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

Patrick Halpin & Jesse Cleary
John Fay
Marine Geospatial Ecology Lab
Duke University

Eric Treml
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...
...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 affecting 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

Winter

Spring

Autumn

Summer

Projected temperature change, °C

©AMAP
Changing freshwater circulation

Russian runoff “freshening” Canadian waters...
Changing wind regimes

61 km/h or 38 mph
Arctic Ocean green circle surface

August 26, 2016, 18:00 UTC
Northern Hemisphere Wind speed

Wind @ 250hPa (jet stream)

Created by Sam Carana with nullschool.net images for Arctic-news.blogspot.com
Changing sea ice
Changing seasonality/phenology

A

B

Autotroph

Biomass

Heterotroph
Topics:
• The Arctic context
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• Next steps
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

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

Steven R. Schill1, George T. Raber**, Jason J. Roberts4, Eric A. Tremblay2, Jorge Brenner3, Patrick N. Halpin4

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 (EEZ) 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.

**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..."
Caribbean Biological Corridor Connectivity Model
Simulation of a coral mass spawning event and larval dispersal.
24 AUG 2008  Time 19:00
Strength of Reef Connections

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:

• The Arctic context
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• Next steps
Arctic connectivity pilot analysis

- Surface currents 1978 - 2013
- Source/destination scenarios
- Ice tracking 1987 – 2013
- Management & jurisdictional overlays
Arctic connectivity pilot analysis

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

Monthly data, 1978 – 2013
partially-coupled, data assimilative
Arctic connectivity pilot analysis

Potential pilot scenarios

<table>
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3 x 2 x 2 = 12 initial pilot scenarios
**Arctic connectivity pilot analysis**

**Potential pilot scenarios**

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3 x 2 x 2 = 12 initial pilot scenarios
Arctic connectivity pilot analysis

500km coastal segments
Arctic Sea Ice Extent

(Area of Ocean with at least 15% sea ice)

1979 – “normal” ice extent
Coastal water connectivity
summer normal year (1979)
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
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.
Coastal water connectivity
summer vs. winter normal year (1979)
### Arctic connectivity pilot analysis

#### Potential pilot scenarios

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3 x 2 x 2 = 12 initial pilot scenarios
Arctic connectivity pilot analysis

2012 - low ice extent
Connectivity
100 days
summer
2012

Low ice year
Arctic connectivity pilot analysis

Connectivity
100 days
winter
2012

Low ice year
Arctic connectivity pilot analysis
summer / winter comparison
2012
Arctic connectivity pilot analysis

- Surface currents 1978 - 2013
- Source/destination scenarios
- Ice tracking 1987 – 2013
- Management & jurisdictional overlays
## Arctic connectivity pilot analysis

### Potential pilot scenarios

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Arctic connectivity pilot analysis

Polar cod
*Boreogadus saida*
Spawning areas

From: AMSA-IIc
Polar cod
*Boreogadus saida*
Spawning areas

From: AMSA-IIc

connectivity winter 1979
Arctic connectivity pilot analysis

Polar cod
*Boreogadus saida*
Spawning areas

From: AMSA-IIC

connectivity winter 2012
Arctic connectivity pilot analysis

Polar cod
*Boreogadus saida*
Spawning areas

From: AMSA-IIc

Flow from spawning areas 1979
Under-ice distribution of polar cod *Boreogadus saida* in the central Arctic Ocean and their association with sea-ice habitat properties

Carmen David¹², Benjamin Lange¹², Thomas Krumpen¹, Fokje Schaafsma³, Jan Andries van Franeker³, Hauke Flores¹²

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Abstract In the Arctic Ocean, sea-ice habitat is undergoing rapid environmental change. Polar cod (*Boreogadus saida*) is the most abundant fish known to use the pack-ice. The under-ice distribution, associated with sea-ice habitat properties and origins of polar cod in the central Arctic Ocean, however, are largely unknown. During the RV *Polarstern* expedition ARK XXVII/3 in the Eurasian Basin in 2012, we used for the first time in waters a Surface and Under Ice Trawl with an integrated bio-environmental sensor array. Polar cod was ubiquitous throughout the Eurasian Basin with a median abundance of 5000 ind. km⁻². The under-ice population consisted of young specimens with a total length between 5 and 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

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$3 \times 2 \times 2 = 12$ initial pilot scenarios
Arctic connectivity pilot analysis

Foraging areas
AMSA-IIc
(multiple types)
Arctic connectivity pilot analysis

- Surface currents 1978 - 2013
- Source/destination scenarios
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Topics:
• The Arctic context
• Connectivity modeling framework
• 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

Top Predators
Marine mammal and bird populations are of global significance.

Oil Impact
Oil can produce health effects and degrade food web.

Ice Habitat
Seasonally important source of production, habitat for marine mammals.

Oil Impact
Sensitivity to oiling is poorly studied.

Wetlands, low coastal tundra, lagoons:
Provide refuge, nesting, and spawning areas. Highly productive.

Oil Impact
Oiled, degraded or eroding habitat reduces productivity.

Pelagic Zone
Productive area for food web.

Oil Impact
Surface and dispersed oil affects food web. Fish eggs and larvae are especially sensitive.

Benthos
Can be highly productive, important in cycling nutrients.

Oil Impact
Oil in sediments reduces productivity and affects food web.

Impacts of an Arctic oil spill will vary due to environmental conditions, spill severity and response capacity.

http://usresponserestoration.files.wordpress.com/2011/05/arctic-food-webs-oil-impacts-illustration_noaa_katesweeney.jpg
Discussion
Arctic connectivity pilot analysis

Ice area/movement

Monthly mean ice velocity circulation, NSIDC data:
Arctic connectivity pilot analysis

February

Jurisdictional EEZ / ABNJ

September