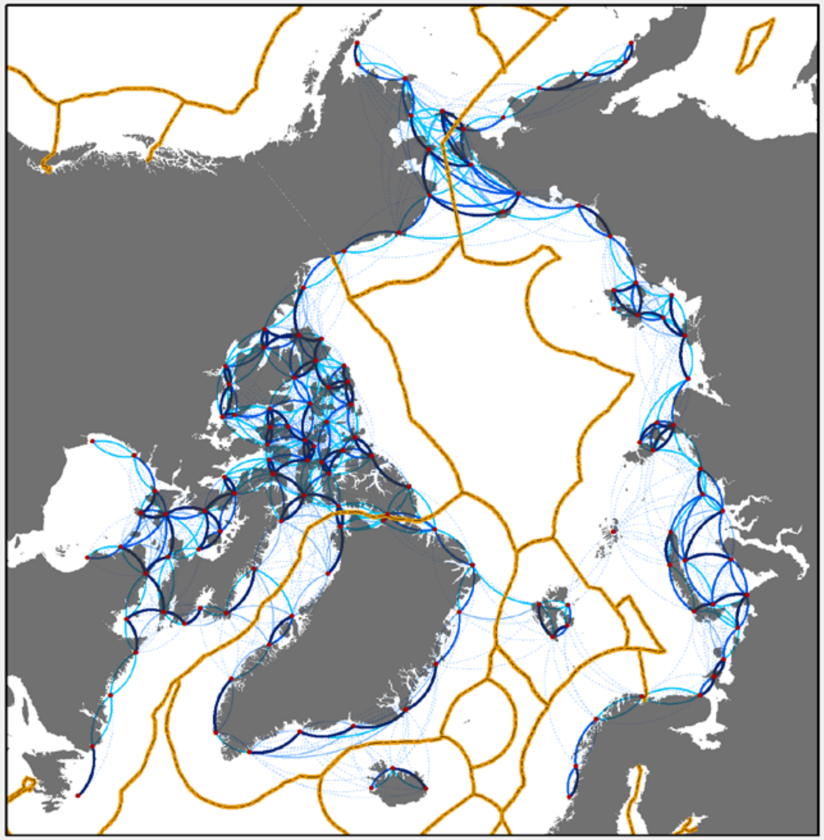
Jurisdictional EEZ / ABNJ

February



February

September



September