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IMPLICATIONS OF A CHANGING EARTH: OBVIOUS AND CASCADING

"Charleston Flooded" BATIK by Mary Edna Fraser, Charleston, SC, USA

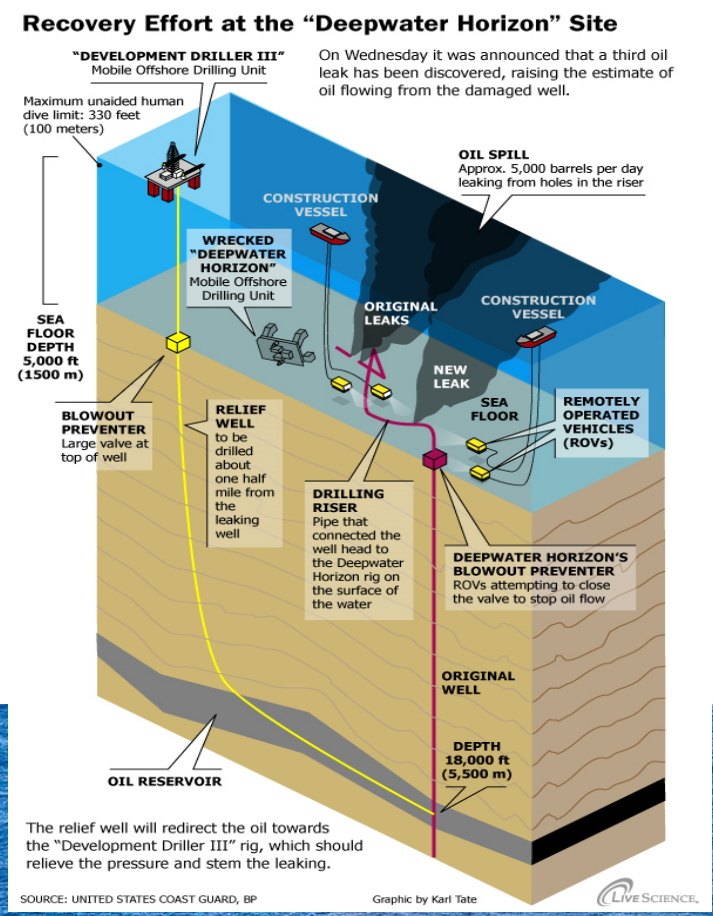
Building a perspective of a Changing Earth

- Change in the state of the Earth and Ocean
- Focused somewhat on the Ocean
- Warming and sea level rise
- Loss of ice cover
- Ocean acidification
- Pollutants: oil, plastics, inorganic nitrogen
- Productivity, diversity, fisheries declines
- Migratory bird populations

Some of the change has a direct relationship to human activity

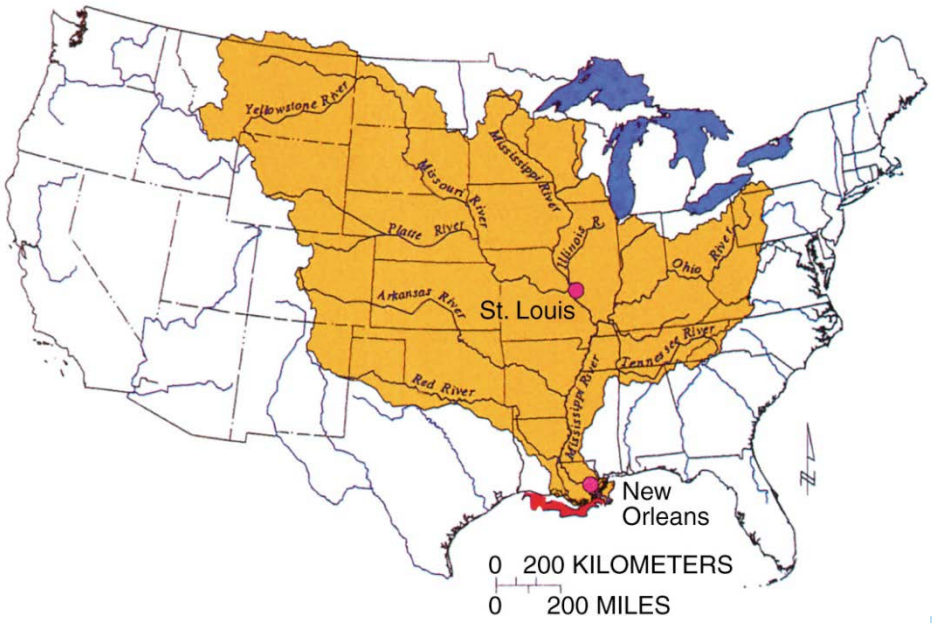
- Plastic waste; islands of waste in central gyres. Unknown effects include particles entering foodchains, endocrine disruption by manufacturing chemicals (BPA)
- Oil spills
- Loss of diversity and modification of trophic structure (food webs) or environment, habitat (overfishing, lack of stock management)

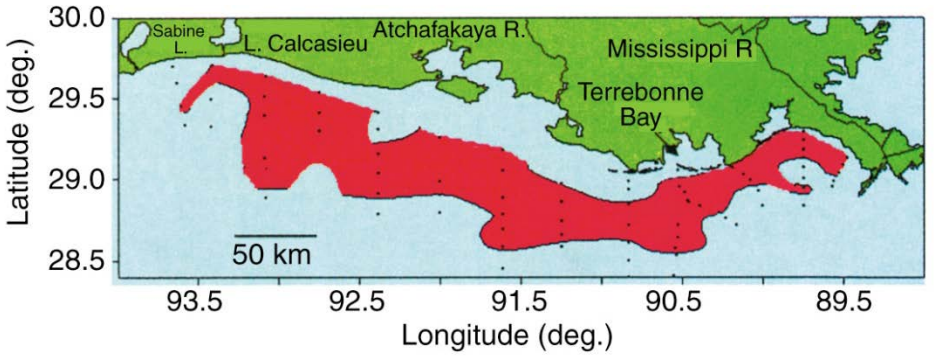
5 MT/year; 50,000 piece/ sq mi

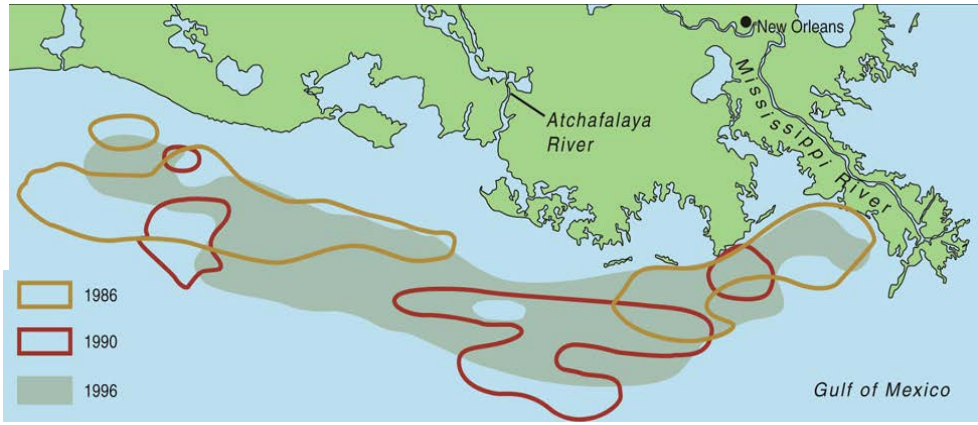


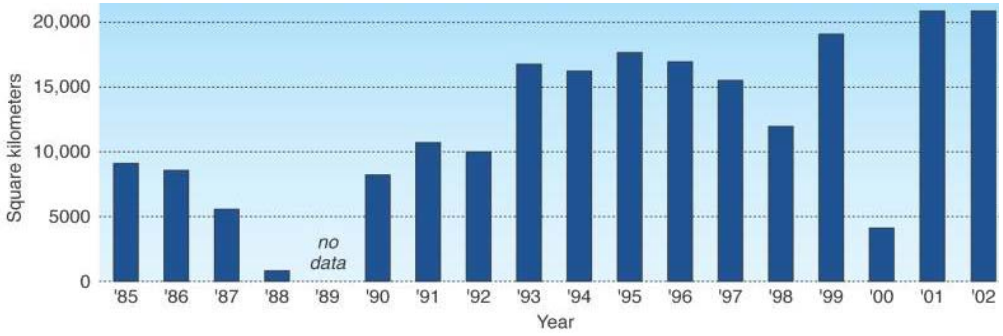
Spill date: 20 April – 15 July 2010
Well officially sealed: 19 September 2010

up to 4,900,000 barrels;
(206,000,000 US gallons;
779,000 cubic meters)







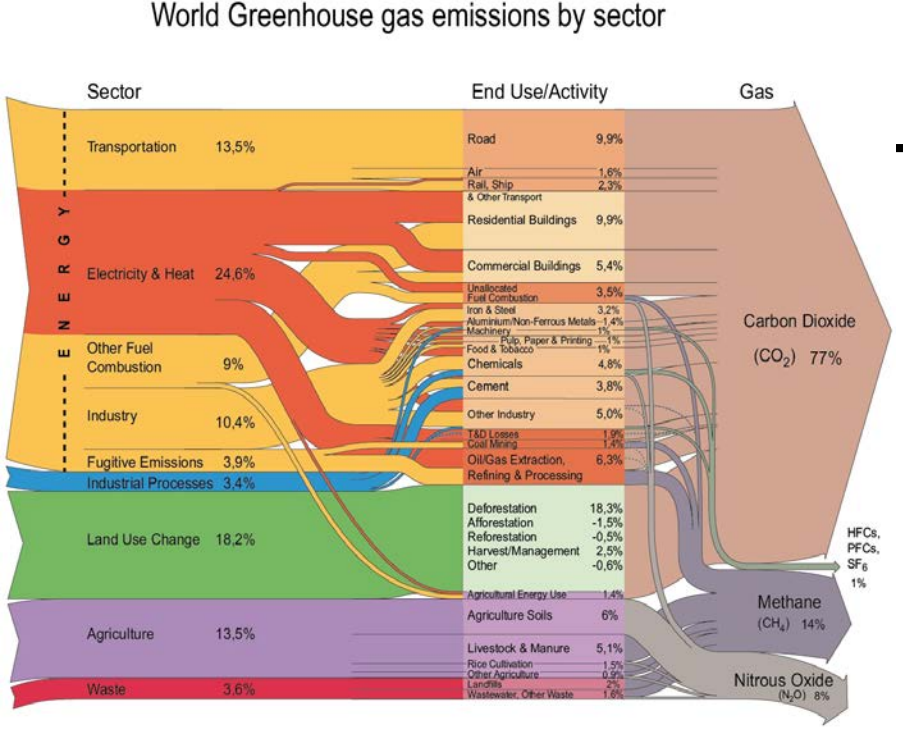


Dead Zones in the Gulf of Mexico


The Earth in a time of climate change

The “usual” suspects

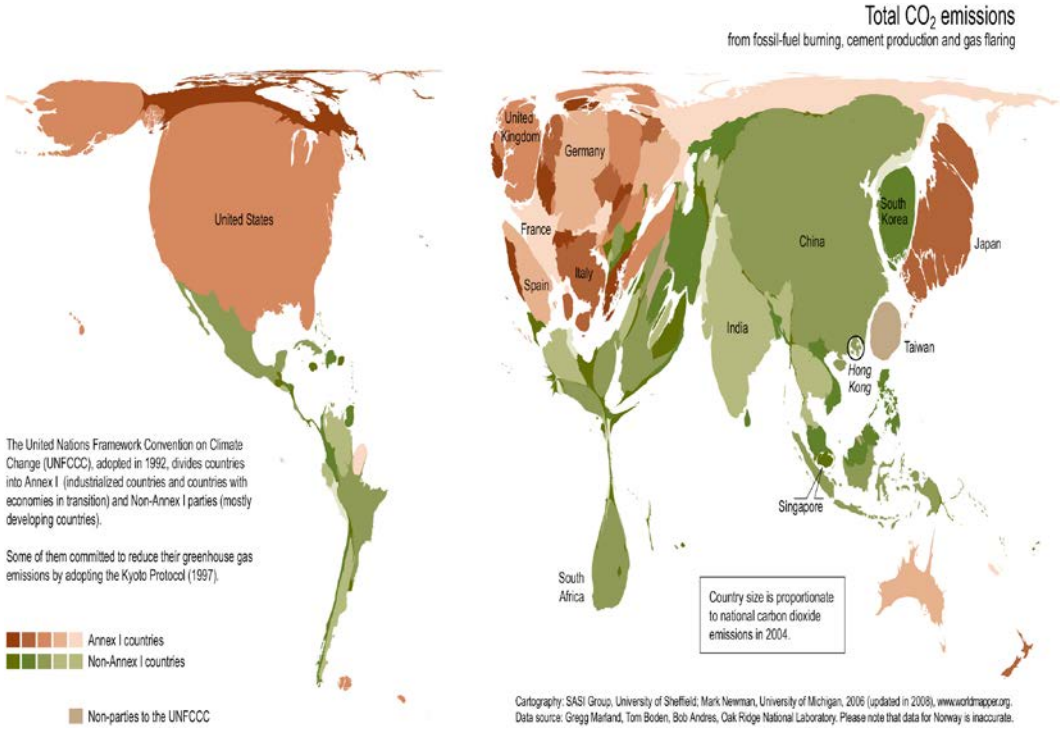
Methane has ~20 times the effect of carbon dioxide, but does not reside in the atmosphere as long



All data is for 2000. All calculations are based on CO_2 equivalents, using 100-year global warming potentials from the IPCC (1996), based on a total global estimate of 41 755 $MtCO_2$ equivalent. Land use change includes both emissions and absorptions. Dotted lines represent flows of less than 0.1% percent of total GHG emissions.

Source: World Resources Institute, Climate Analysis Indicator Tool (CAIT), Navigating the Numbers: Greenhouse Gas Data and International Climate Policy, December 2005; Intergovernmental Panel on Climate Change, 1996 (data for 2000).

Most of the emissions come from the developed world, and chiefly a few countries. These could change with higher and warmer seas.



Some expected changes have direct relationship to human activity: certain effects are identified, others less so

- Warming of the ocean (thermal expansion, melting of sea ice, glaciers, rise in sea level, loss of coastal environments)

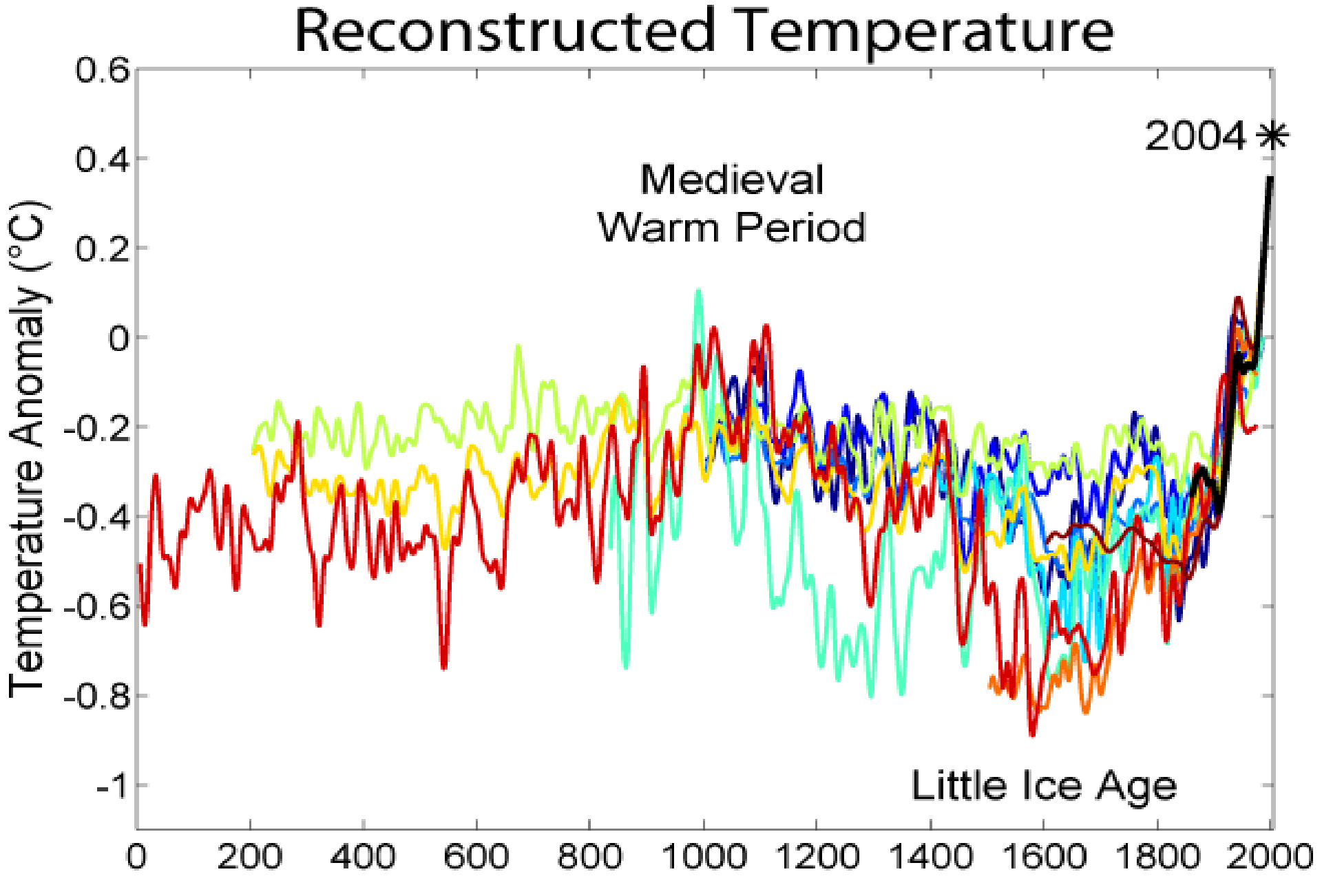
- The other carbon dioxide problem: lowering of the pH though carbonic acid acidification (food chain disruption, loss of species?)

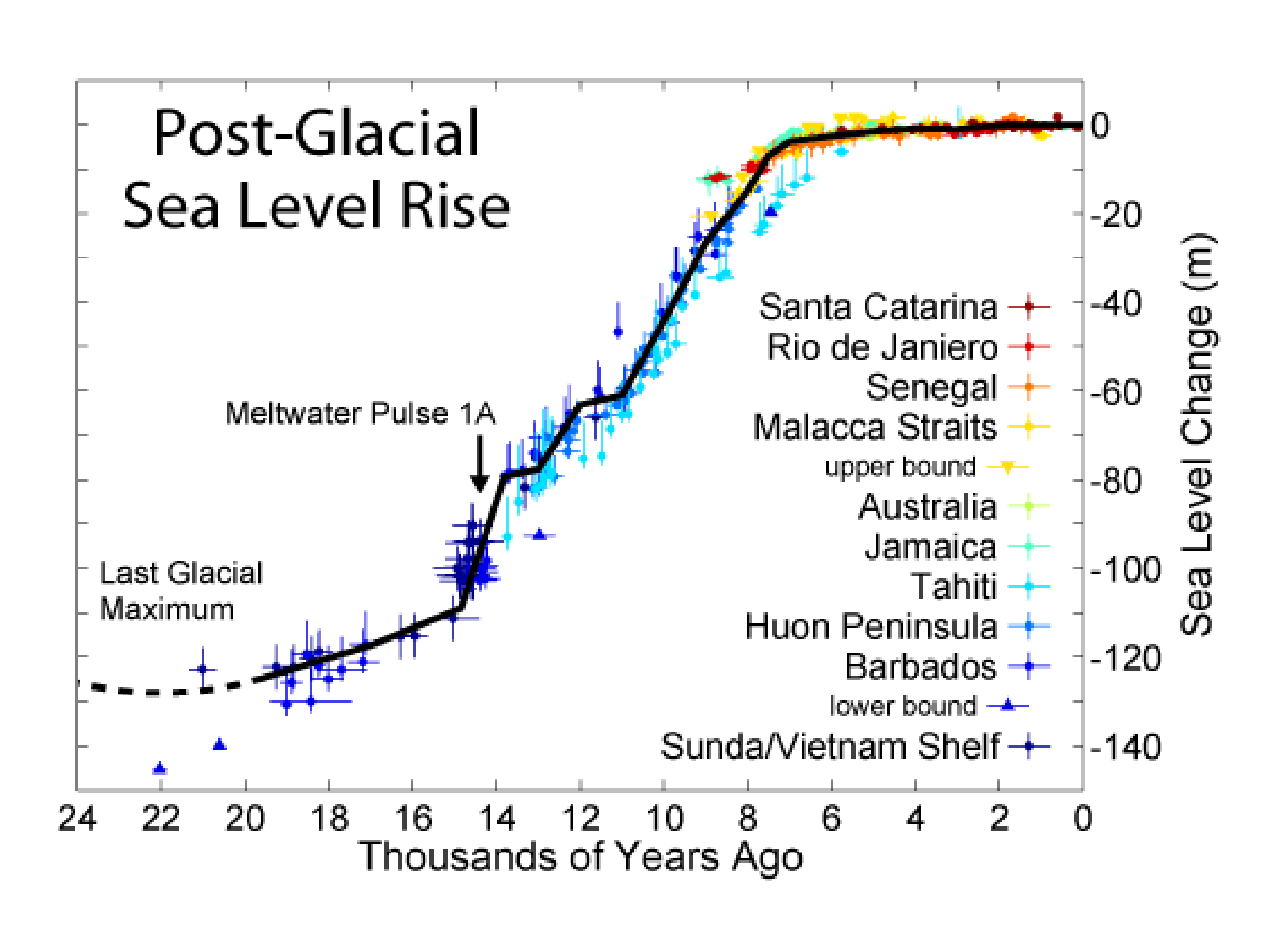
Other effects or “cascading” impacts are not so obvious and desperately need more data

- Release of methane from either gas hydrates on the seabed, or stored in the coastal permafrost peats (coastal modification, GHG amplification)

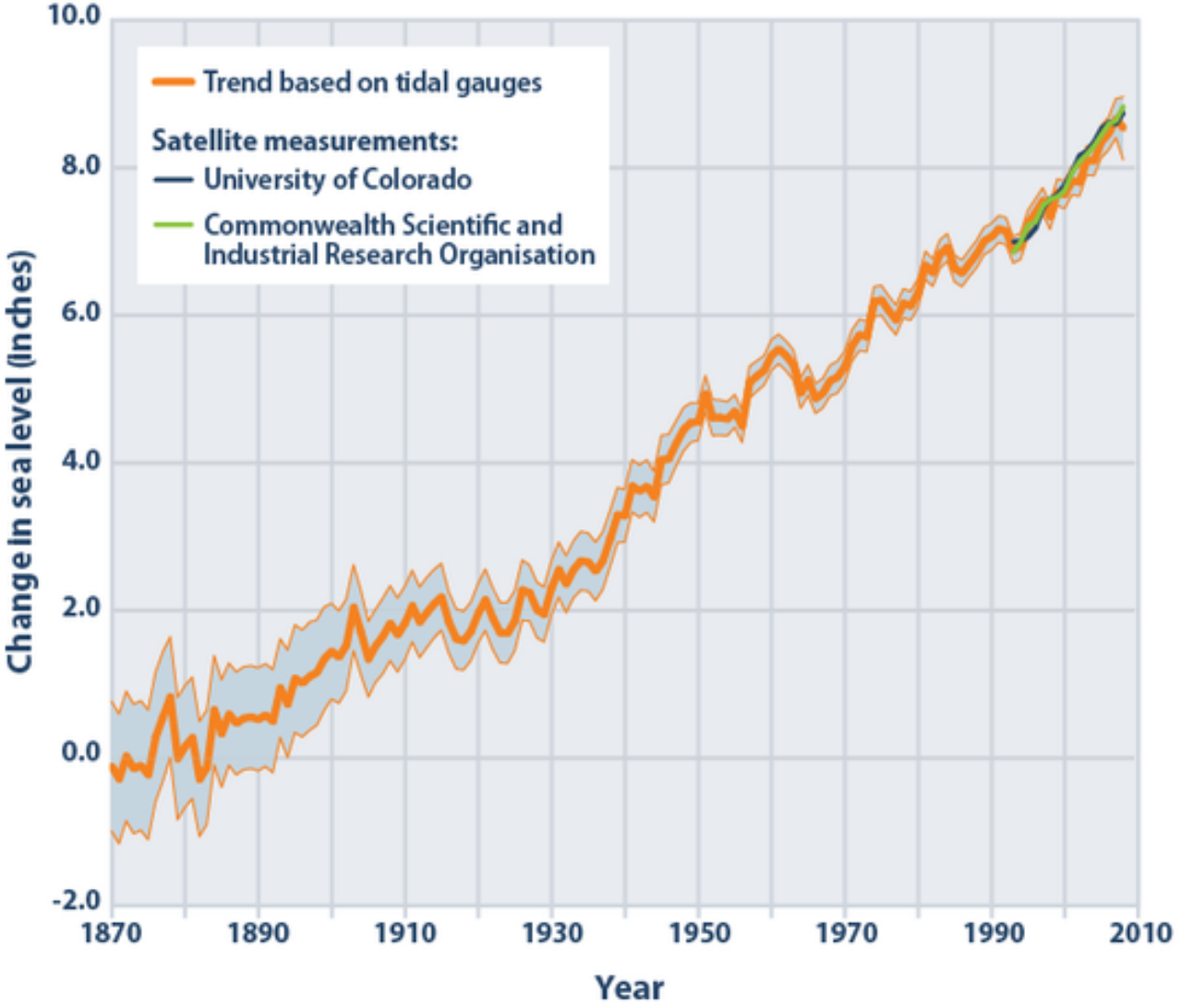
- Loss of diversity and modification of trophic structure (food webs) or environment, habitat loss, poor fisheries management

Graphics courtesy Michael Mann/ IPCC




Post-Glacial
Sea Level Rise
Meltwater Pulse 1A
Last Glacial
Maximum
Santa Catarina
Rio de Janiero
Senegal
Malacca Straits
upper bound
Australia
Jamaica
Tahiti
Huon Peninsula
Barbados
lower bound
Sunda/Vietnam Shelf
0
-20
-40
-60
-80
-100
-120
-140
Sea Level Change (m)
24
22
20
18
16
14
12
10
8
6
4
2
0
Thousands of Years Ago

Trends in Global Average Absolute Sea Level, 1870–2008

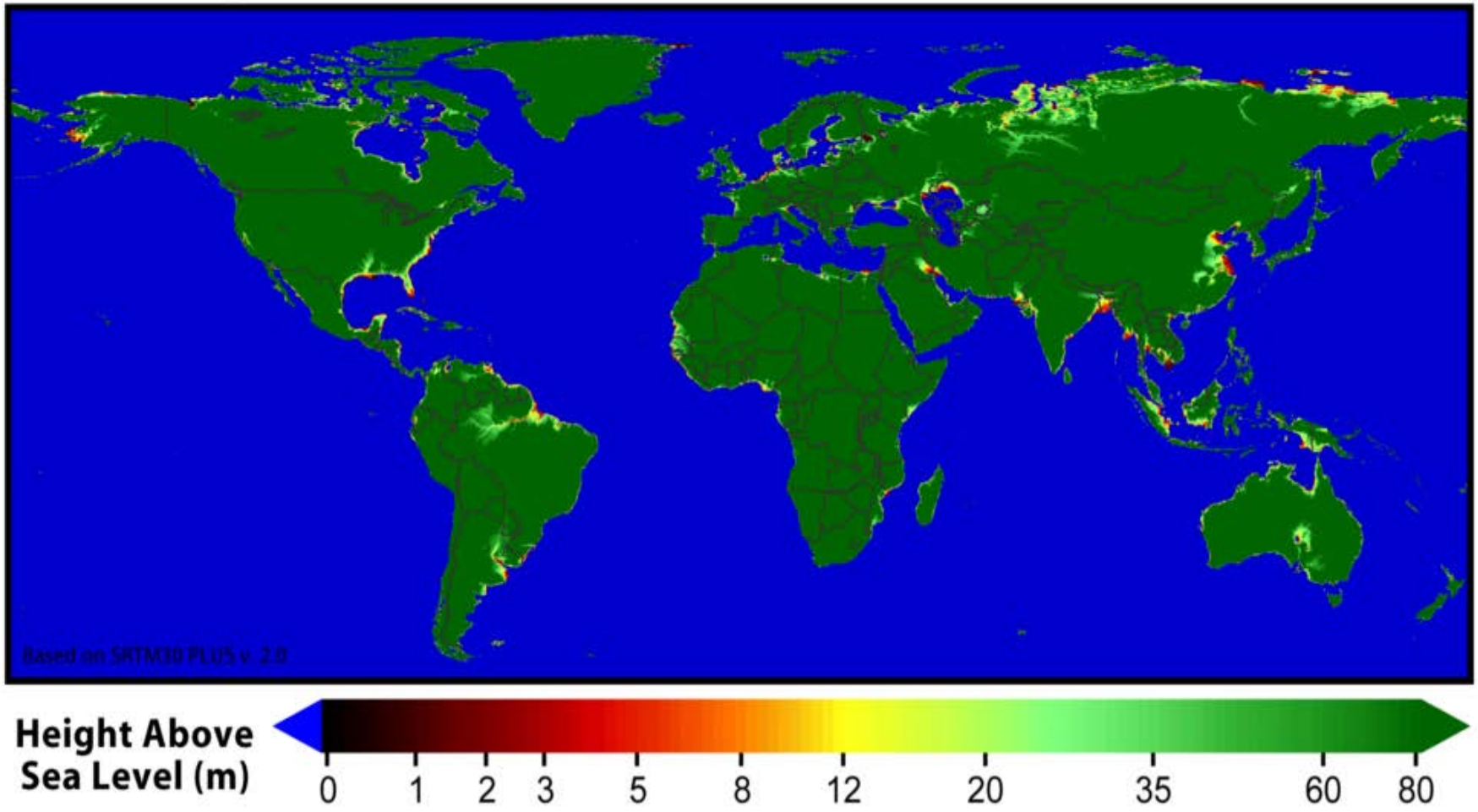


Data sources:
- CSIRO (Commonwealth Scientific and Industrial Research Organisation). 2009. Sea level rise. Accessed November 2009. http://www.cmar.csiro.au/sealevel.
- University of Colorado at Boulder. 2009. Sea level change: 2009 release #2. http://sealevel.colorado.edu.

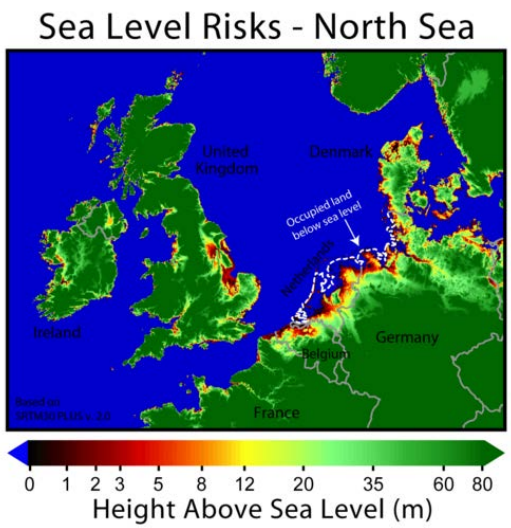
For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climatechange/science/indicators.

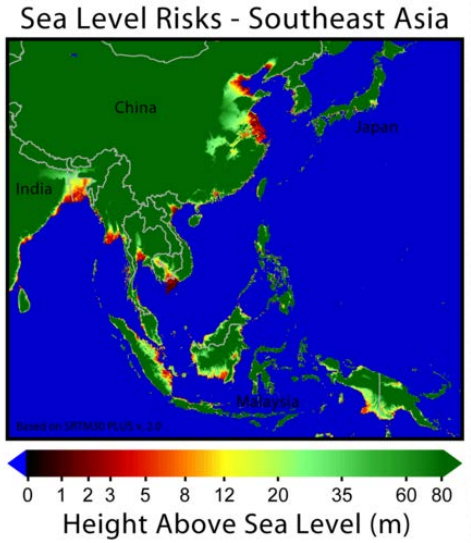

This is a time of unprecedented change in the Arctic. Conditions are changing faster than at any time in the past 10,000 years.
Photo: Stephen Macko

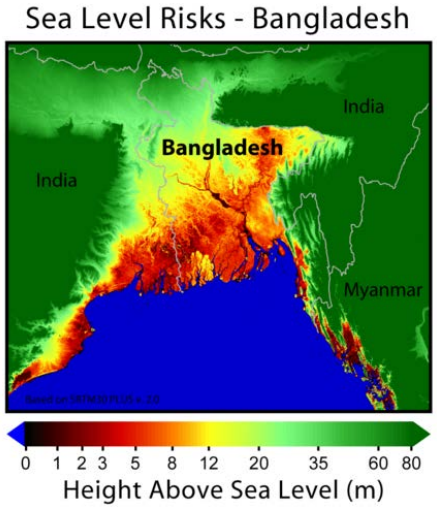
Regions Vulnerable to Sea Level Rise

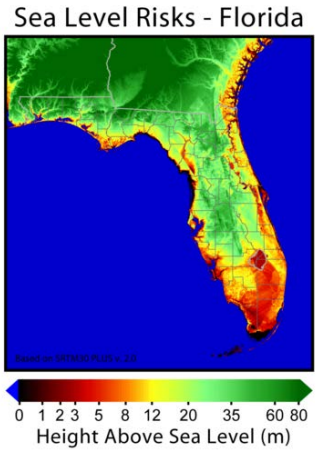


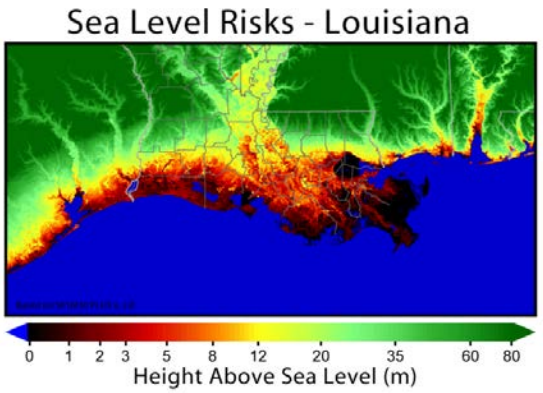
Hundreds of millions of people will be affected by rising sea level











Graphics courtesy Robert A. Rohde / Global Warming Art

Some of the changes influenced by rising sea levels and warming temperatures are obvious:

Increased exploration and exploitation of Arctic mineral resources (hydrocarbons)

Increased avenues for maritime transport between the Atlantic and Pacific (Northwest Passage)

Increased tourism

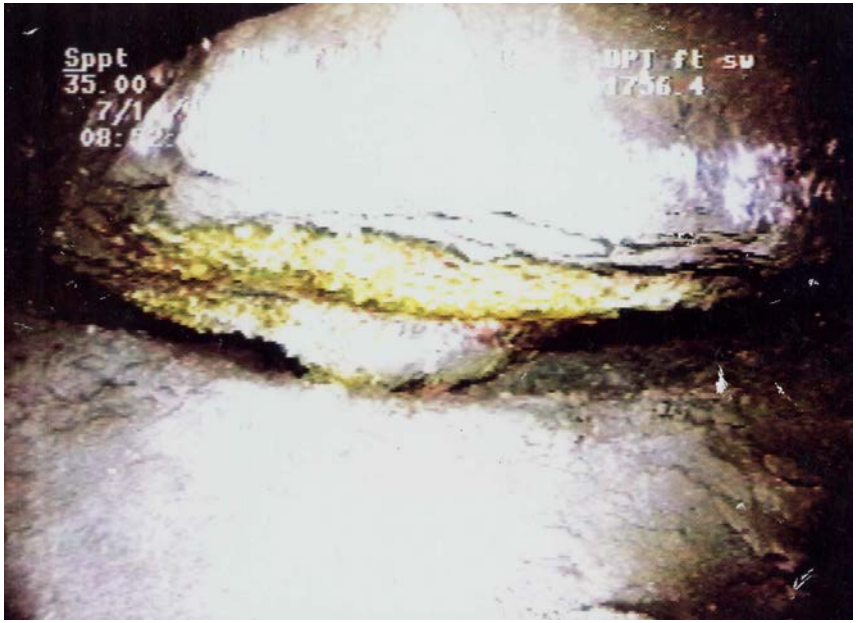
Effects on fisheries and ecosystems are less obvious, more complex, and needing fundamental knowledge

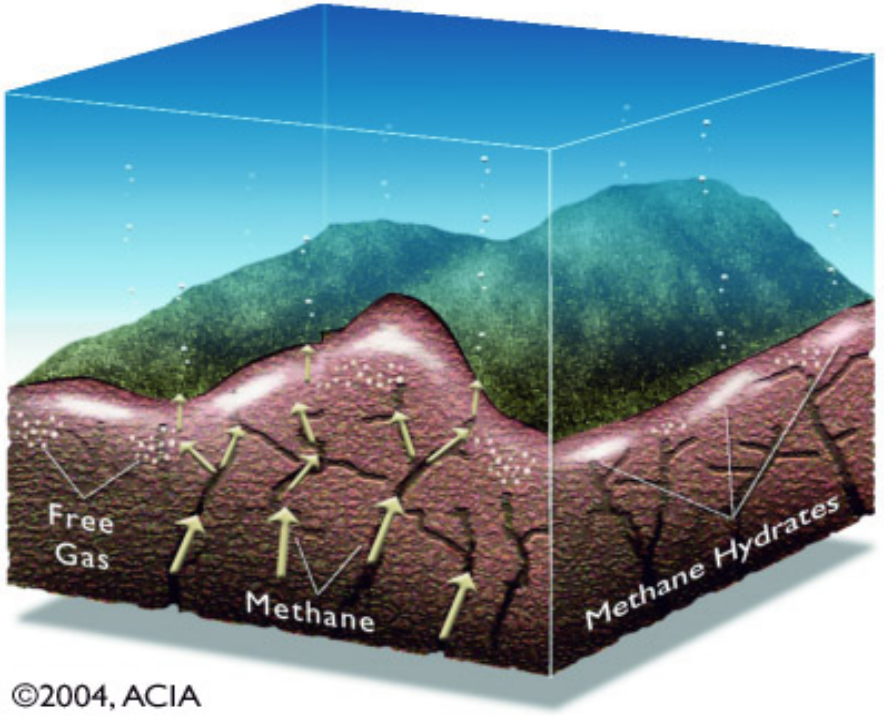
Photo: Stephen Macko

As exploration increases in newly available locations in the ice free Arctic and Antarctic, the likelihood of a spill will increase and we are essentially unprepared for even moderate amounts of introduction in remote locations

2006, Prudhoe Bay, 1 million liters

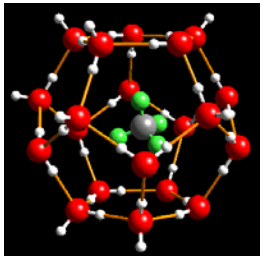
Gas Hydrates on the Seabed





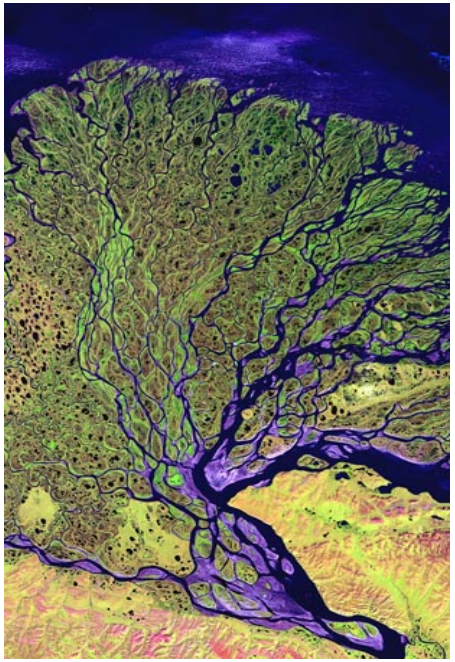
Potentially many times the reserves of fossil fuel carbon exists as methane hydrates.

The Arctic alone is estimated to have greater than 400 Gt .



Modification of coasts (loss of peats and permafrost, release of methane, also in the subsurface seabed- perhaps 1,000s of Gt)

Lena River delta , Siberia



North slope, Alaska

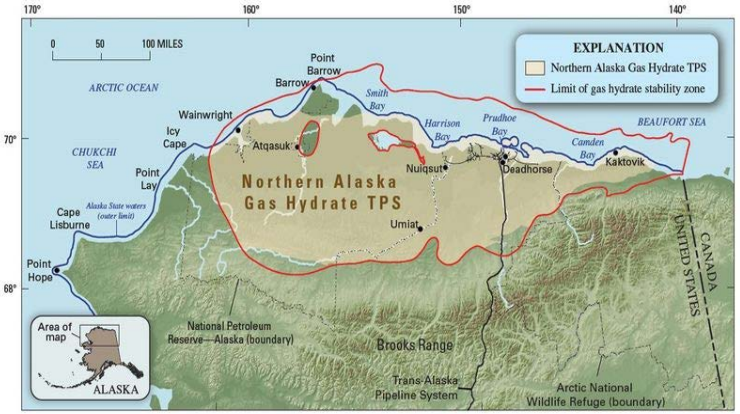
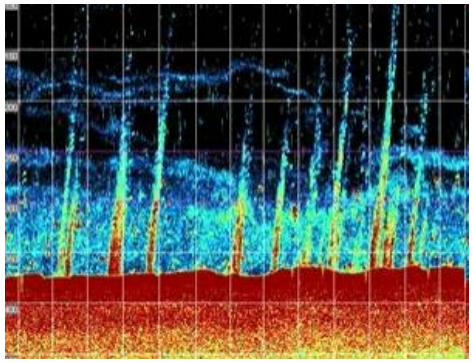
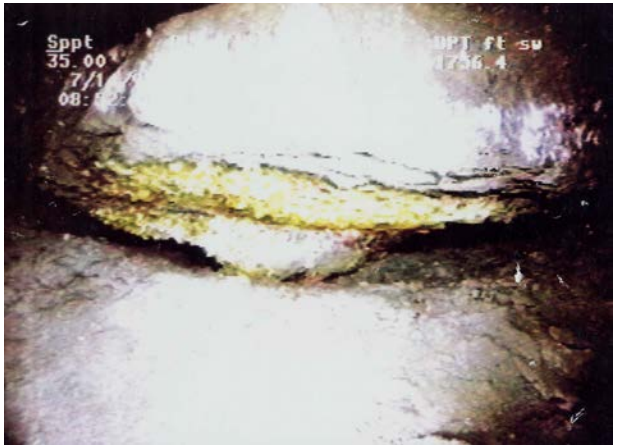
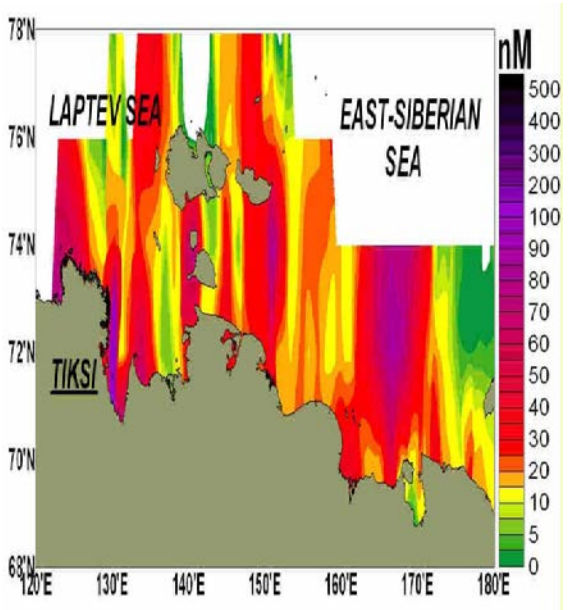


Photo credit Department of Energy

Methane seep, Svalbard Island (National Oceanographic Center, Southhampton), 1^{o}C increase in temperature, may release locally 20MT/ y; Arctic total unsurveyed





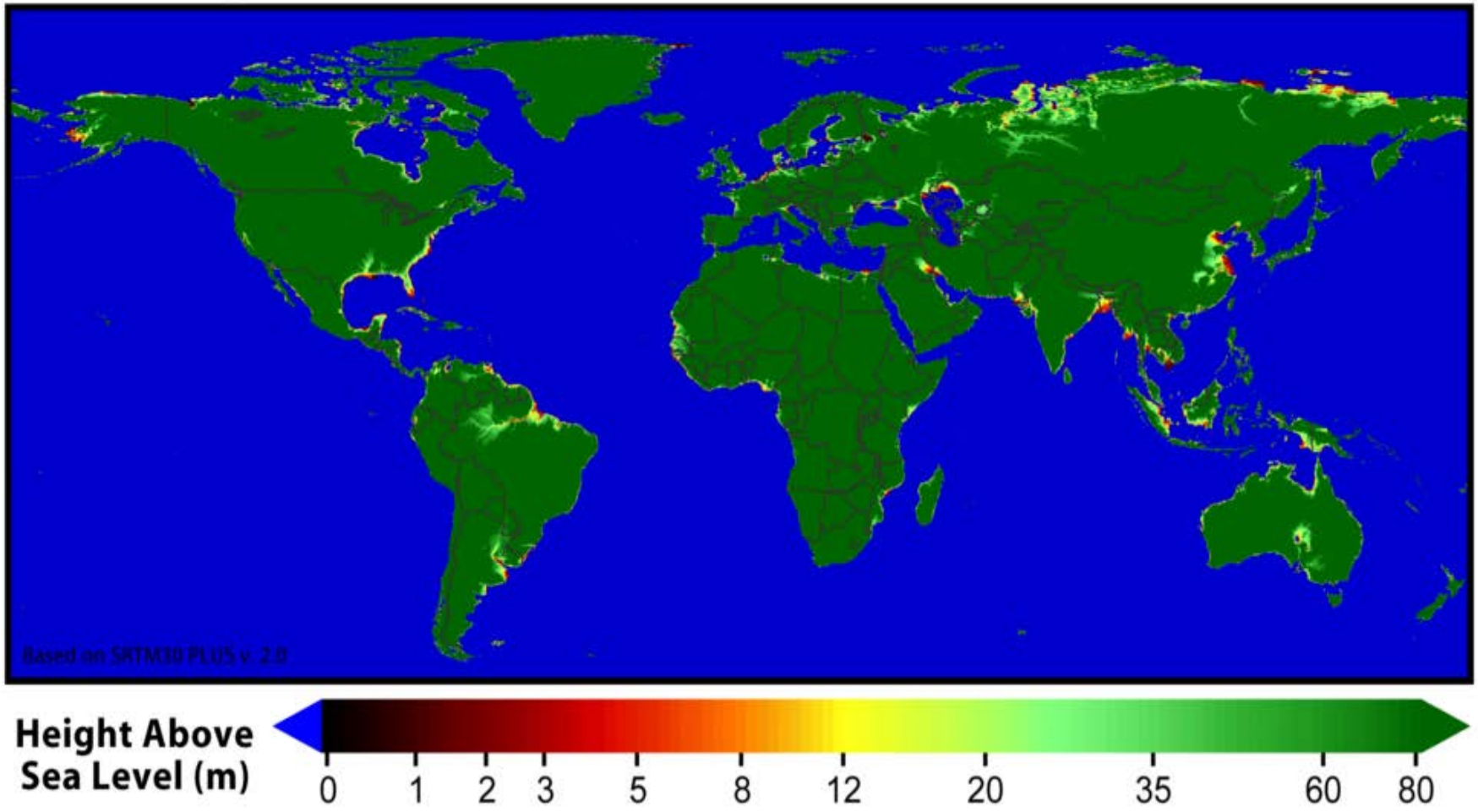


Effects on fisheries:

Avoidance of plumes, respiration?

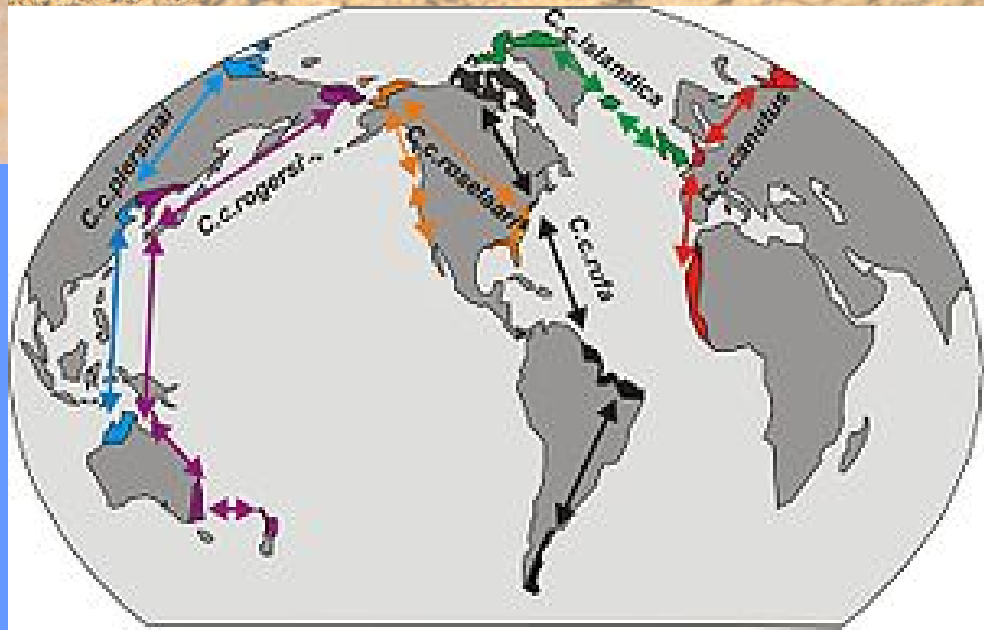
Accelerate warming and associated effects

Regions Vulnerable to Sea Level Rise

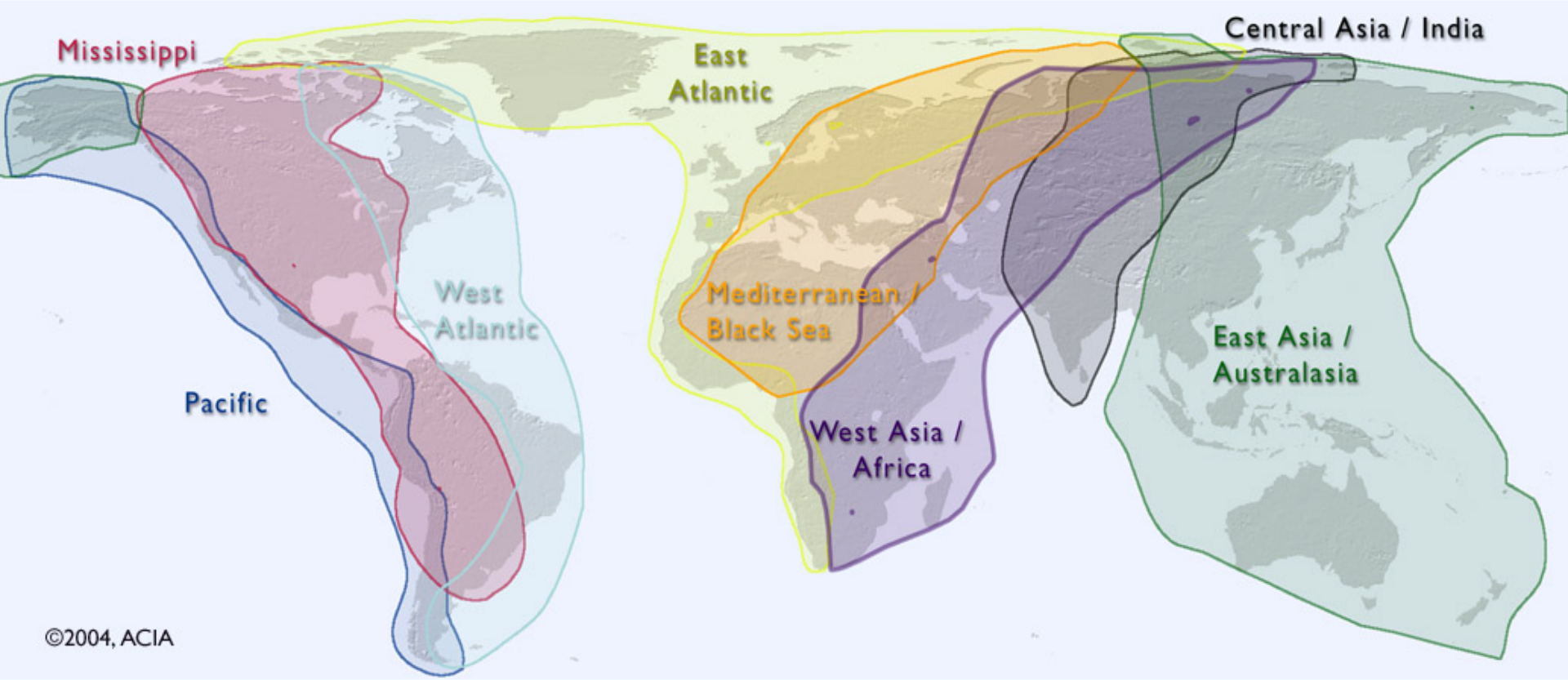


Red Knot

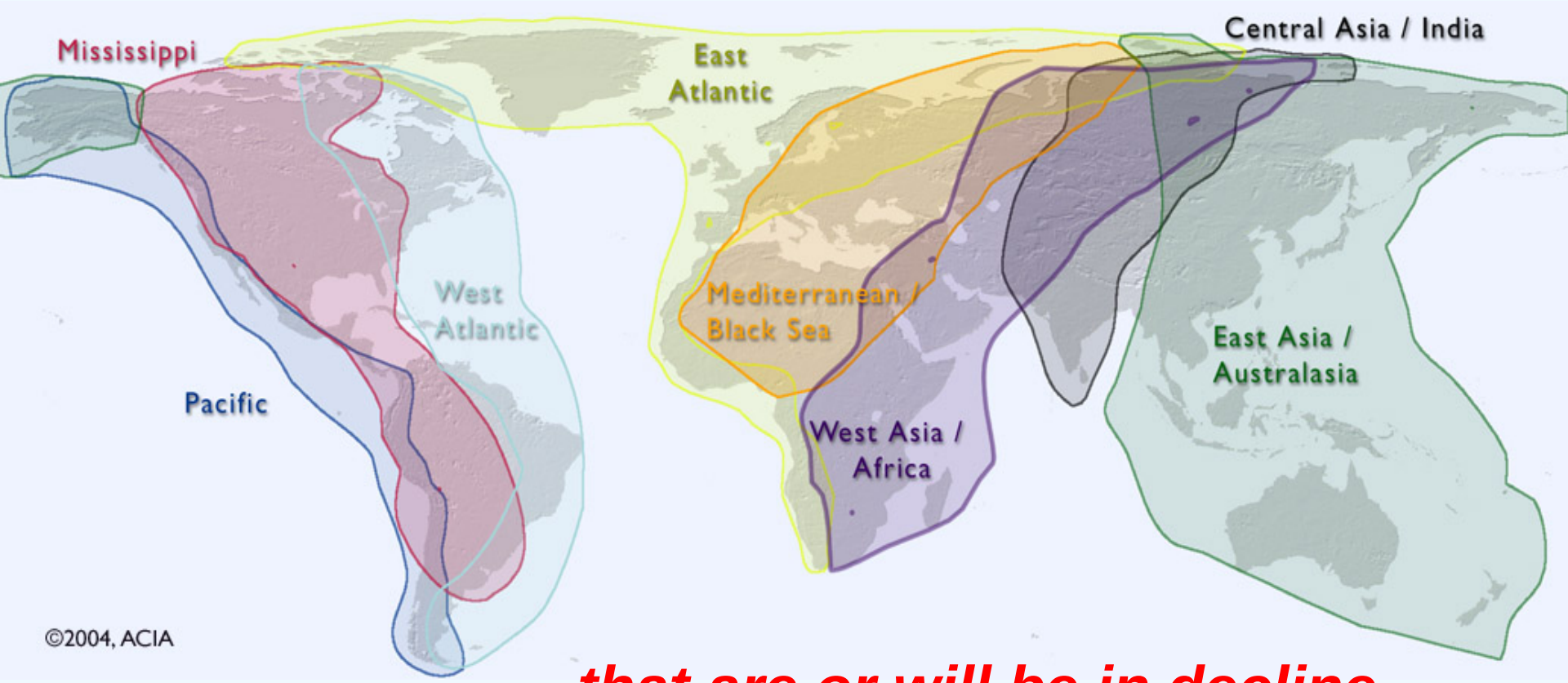
Declines in migratory birds



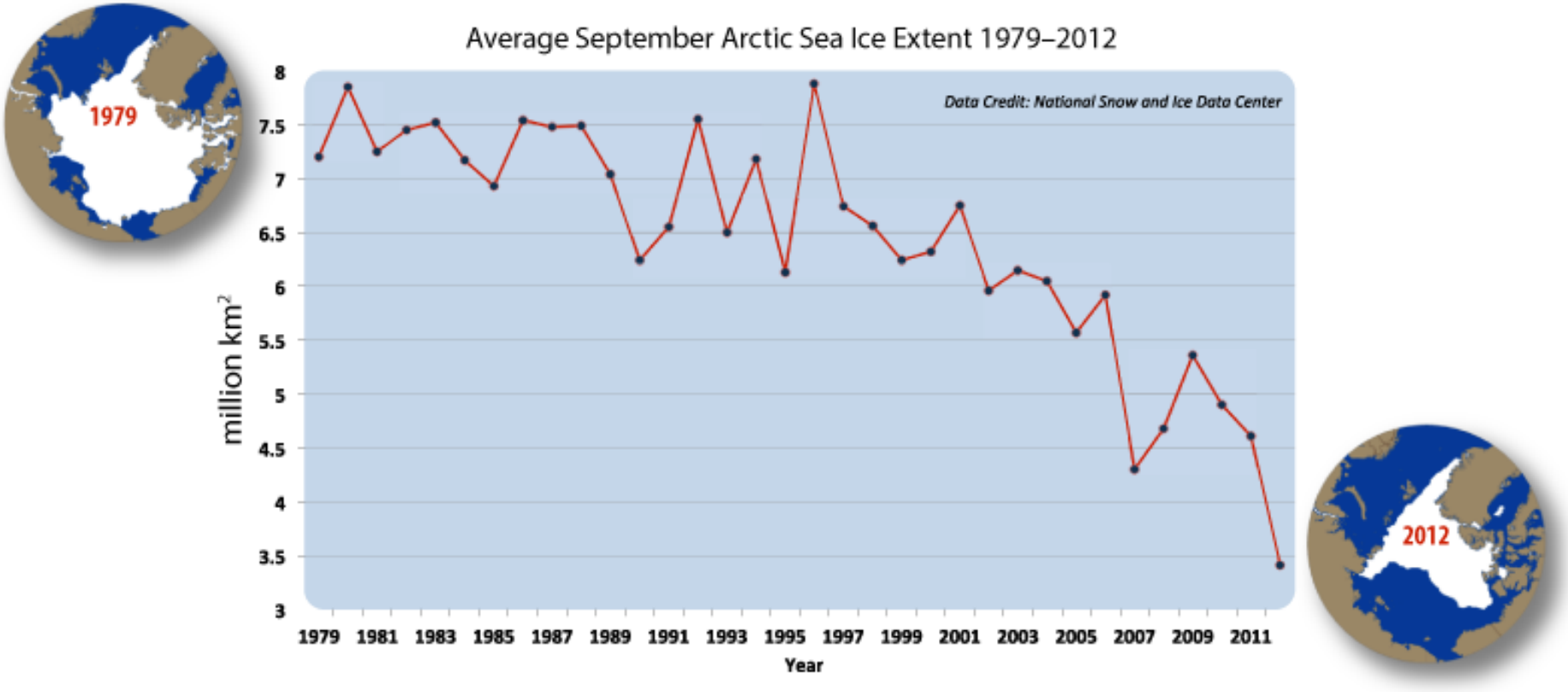
One of hundreds of species …. and millions of shorebirds… that use the coastal zone for breeding



One of hundreds of species …. and millions of shorebirds… using the Arctic coastal zone for breeding….



that are or will be in decline

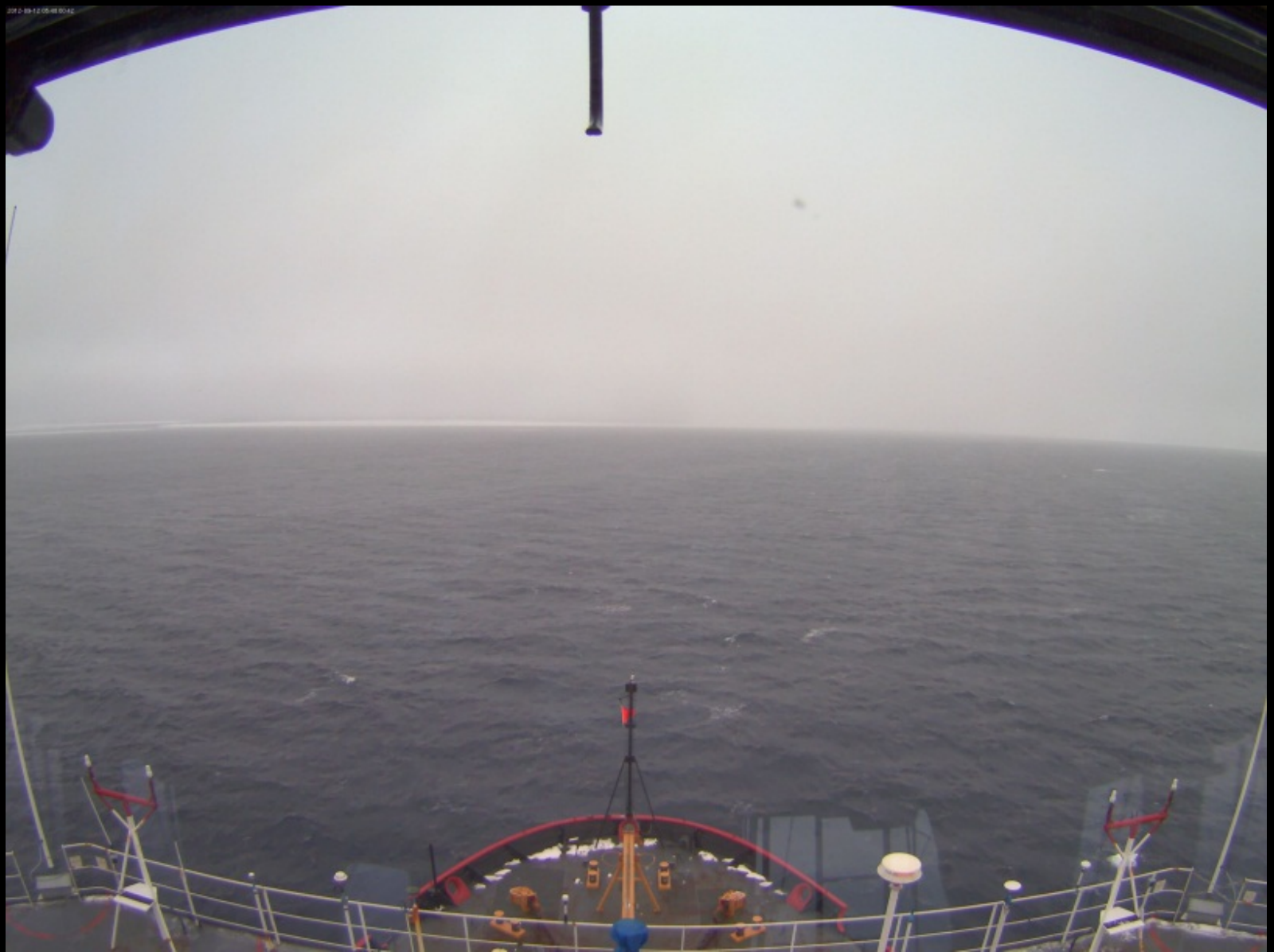

1979
Average September Arctic Sea Ice Extent 1979–2012
Data Credit: National Snow and Ice Data Center
million km²
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011
Year
2012

Long/Lat.: -156.072055 W, 80.293353 N

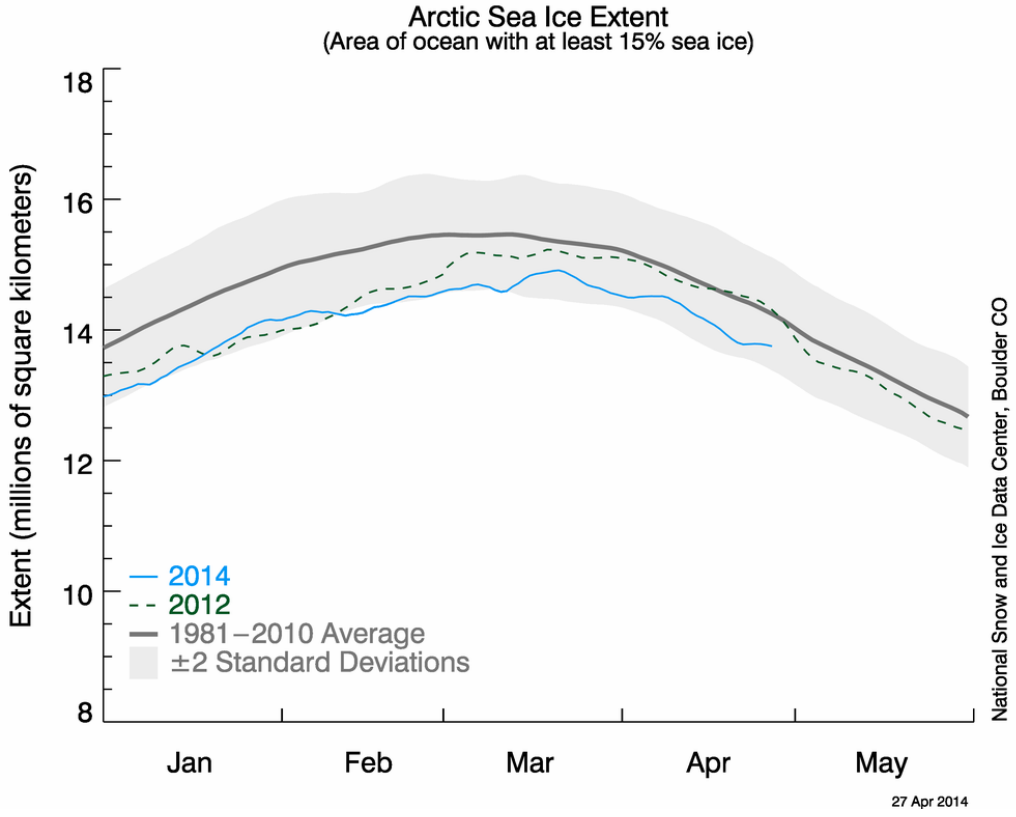
2007 (9-06-2007)

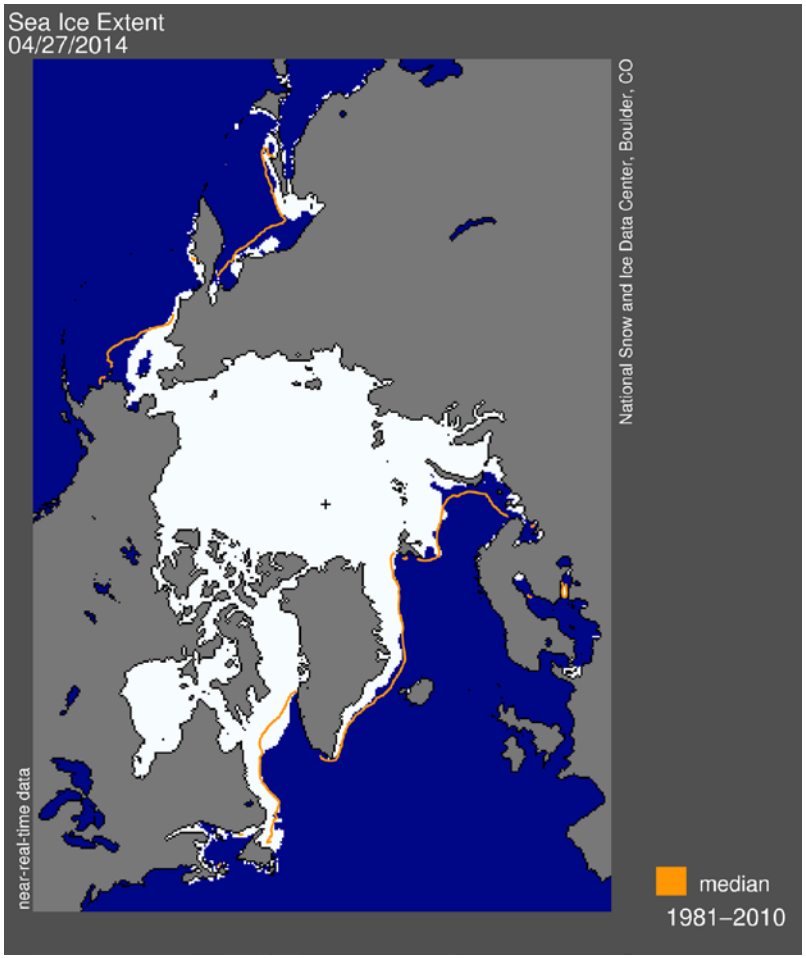
Long/Lat.: -156.072055 W, 80.293353 N

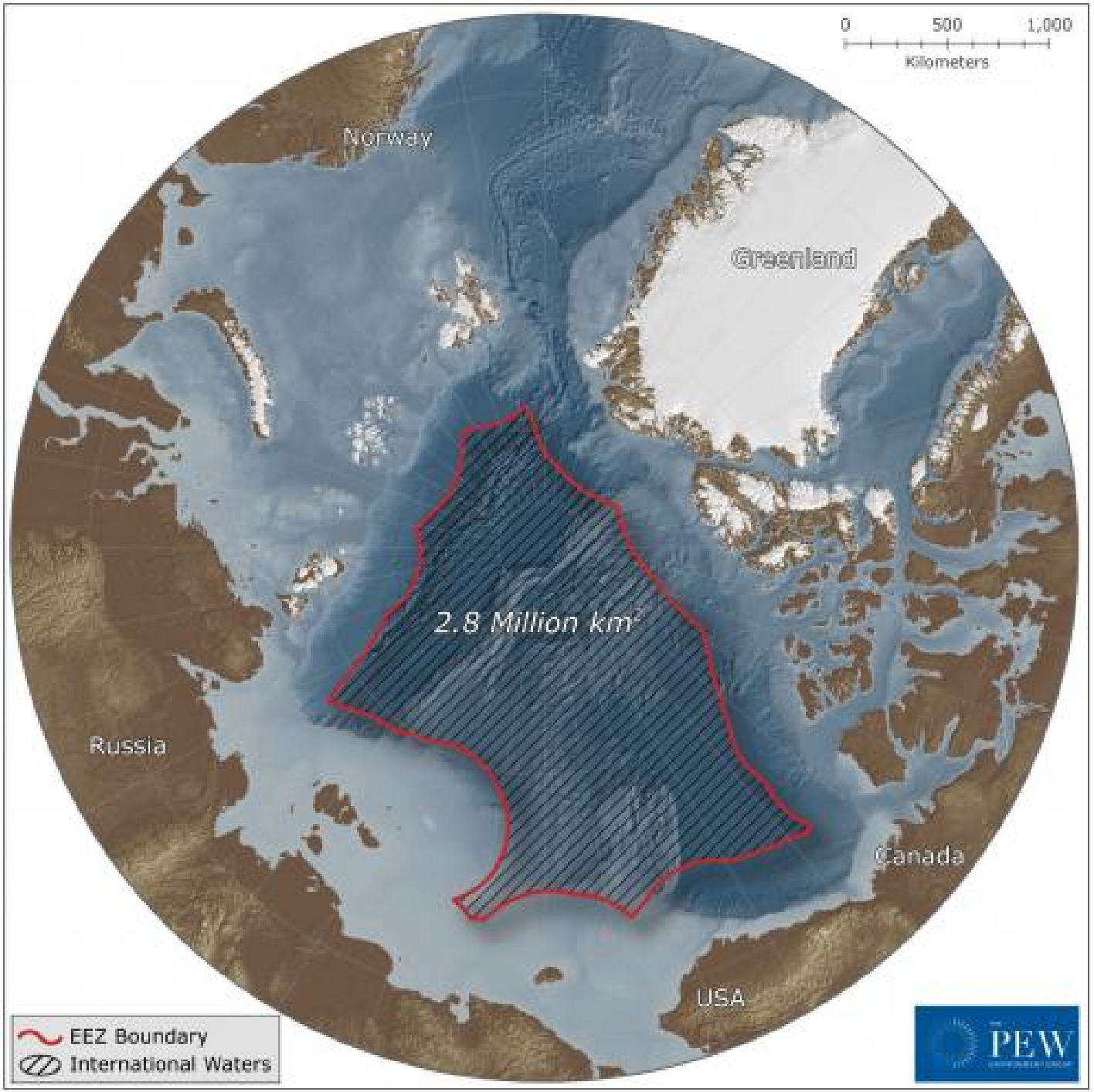
2012 (9-12-2012)

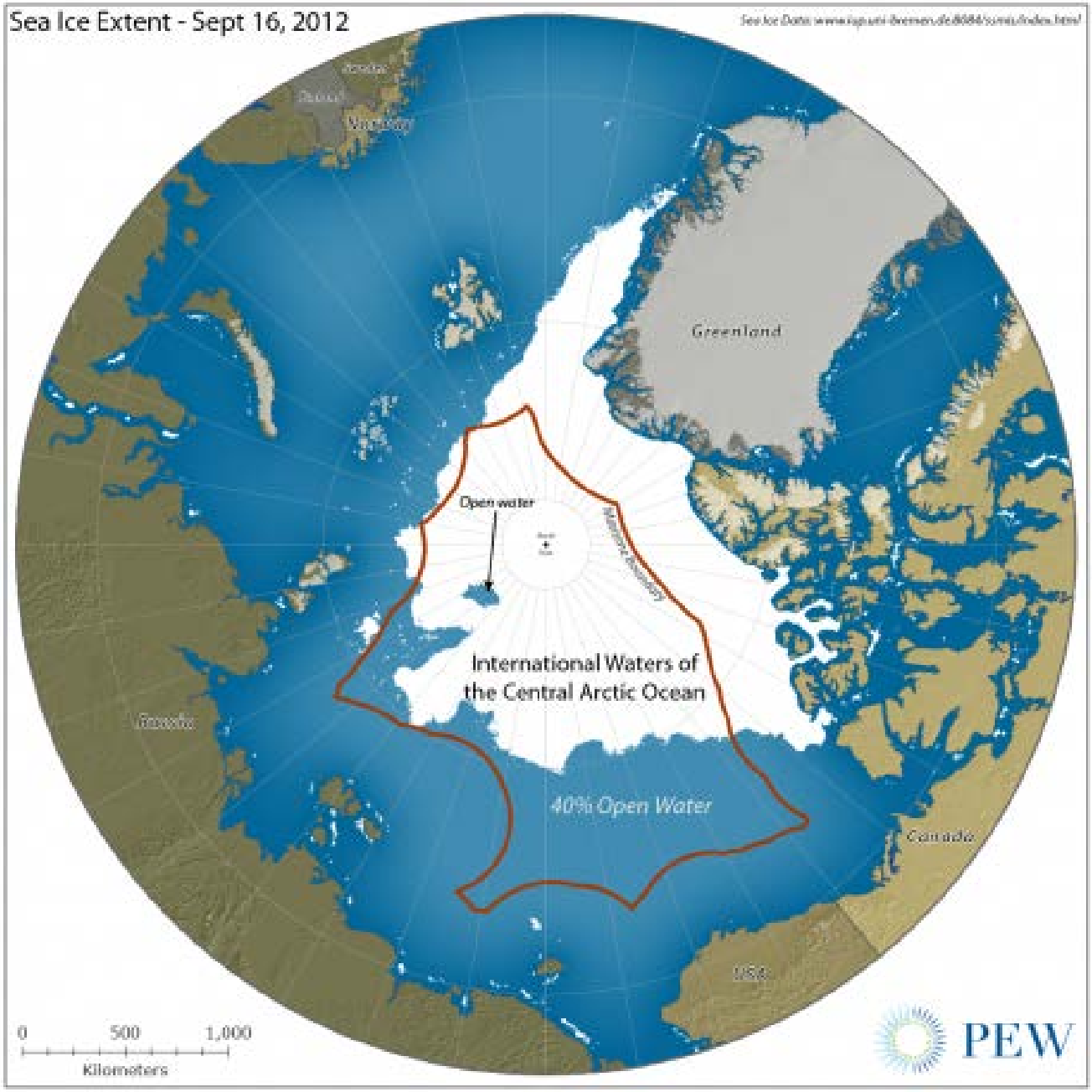


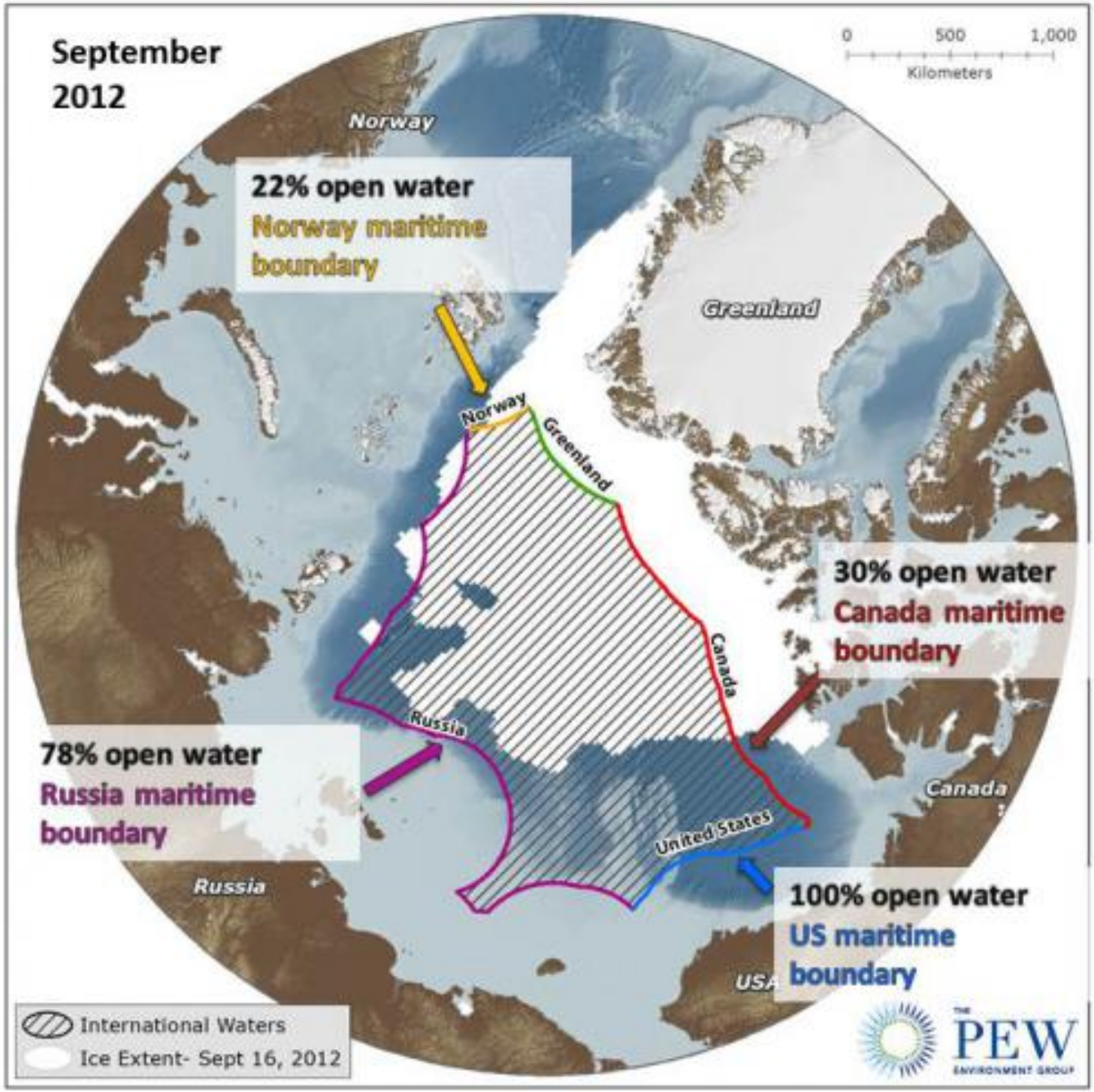
Sea Ice Cover April 29, 2014



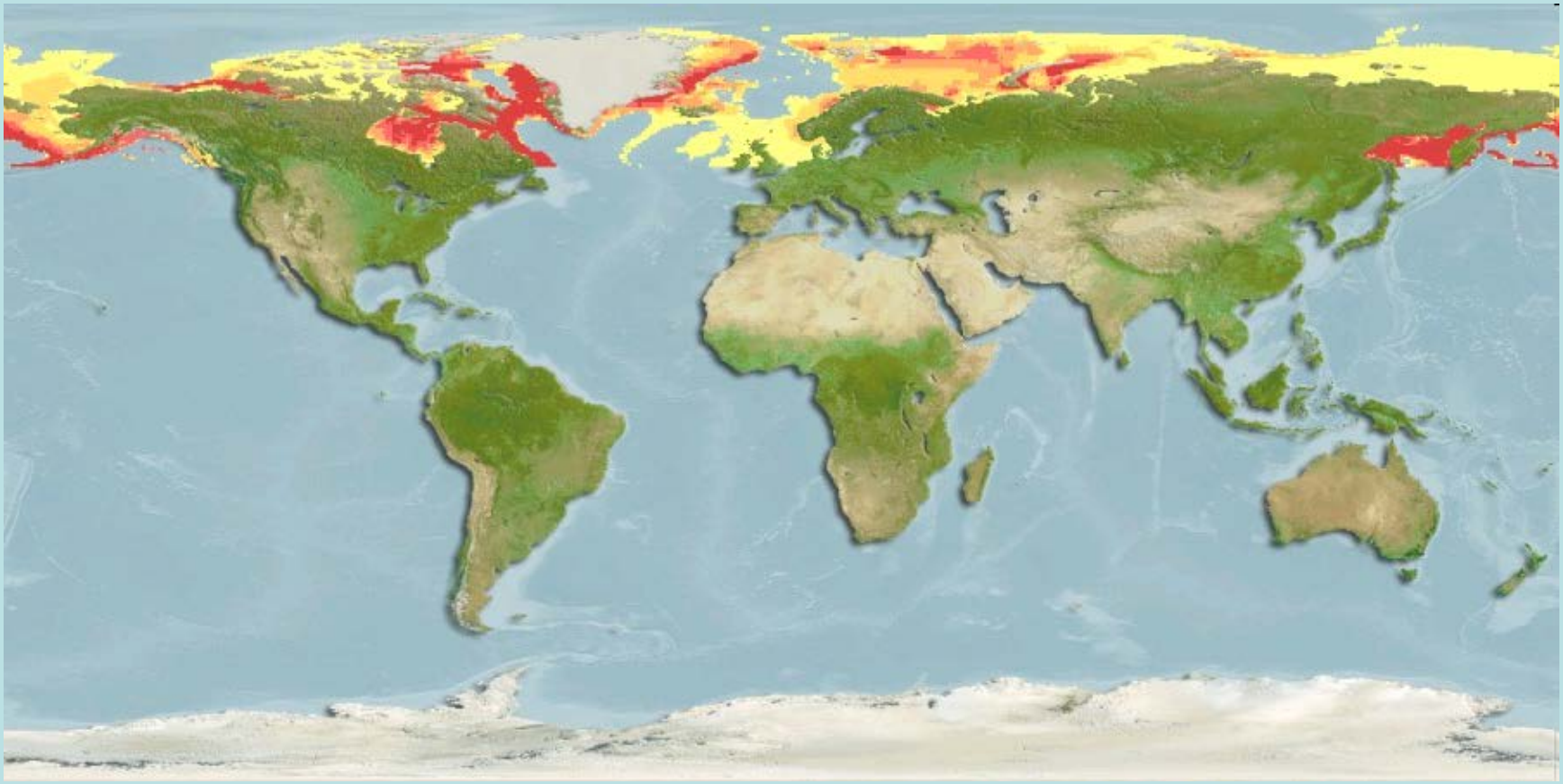



0
500
1,000
Kilometers
Norway
Greenland
2.8 Million km²
Russia
Canada
USA
EEZ Boundary
International Waters
PEW


Sea Ice Extent - Sept 16, 2012
Sea Ice Data: www.iup.uni-bremen.de:8084/amsr/index.html
Greenland
Open water
International Waters of
the Central Arctic Ocean
40% Open Water
Canada
USA
0
500
1,000
Kilometers
PEW

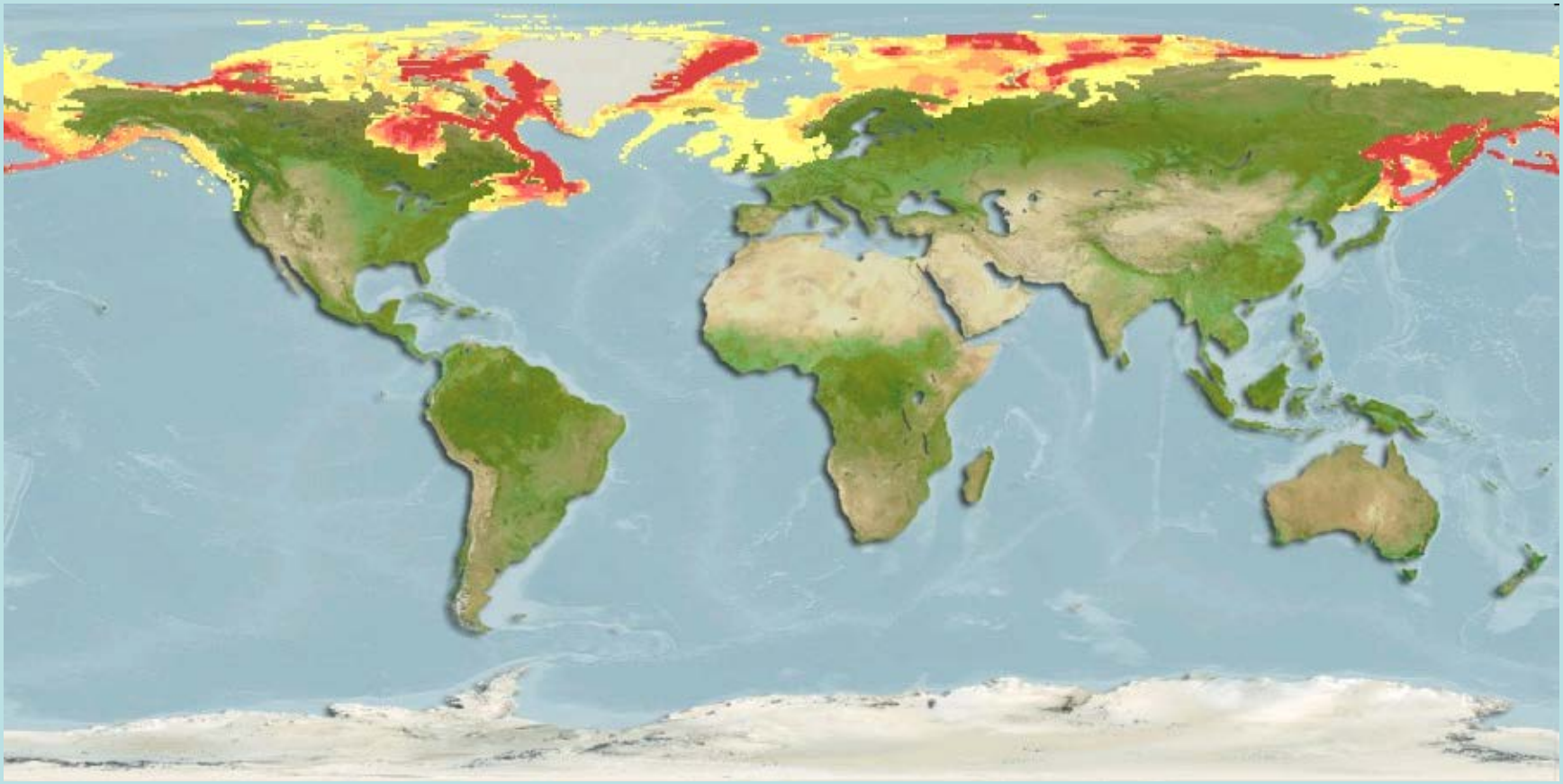

September
2012
0
500
1,000
Kilometers
Norway
22% open water
Norway maritime
boundary
Greenland
Norway
Greenland
Canada
30% open water
Canada maritime
boundary
Russia
78% open water
Russia maritime
boundary
Canada
United States
Russia
100% open water
US maritime
boundary
USA
International Waters
Ice Extent- Sept 16, 2012
THE PEW ENVIRONMENT GROUP

Arctic cod: *Boreogadus saida*



Where fisheries are today……

2050: *Boreogadus saida*

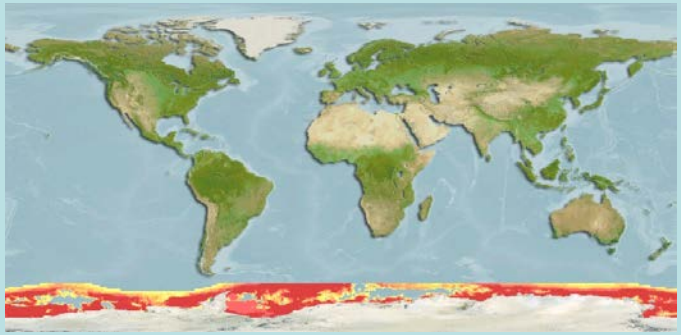


will not be where they are tomorrow.

With some depending on sea ice habitat?

Antarctic silverfish:

Pleuragramma antarcticum



Effects on fisheries:

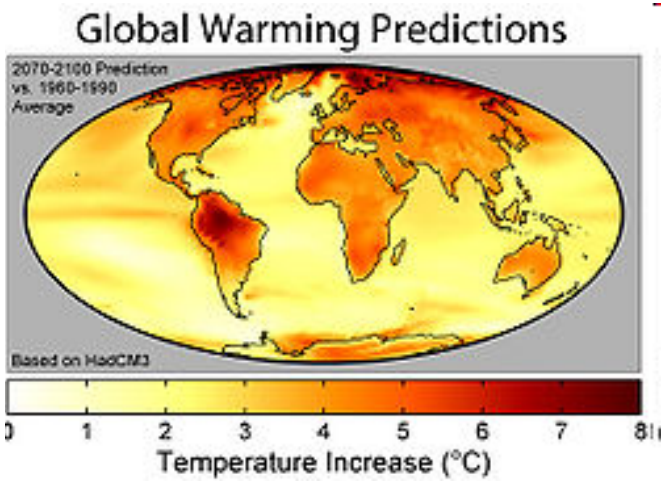
Timing of spawning/ food availability

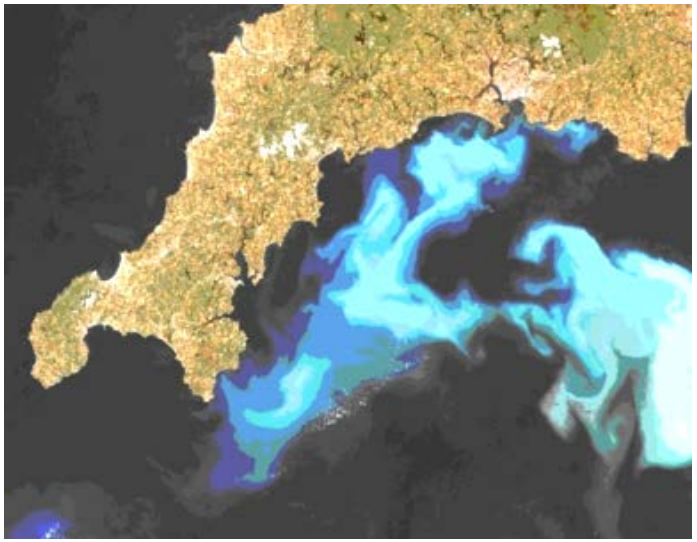
Loss of energy transfer/ trophic structure

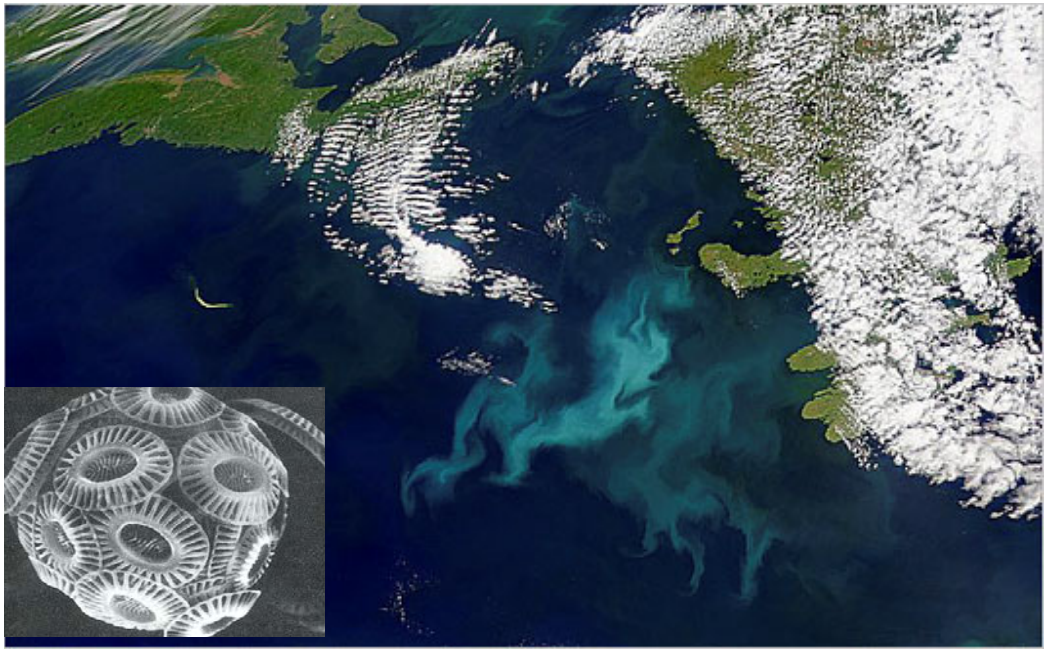
Loss of habitat for spawning?

Loss of benthic productivity with ice loss

Primary production may increase in the warmer, ice free water column but are there enough nutrients in ice meltwaters?







A bloom of coccolithophore plankton recorded near Newfoundland in 1999 and by NASA's SeaWiFs satellite

SEAWIFS Image courtesy NASA

Science
AAAS

Export of Algal Biomass from the Melting Arctic Sea Ice
Antje Boetius *et al.*
Science **339**, 1430 (2013);
DOI: 10.1126/science.1231346

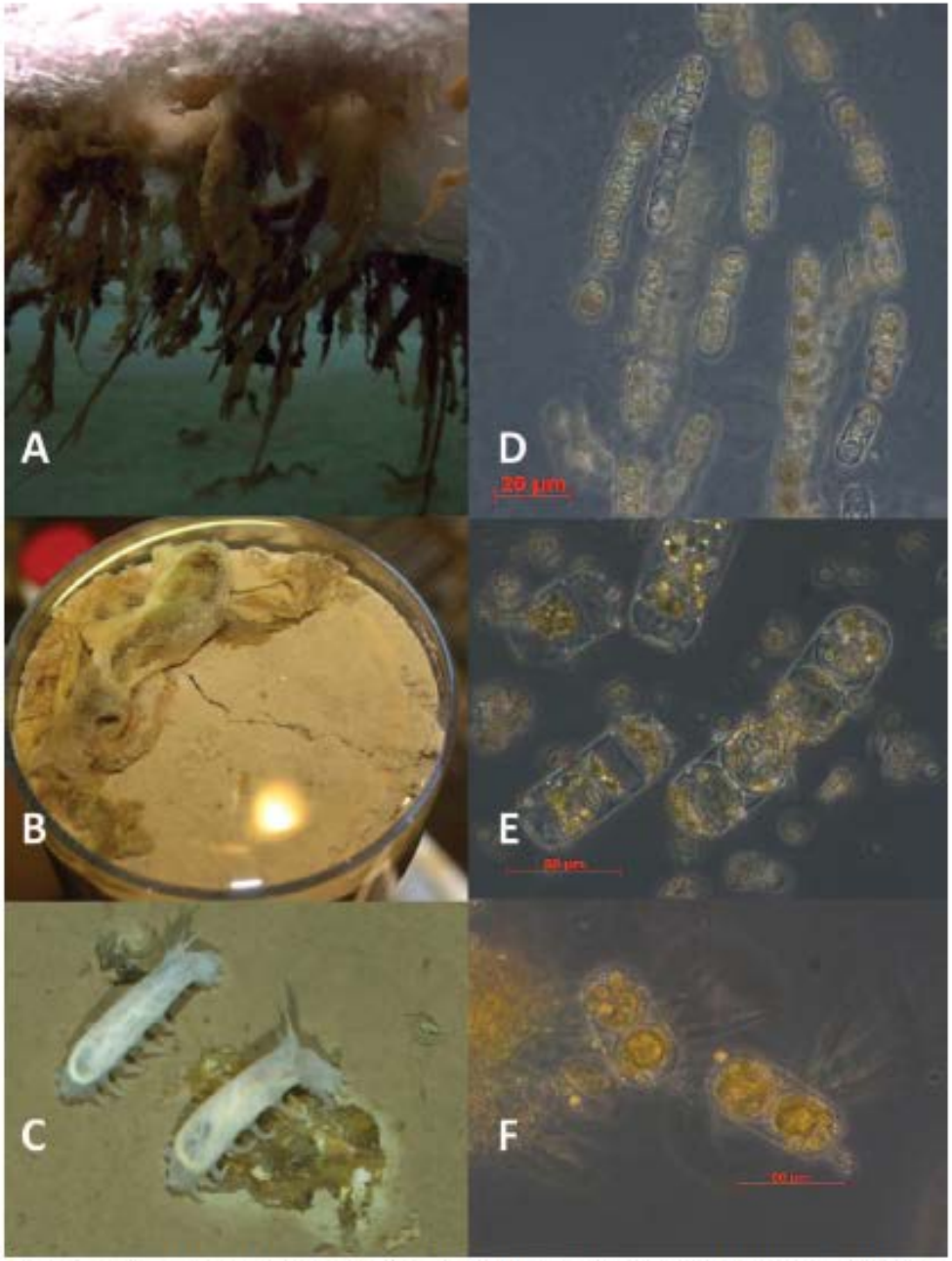
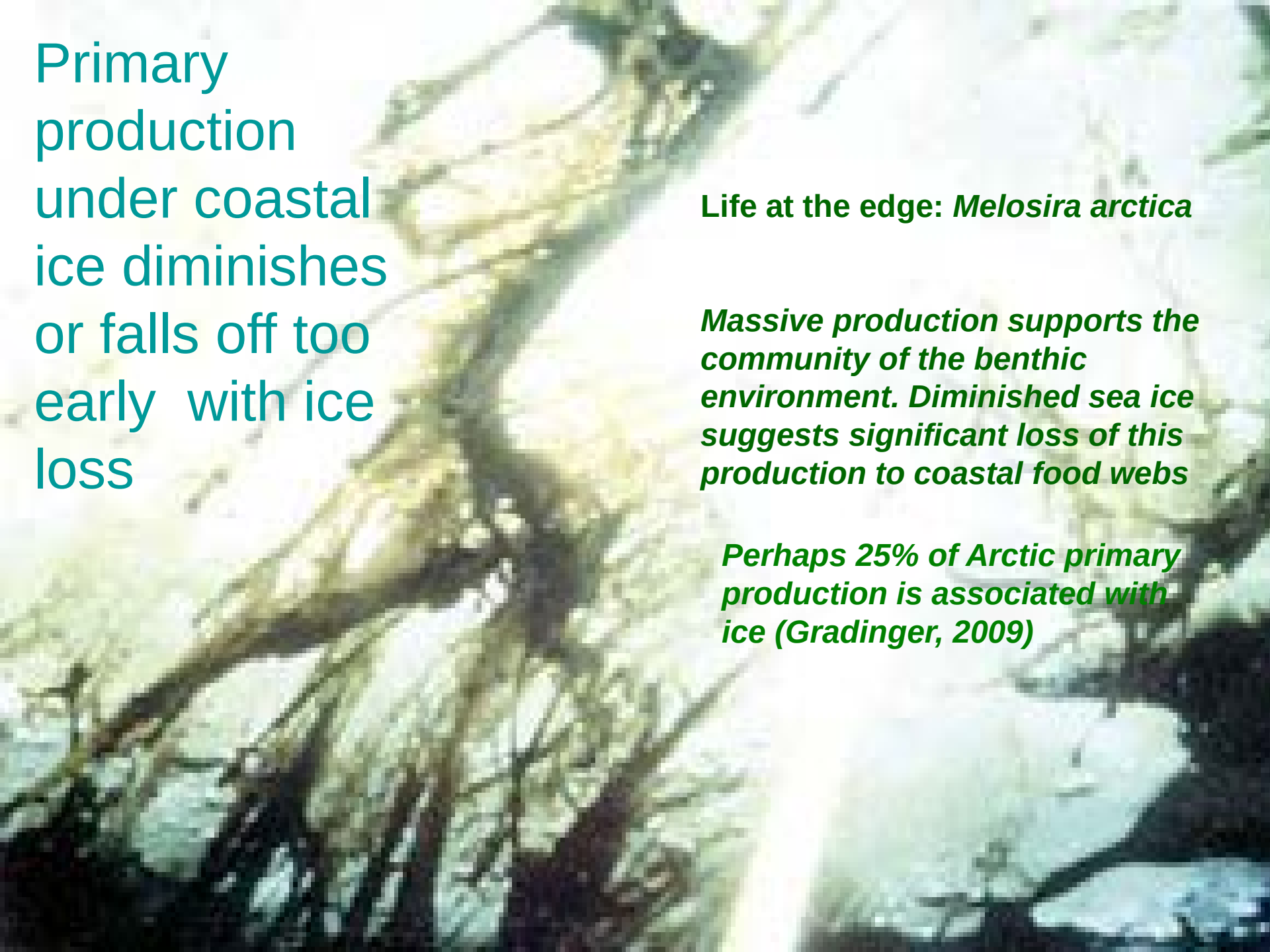


Fig. 2. *M. arctica* aggregations. Strands (~20 cm) of *Melosira* (**A**) under ice (station 7), (B) recovered from the sea floor (station 7), and (**C**) photographed in situ with *K. hyalina* grazing on deposits (station 3). (**D** to **F**) Microscopic images of *Melosira* cells from (A), (B), and (C) (extract of *Kolga* gut), respectively.

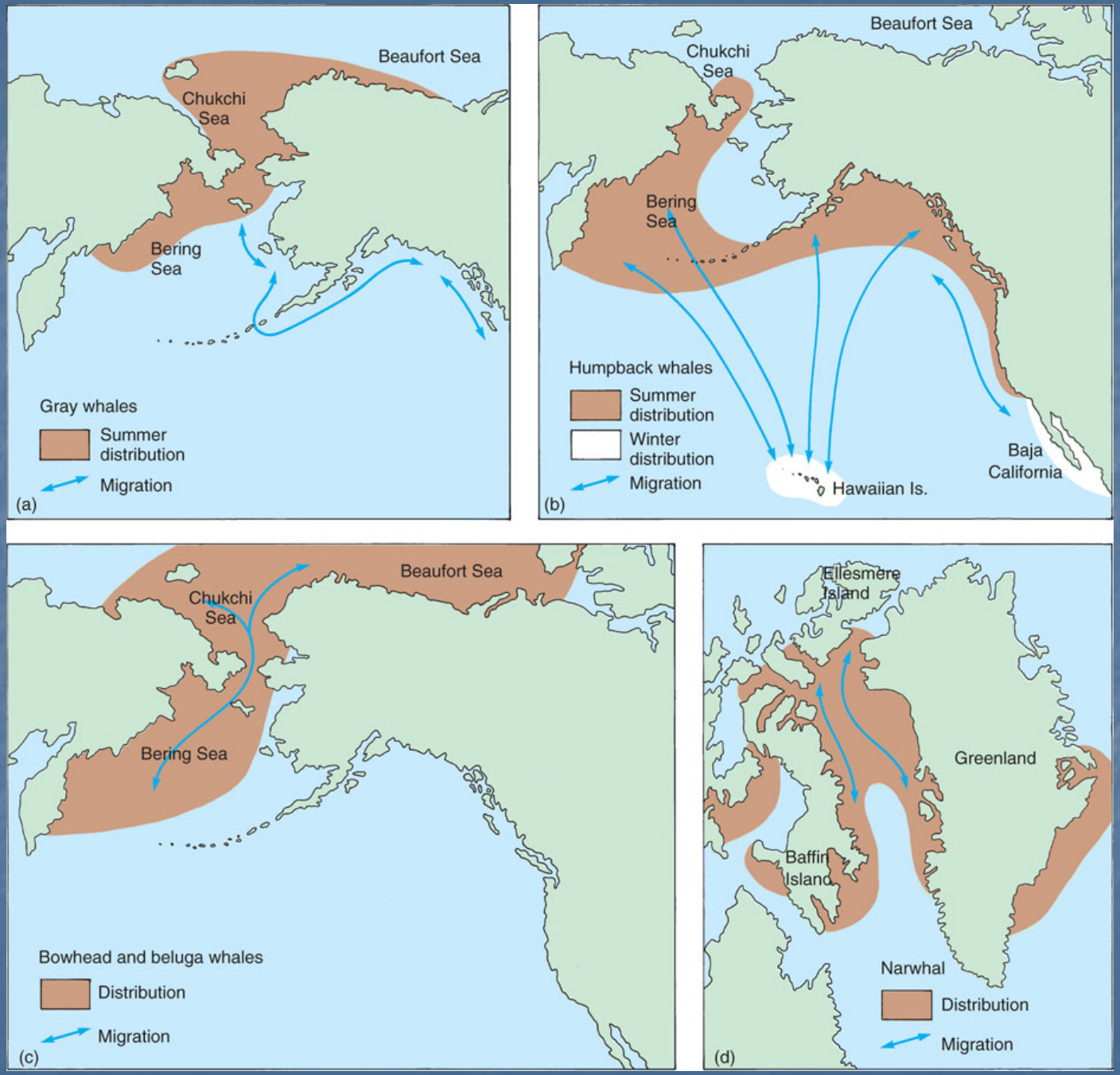


Primary production under coastal ice diminishes or falls off too early with ice loss

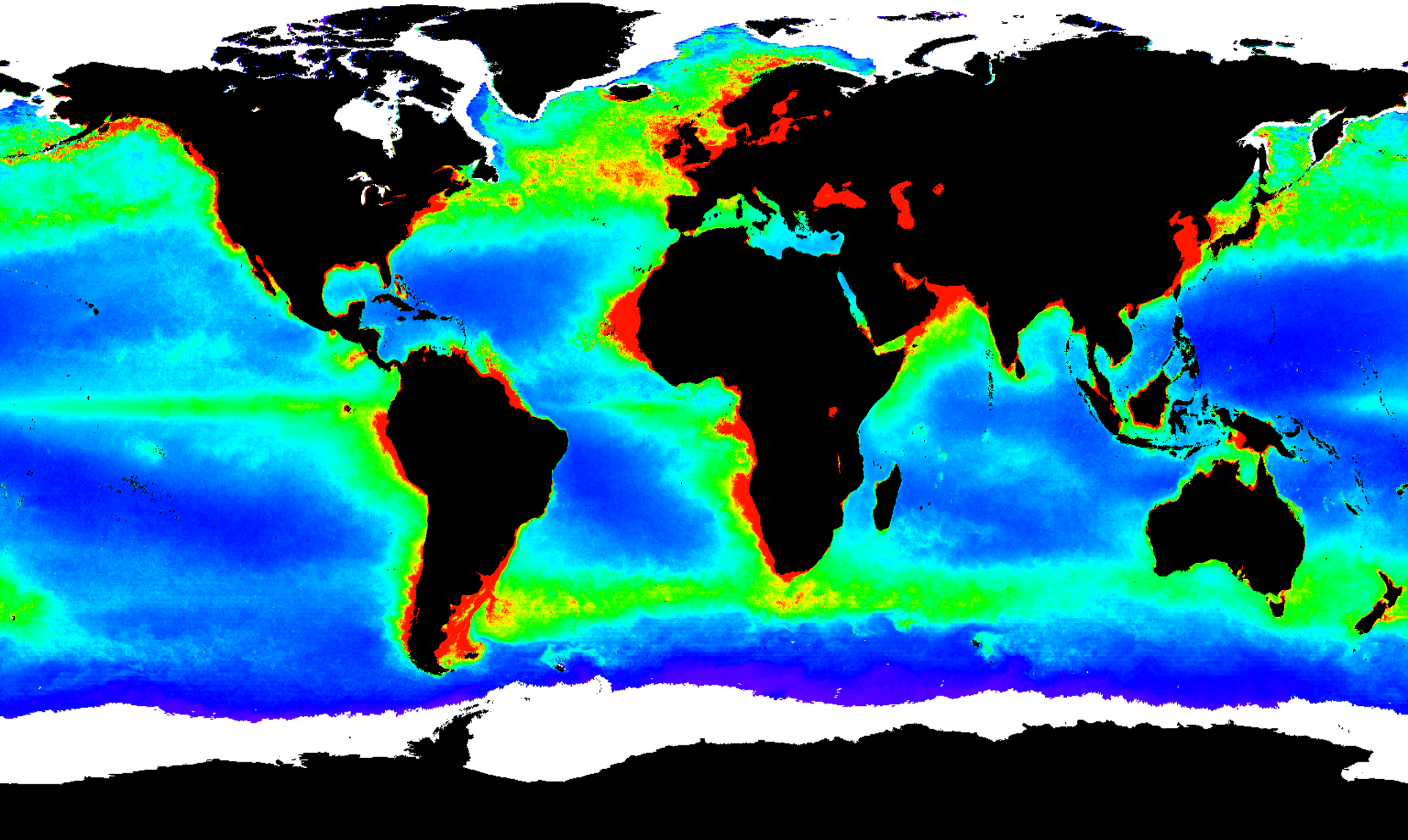
Life at the edge: *Melosira arctica*

Massive production supports the community of the benthic environment. Diminished sea ice suggests significant loss of this production to coastal food webs

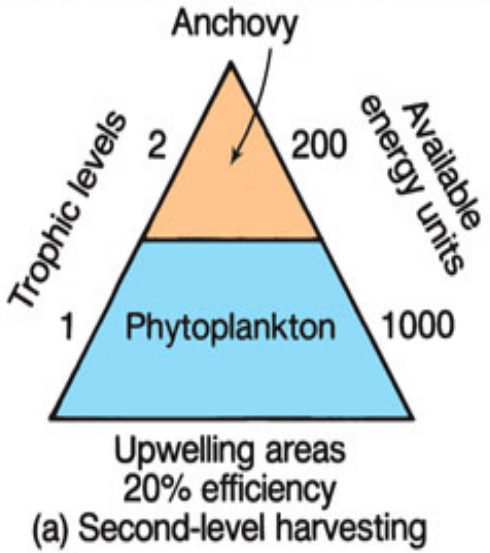
Perhaps 25% of Arctic primary production is associated with ice (Gradinger, 2009)

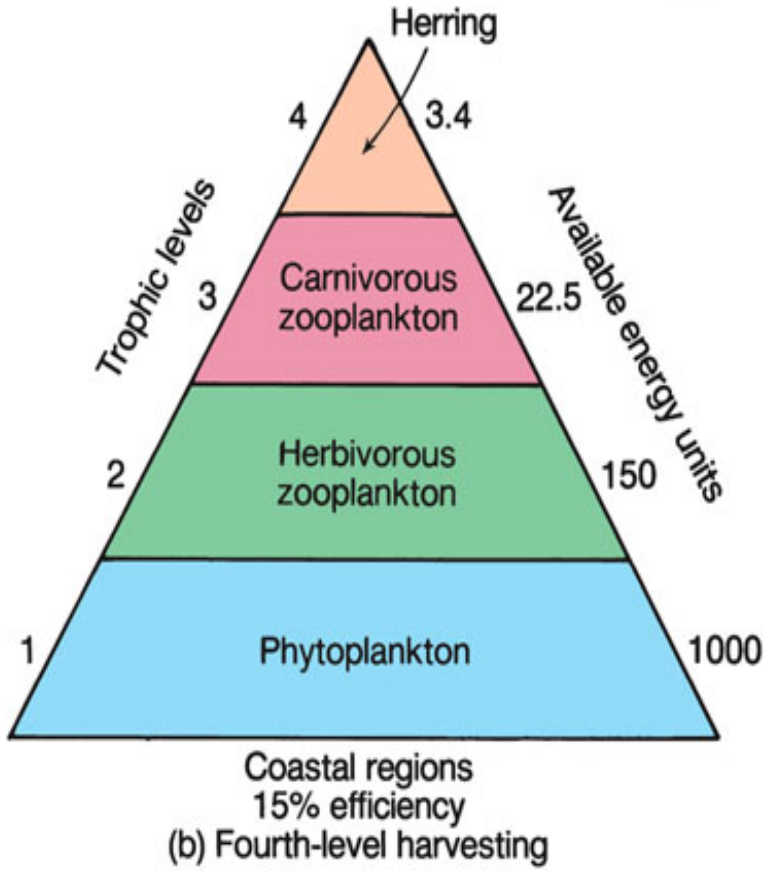

Beaufort Sea
Chukchi Sea
Bering Sea
Gray whales
Summer distribution
Migration
(a)
Beaufort Sea
Chukchi Sea
Bering Sea
Humpback whales
Summer distribution
Winter distribution
Migration
Hawaiian Is.
Baja California
(b)
Beaufort Sea
Chukchi Sea
Bering Sea
Bowhead and beluga whales
Distribution
Migration
(c)
Ellesmere Island
Greenland
Baffin Island
Narwhal
Distribution
Migration
(d)

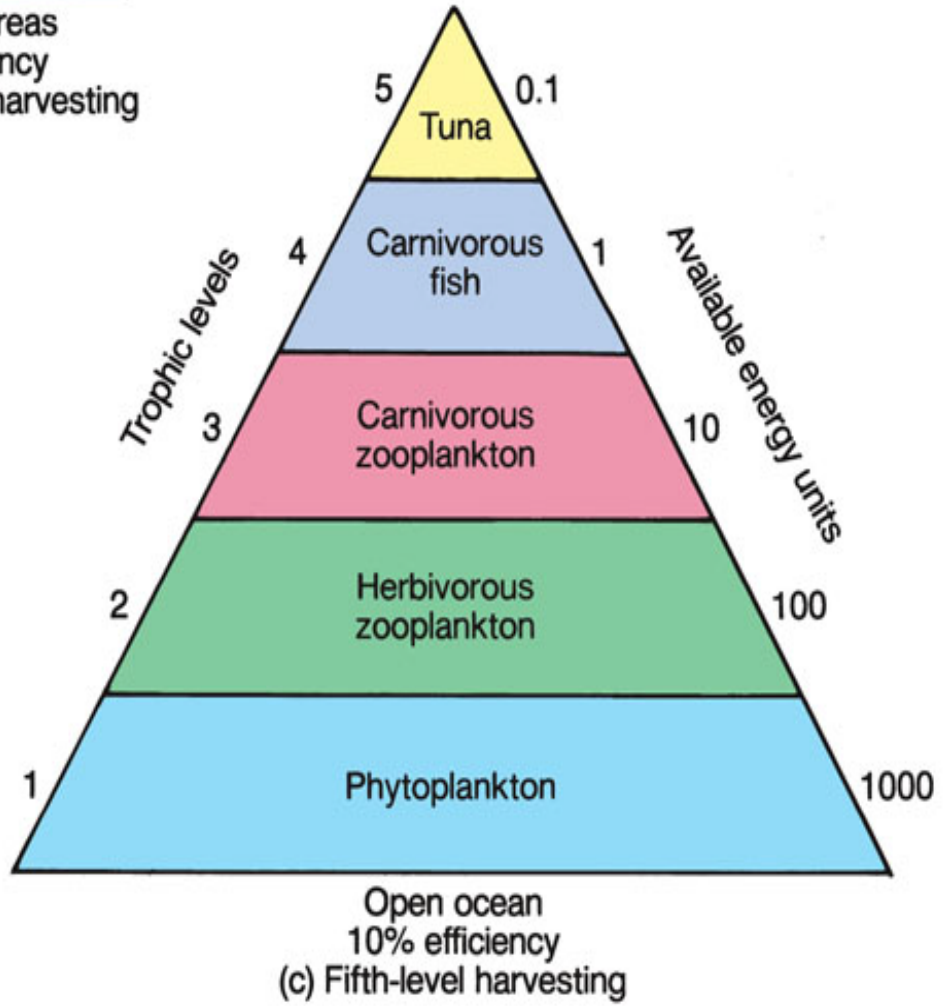
Modification to Primary Production?



If food chains change, then less higher productivity

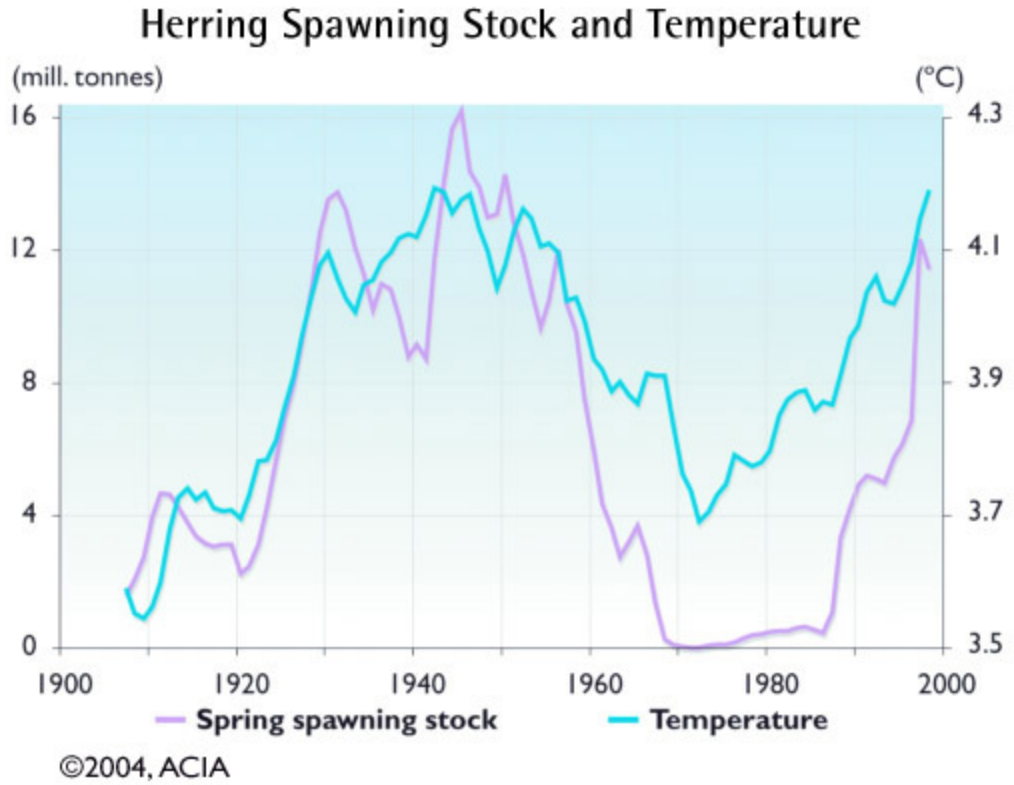






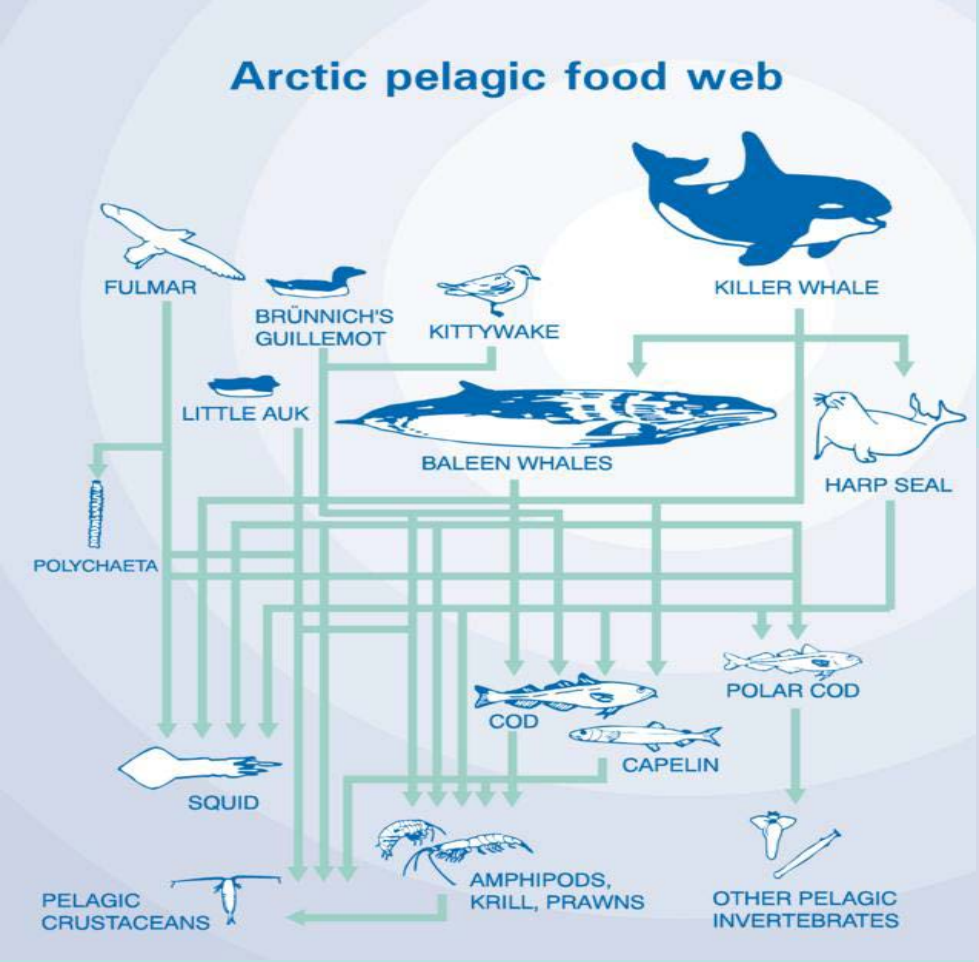
Graphic courtesy Introduction to Oceanography, Sverdrup et al. Prentice Hall

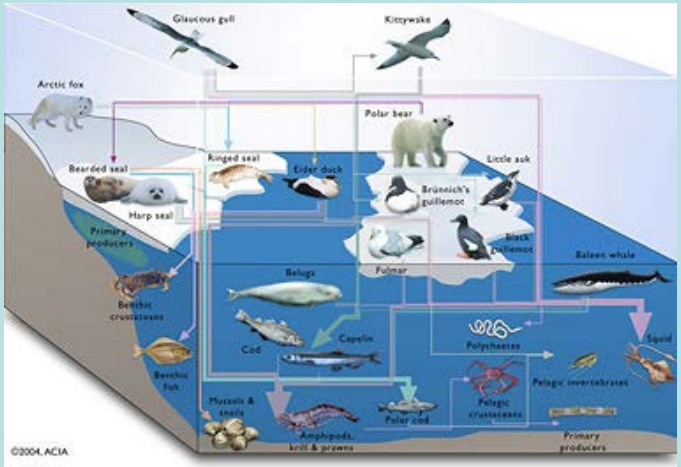
Spawning, higher temperatures and unknown population sizes



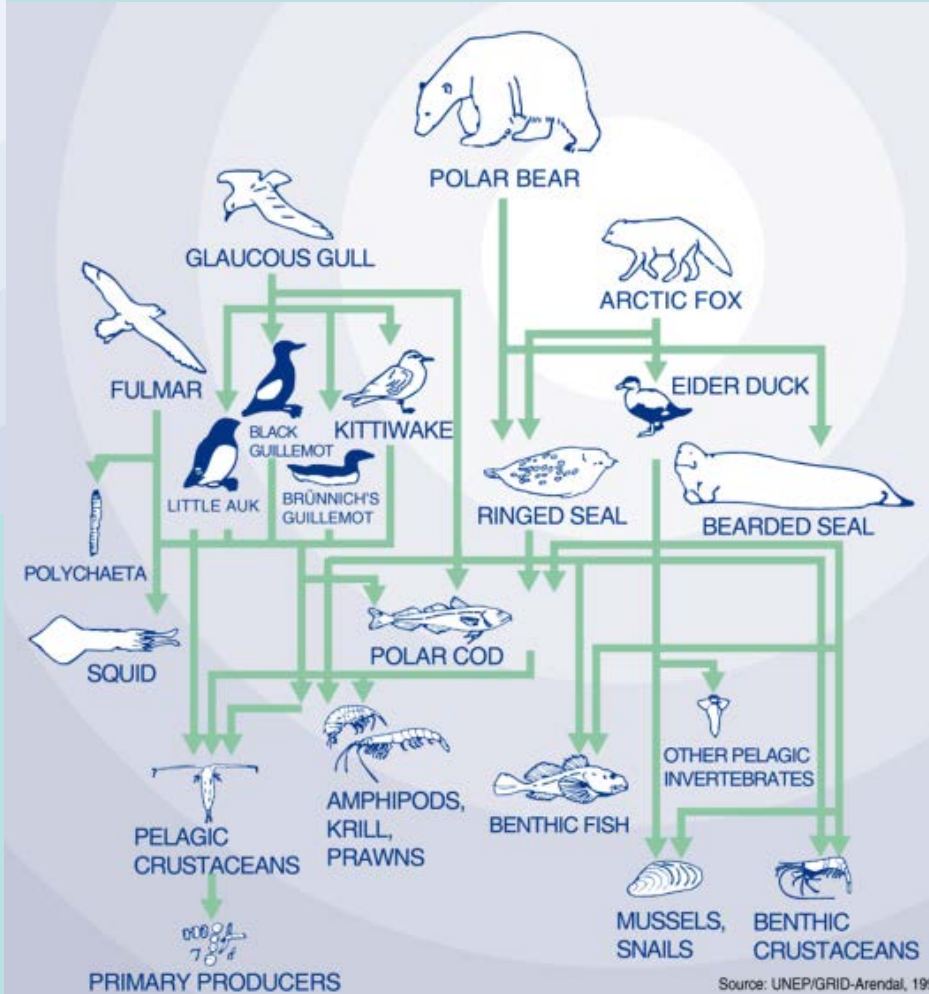
- Critical temperatures exist for all fish spawning
- Need for ice cover is unknown for all of the species
- Stock size for present populations under ice unknown- easy to overfish

Effects on fisheries of changes to primary producers is unknown

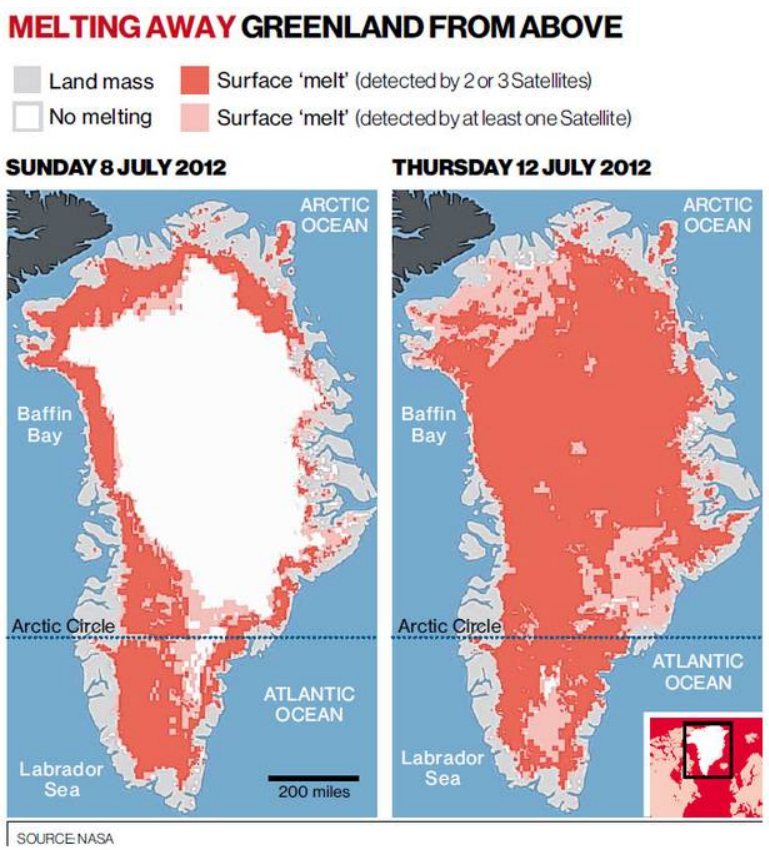




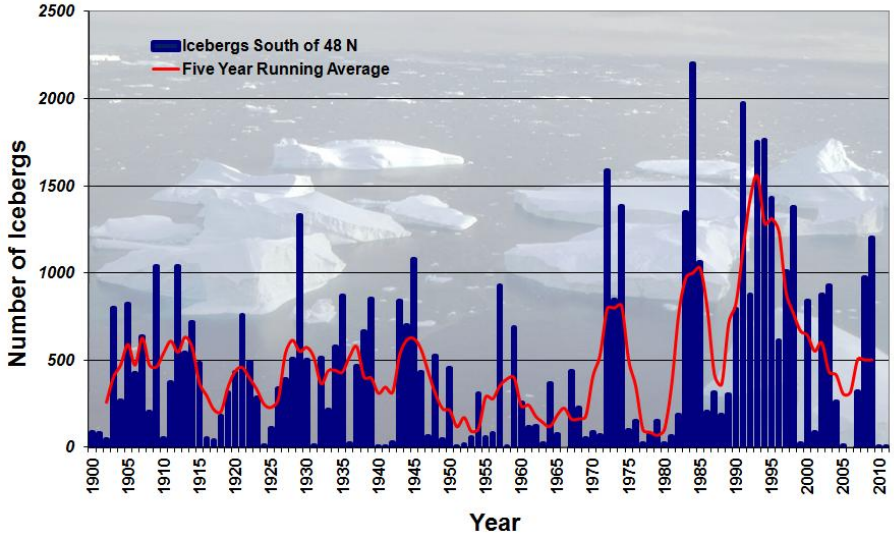
Arctic coastal food web

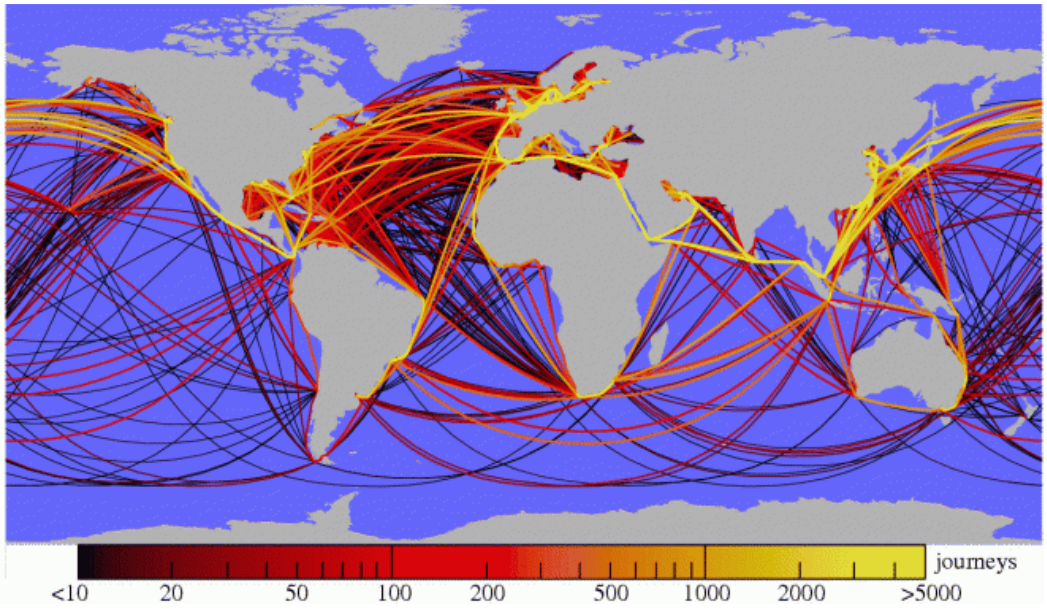


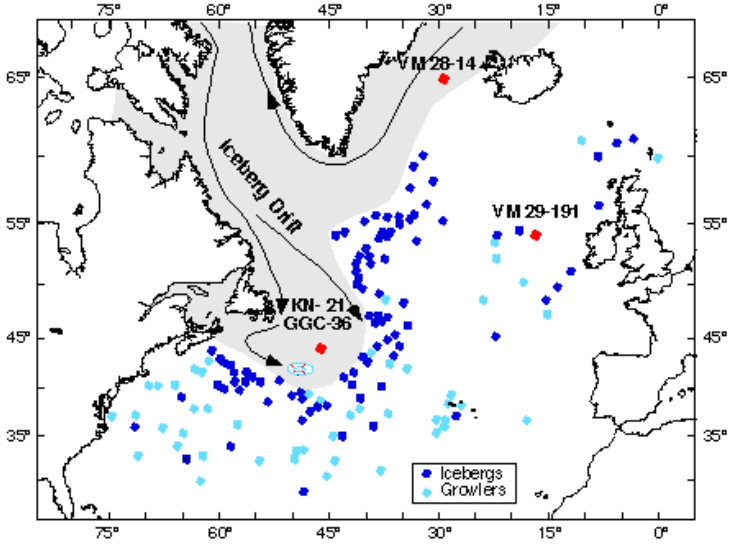
Greenland Ice Sheet



Chasing Ice

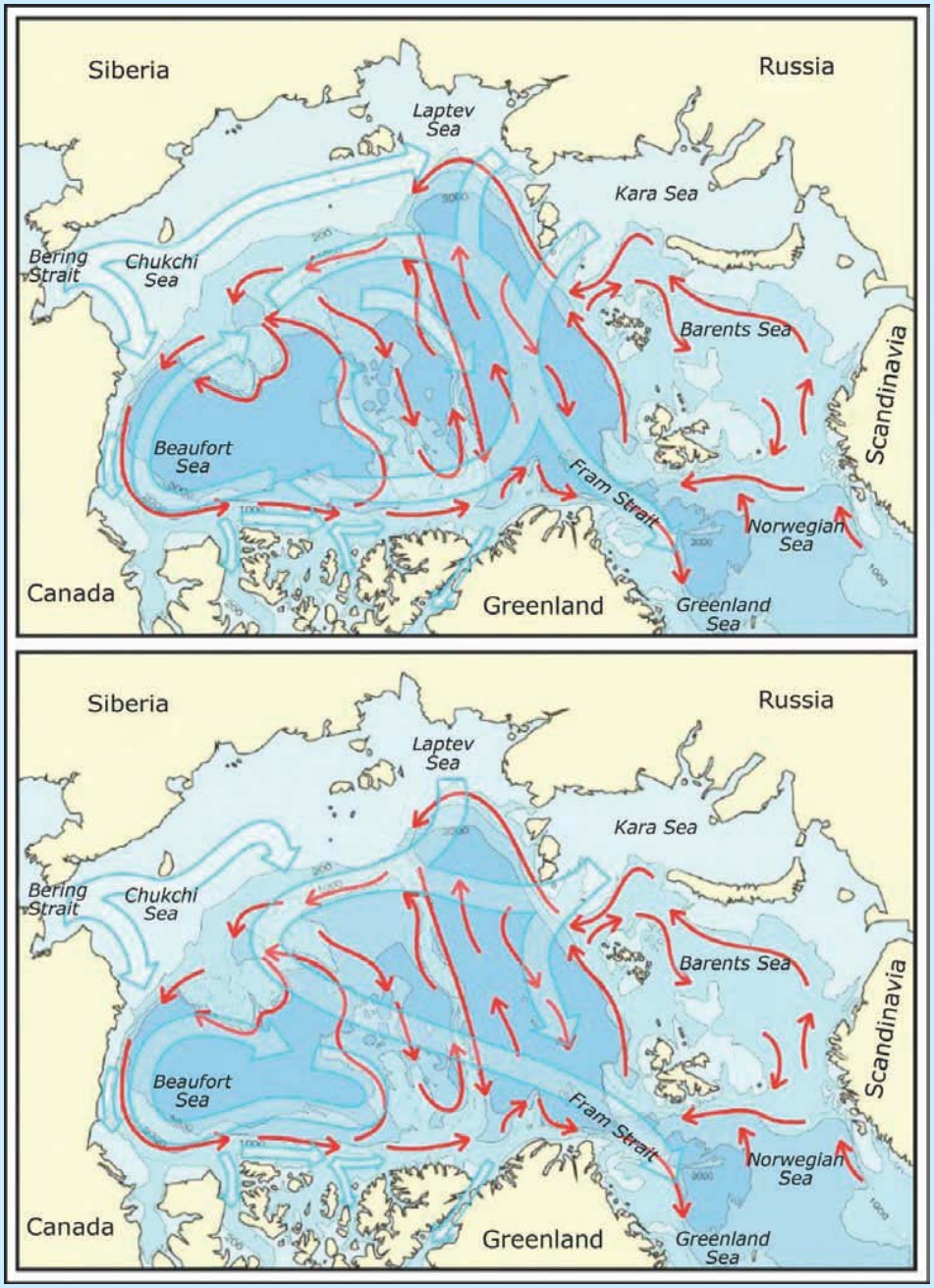






KNOWN EXAMPLES OF EXTREME ICEBERG DRIFT (1890-1966)

From US Naval Ocean. Office, 1968



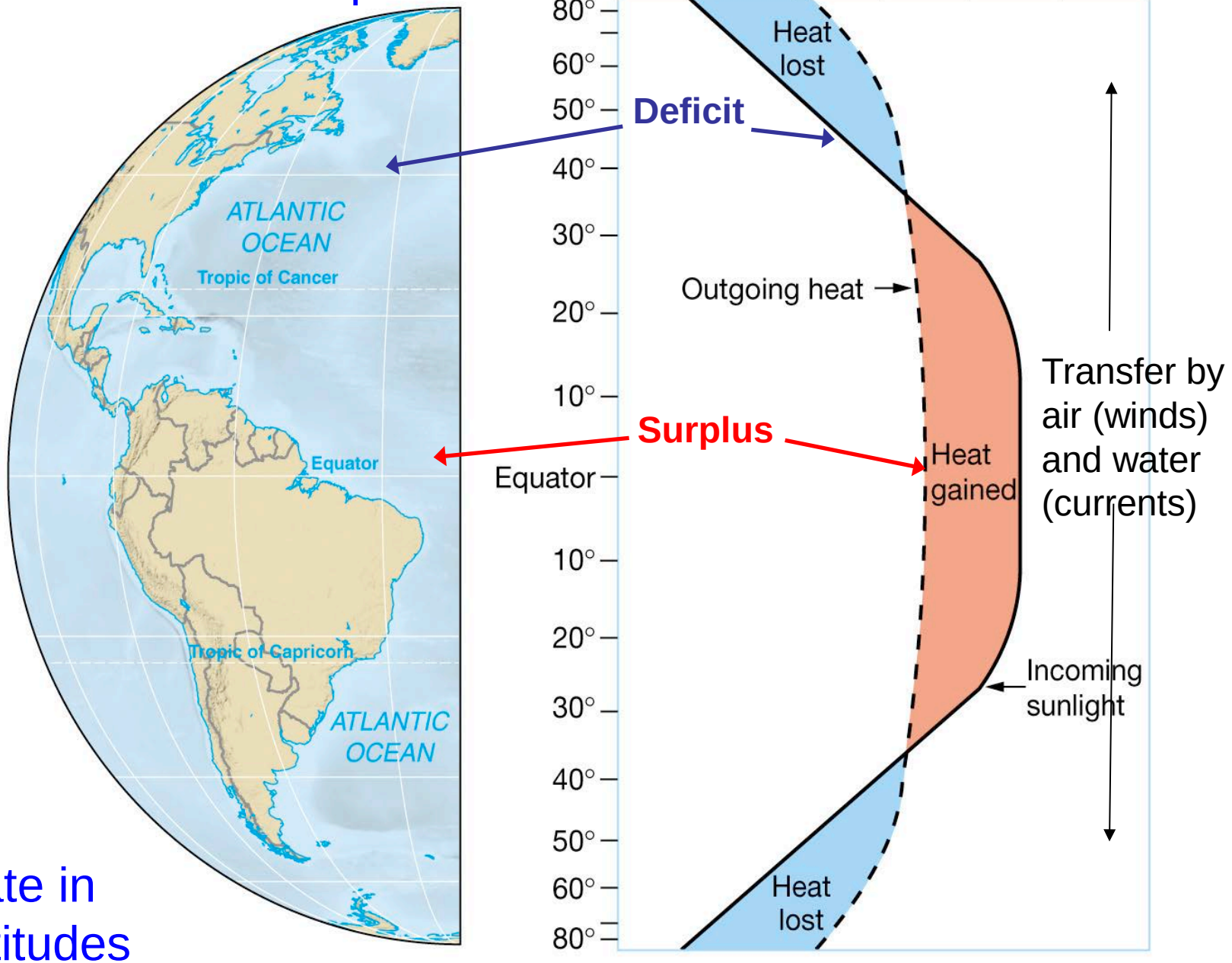
Currents are changing

From 1986-1996; anticyclonic

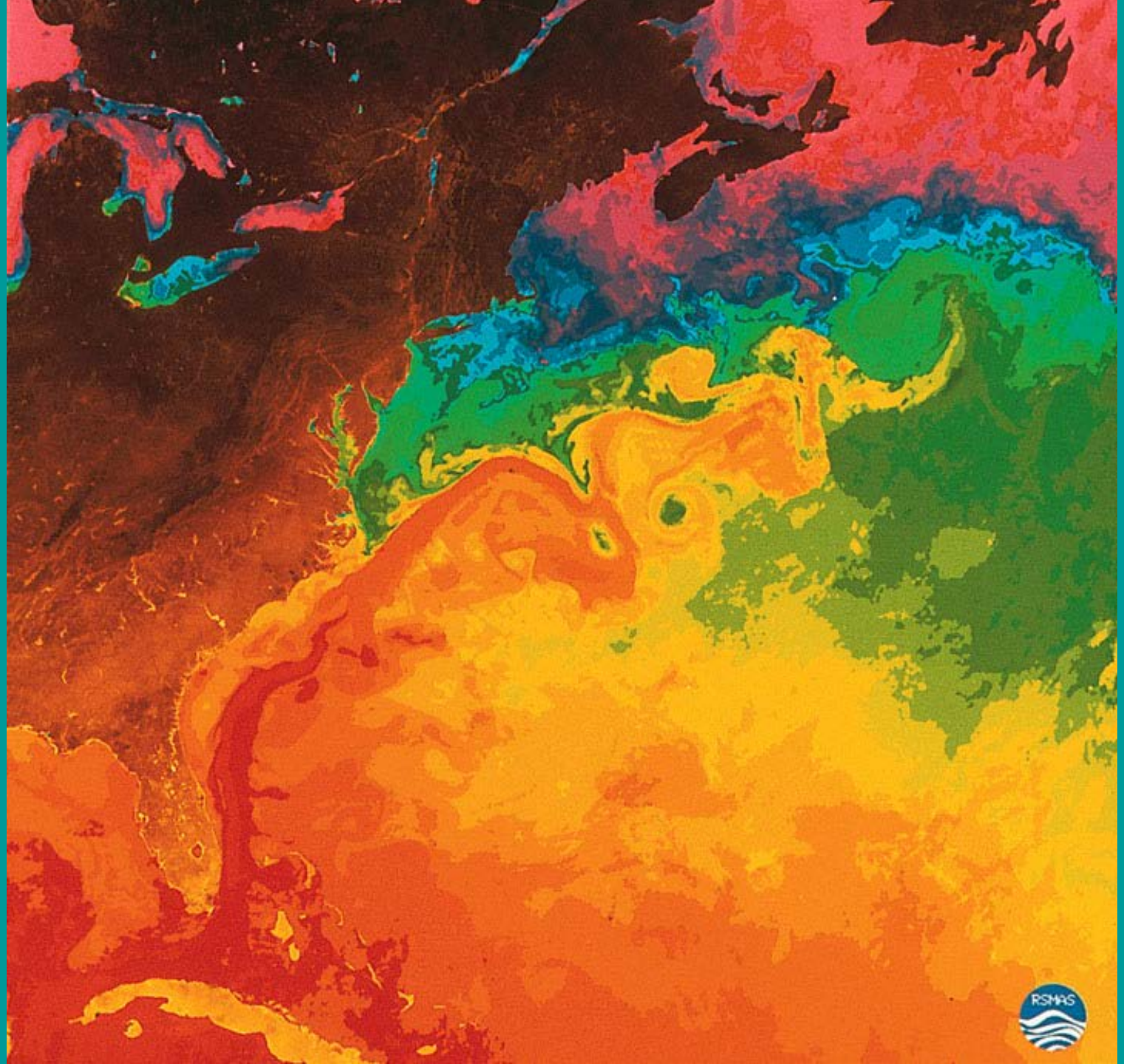
Idealized patterns of the dominant circulation regimes of the Arctic Ocean. Two circulation regimes of **surface waters** (anticyclonic—top; cyclonic—bottom) are shown in wide blue arrows. In the cyclonic regime the clockwise circulation pattern in the Beaufort Sea region (the Beaufort Gyre) weakens, and the flow across the basin, from the Siberian and Russian coasts to Fram Strait (the Transpolar Drift), shifts poleward. The cyclonic pattern dominated during 1989–1996; the anticyclonic pattern has prevailed since 1997. The Atlantic water circulates cyclonically (red arrows) at approximately 200–800 m deep, independent of the circulation regime of the surface layer. (Adapted from Proshutinsky *et al.*, 2005.)

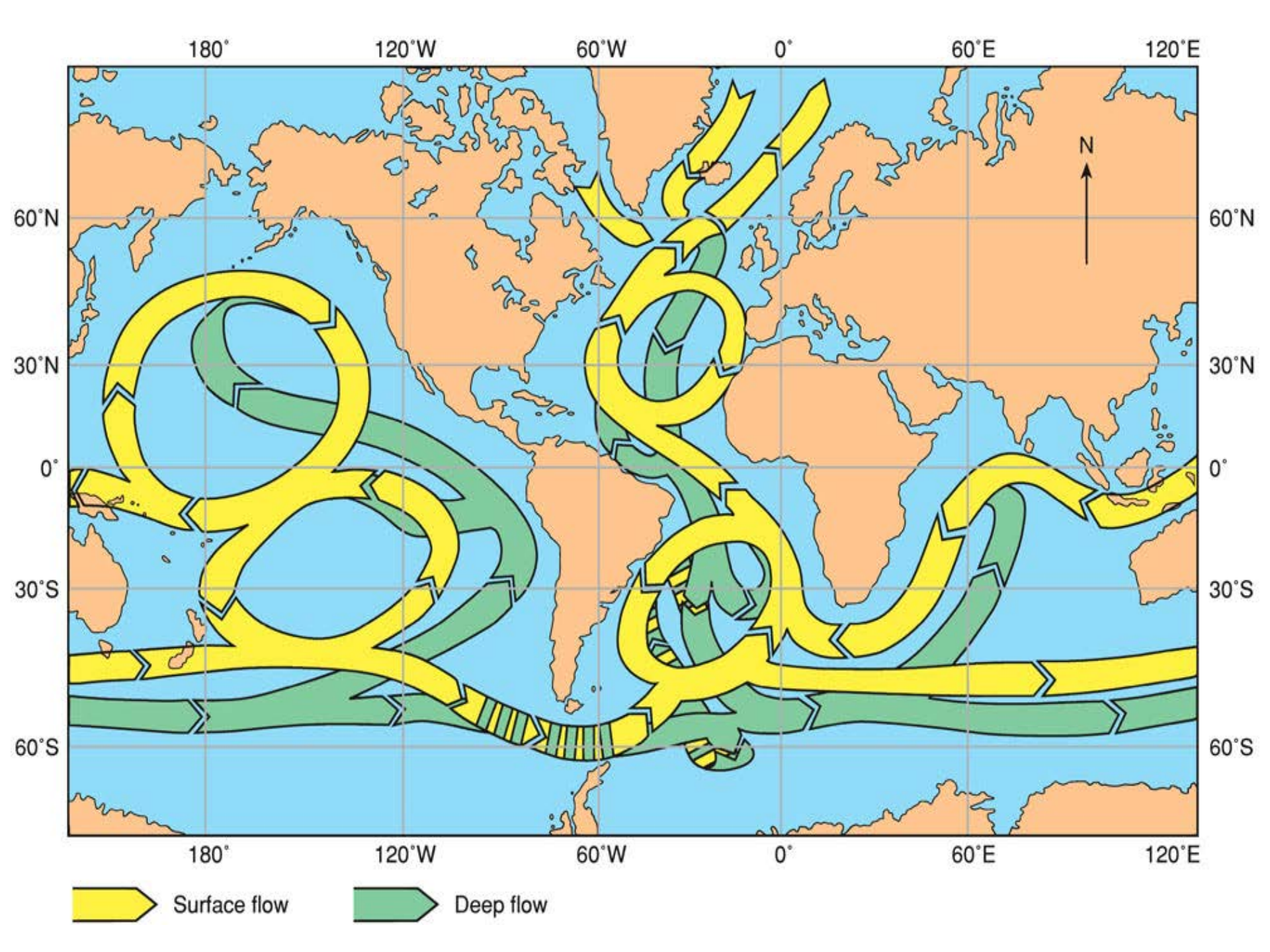
Since 1997; cyclonic

Currents carry about 50-60% of heat excess at the equator



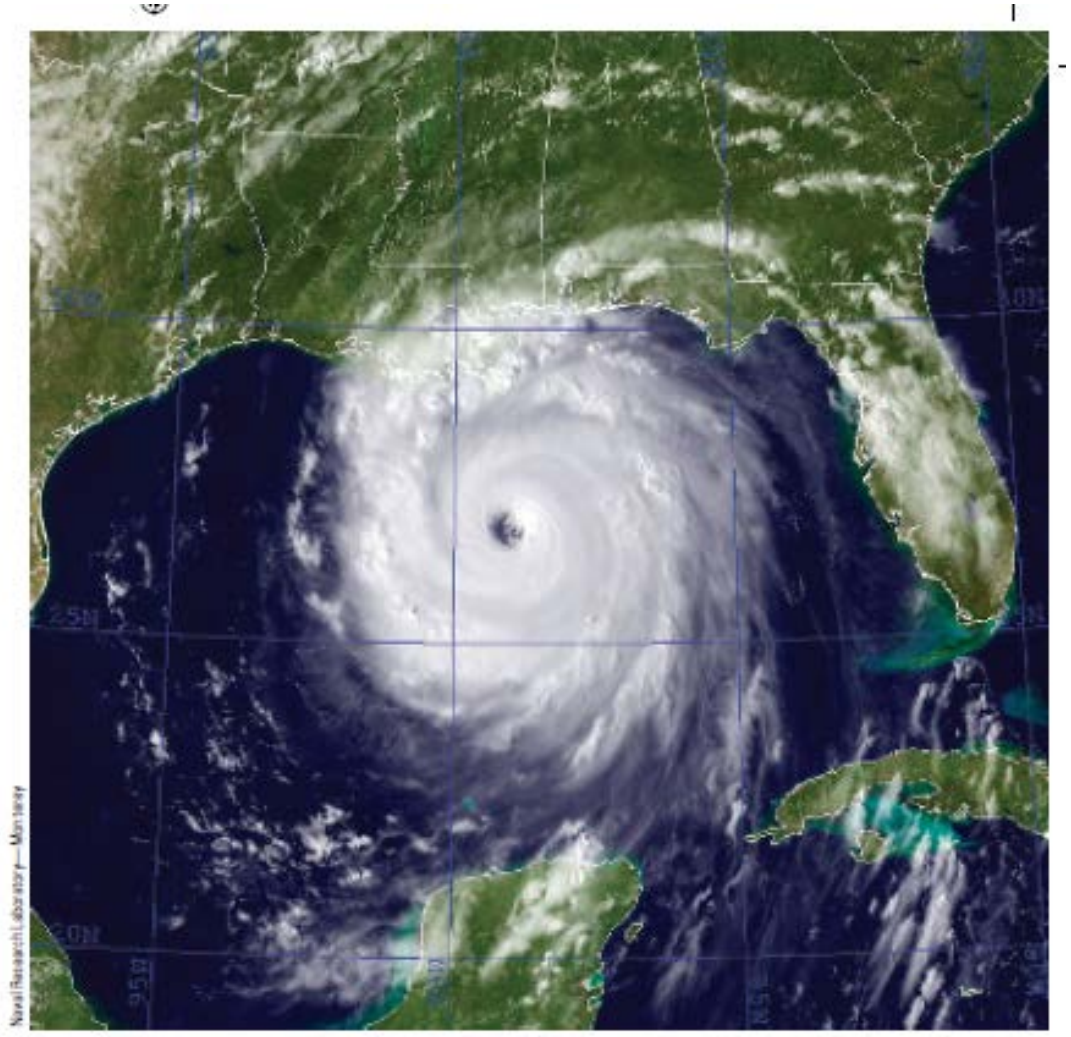
Winds dominate in high latitudes


RSMAS

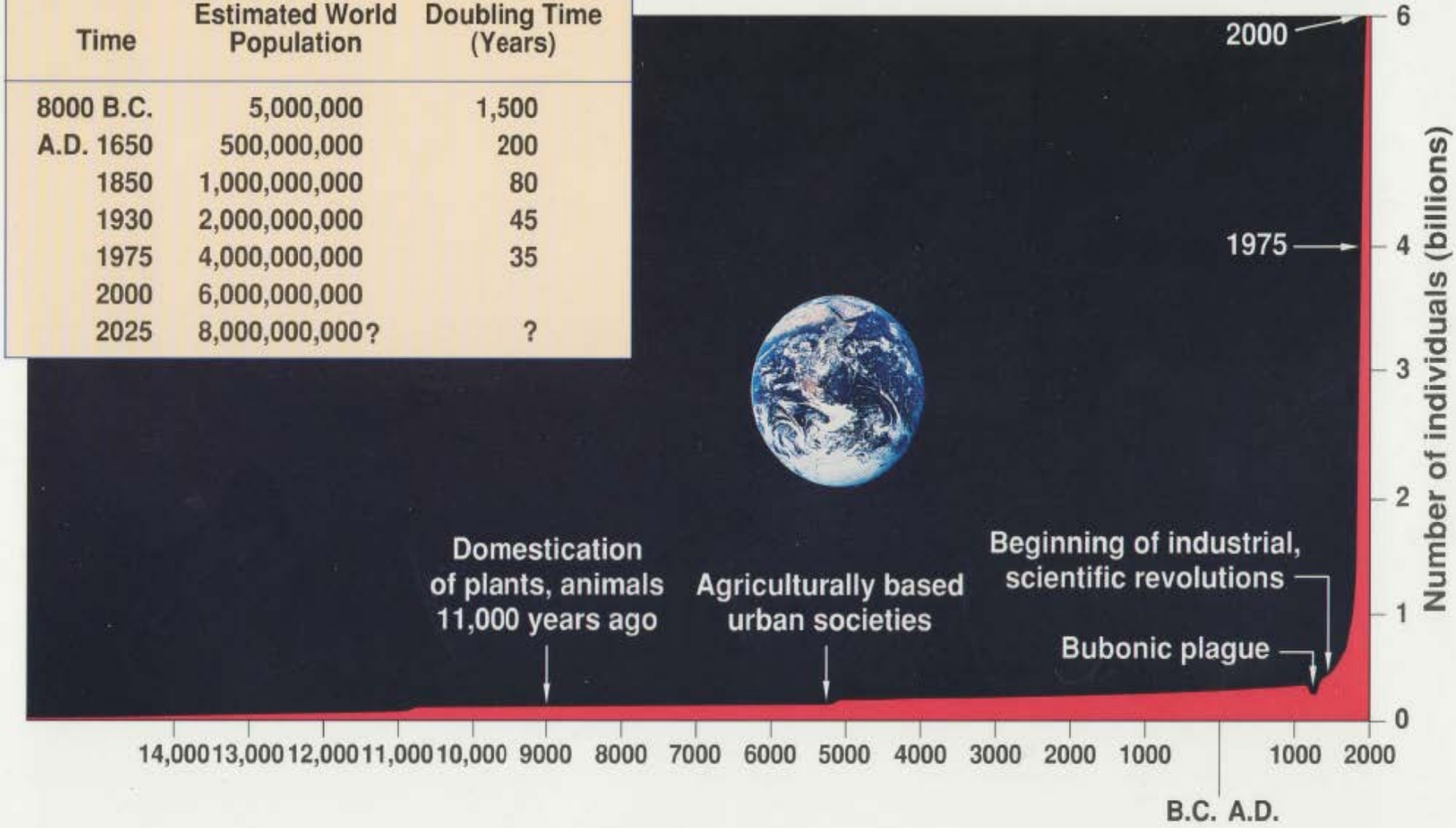

180°
120°W
60°W
0°
60°E
120°E
N
60°N
30°N
0°
30°S
60°S
Surface flow
Deep flow

Implications: High pressure/ low pressure

- Zones of water land interactions/onshore-offshore



Time	Estimated World Population	Doubling Time (Years)
8000 B.C.	5,000,000	1,500
A.D. 1650	500,000,000	200
1850	1,000,000,000	80
1930	2,000,000,000	45
1975	4,000,000,000	35
2000	6,000,000,000	
2025	8,000,000,000?	?



- *Fish are the only important food source that is primarily gathered from wild stock*

- *Represents 16% of human protein nutrition*

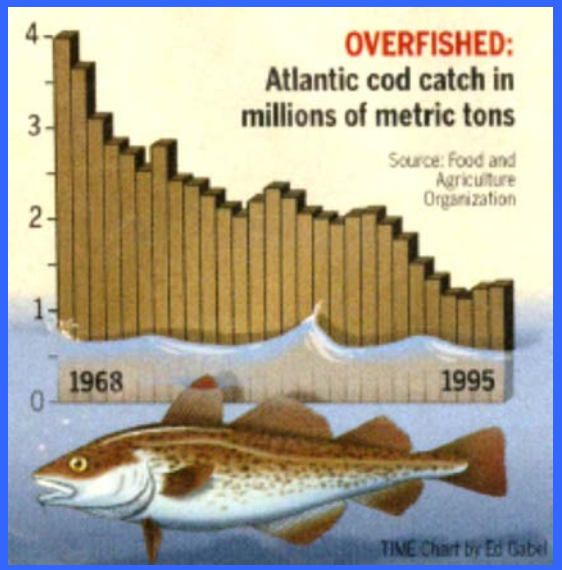
Compounding Issues: Poor management and climate change:From land to sea

- Large land animals almost lost
- Coastal waters overfished
- The open ocean: our last frontier?

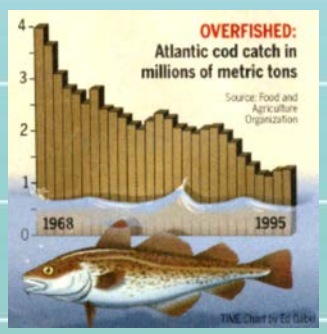

TERRA NOVA
HÆC·TIBI·DONA·FERO

These gifts I bring

Decline in cod fishery



Catches landed, in tonnes



15 May 2003

International weekly journal of science

nature

$10.00

www.nature.com/nature

Net losses

Industrialized fishing hits fish stocks

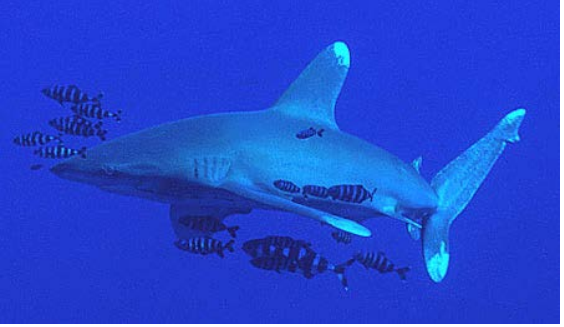
Financial markets
You can't buck the physics

Jupiter's moons
Headed for a hundred

Functional genomics
The power of comparison

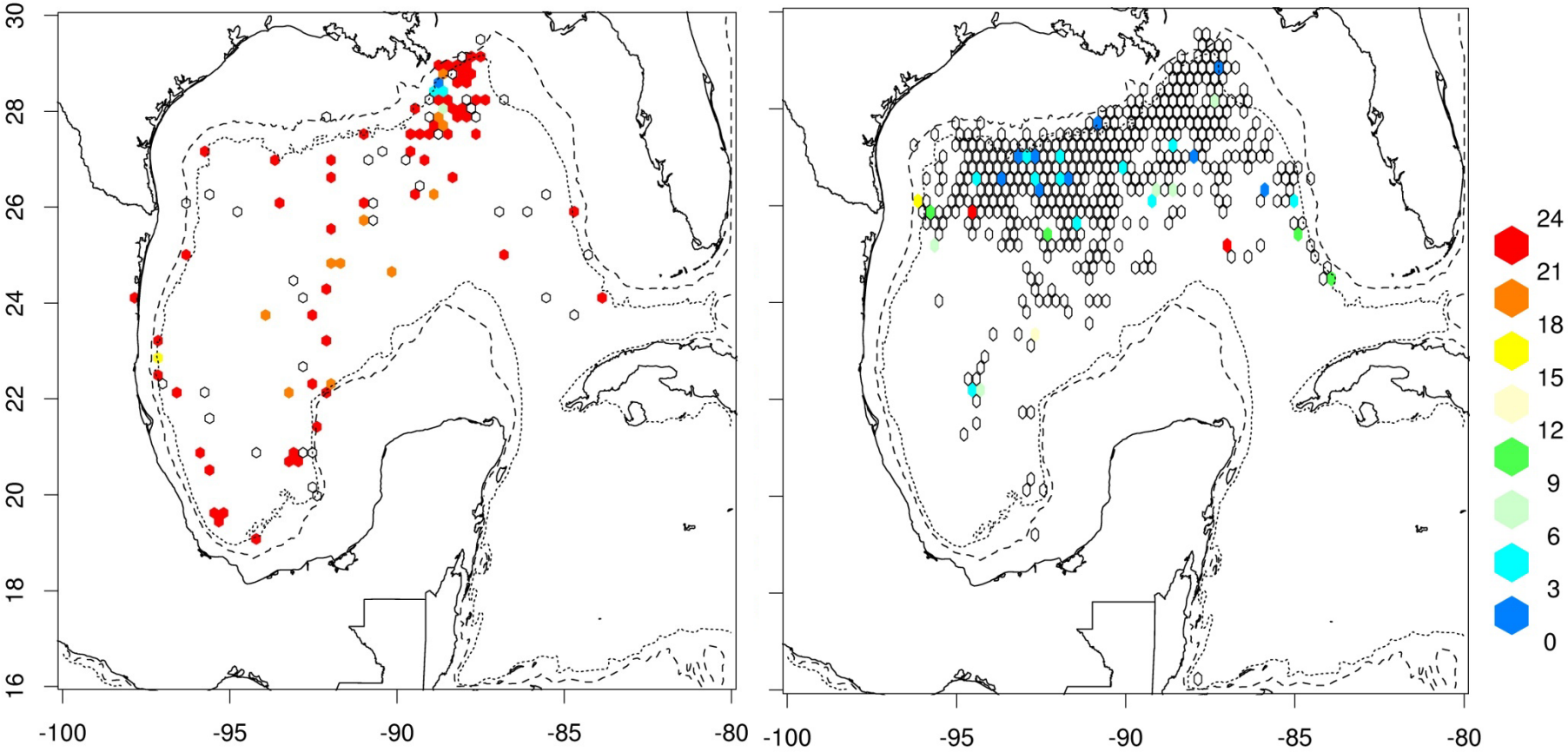
$10.00US $12.99CAN 20

0 771486 030706



Loss of sharks in the Gulf of Mexico

300 fold decline – no one noticed

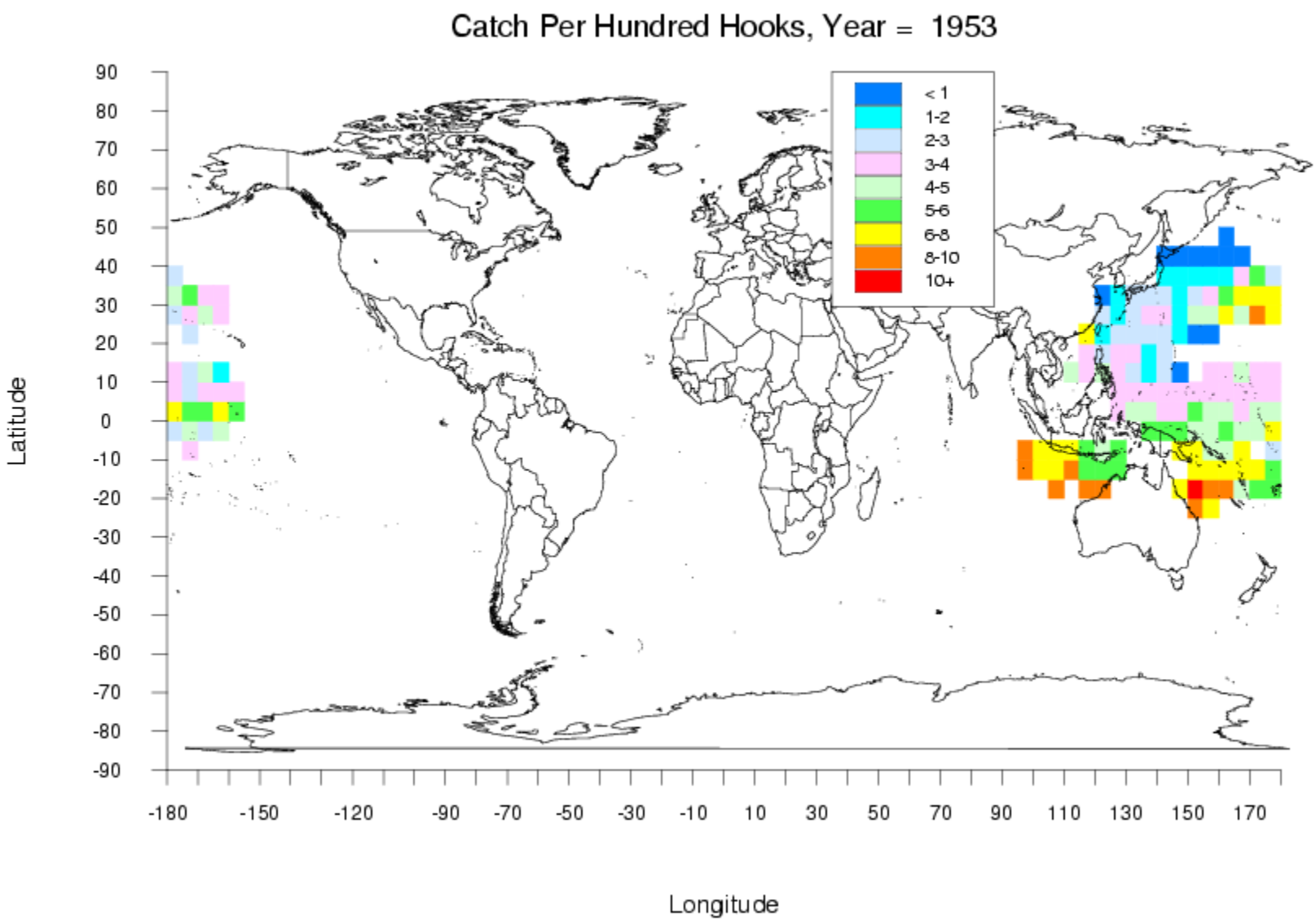


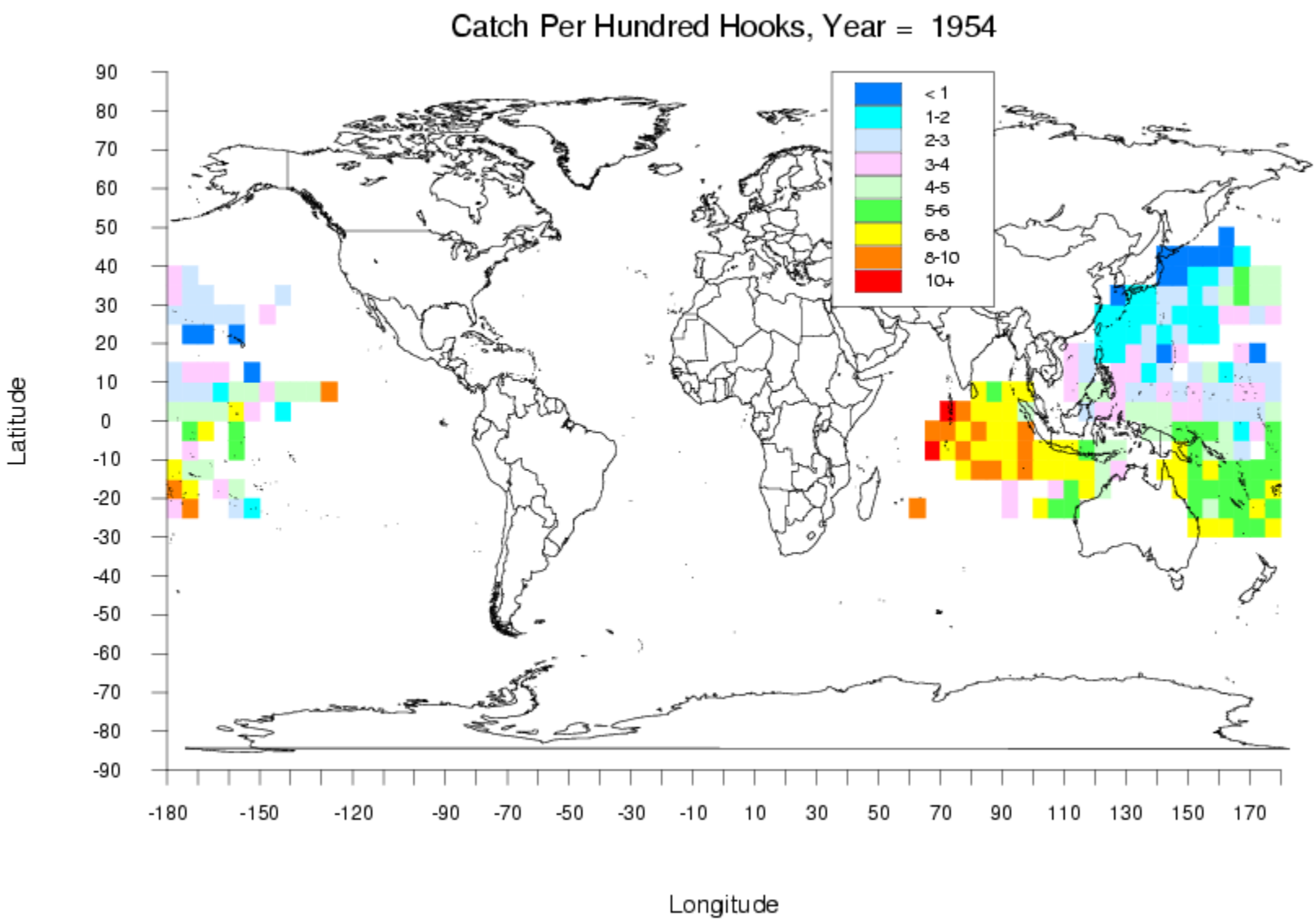
1950's

1990's

Oceanic Whitetip captures per 10,000 hooks

Baum and Myers, Ecology Letters


Catch Per Hundred Hooks, Year = 1953
< 1
1-2
2-3
3-4
4-5
5-6
6-8
8-10
10+
Latitude
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-180
-150
-120
-90
-70
-50
-30
-10
10
30
50
70
90
110
130
150
170
Longitude


Catch Per Hundred Hooks, Year = 1954
< 1
1-2
2-3
3-4
4-5
5-6
6-8
8-10
10+
Latitude
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
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-30
-10
10
30
50
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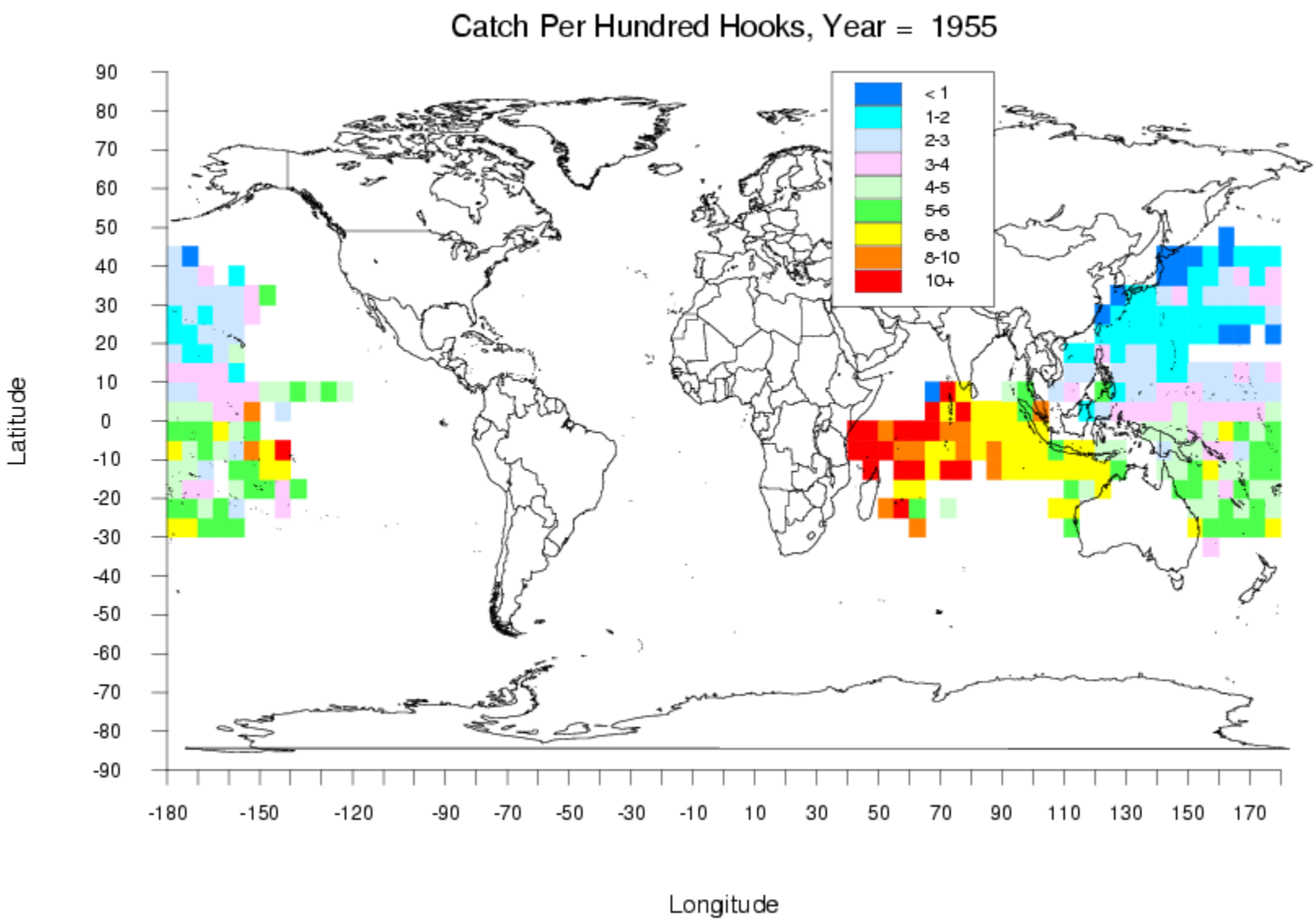
90
110
130
150
170
Longitude


Catch Per Hundred Hooks, Year = 1955
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2-3
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4-5
5-6
6-8
8-10
10+
Latitude
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30
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10
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-80
-90
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-10
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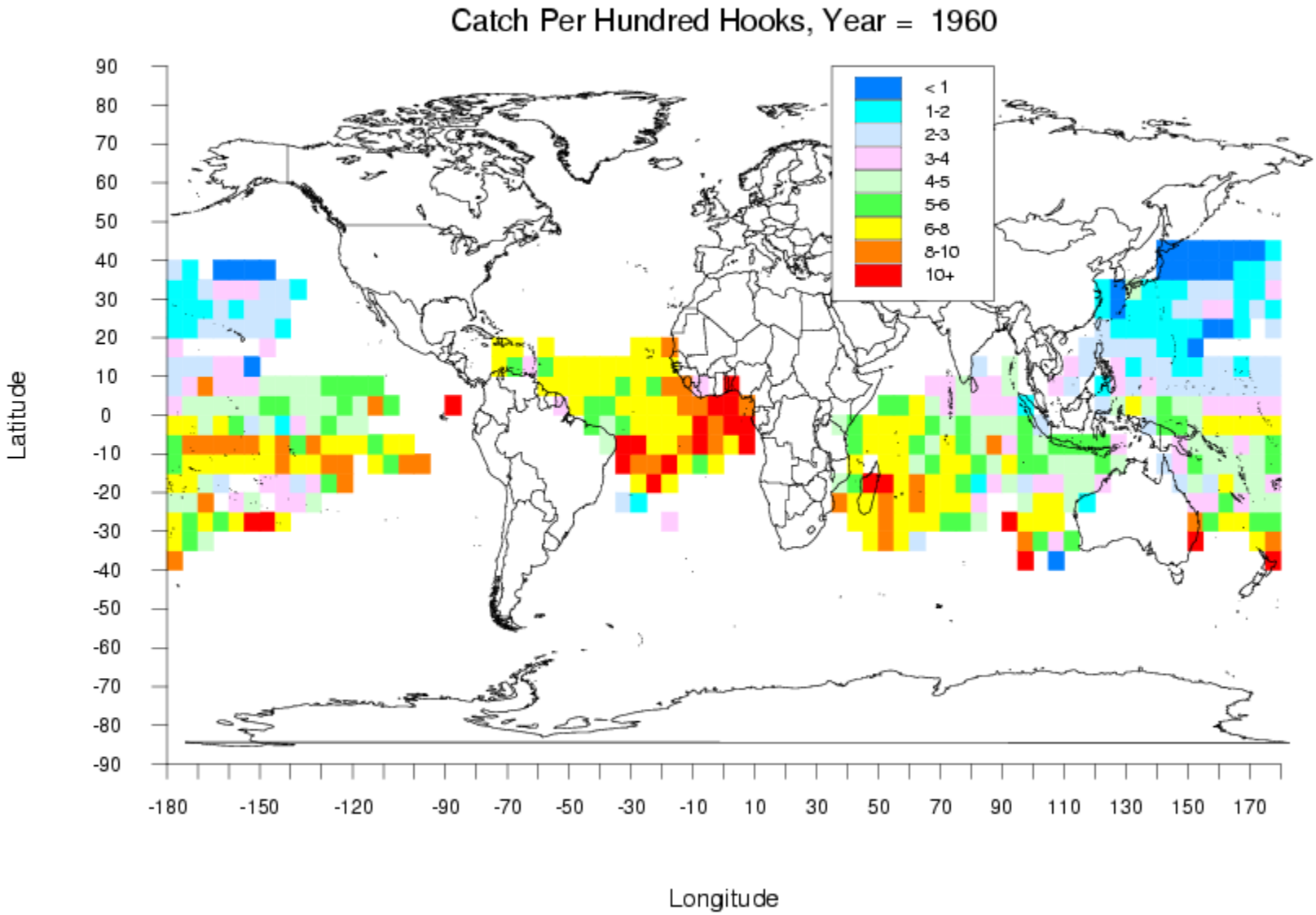
90
110
130
150
170
Longitude


Catch Per Hundred Hooks, Year = 1960
< 1
1-2
2-3
3-4
4-5
5-6
6-8
8-10
10+
Latitude
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80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
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-60
-70
-80
-90
-180
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-70
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-30
-10
10
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50
70
90
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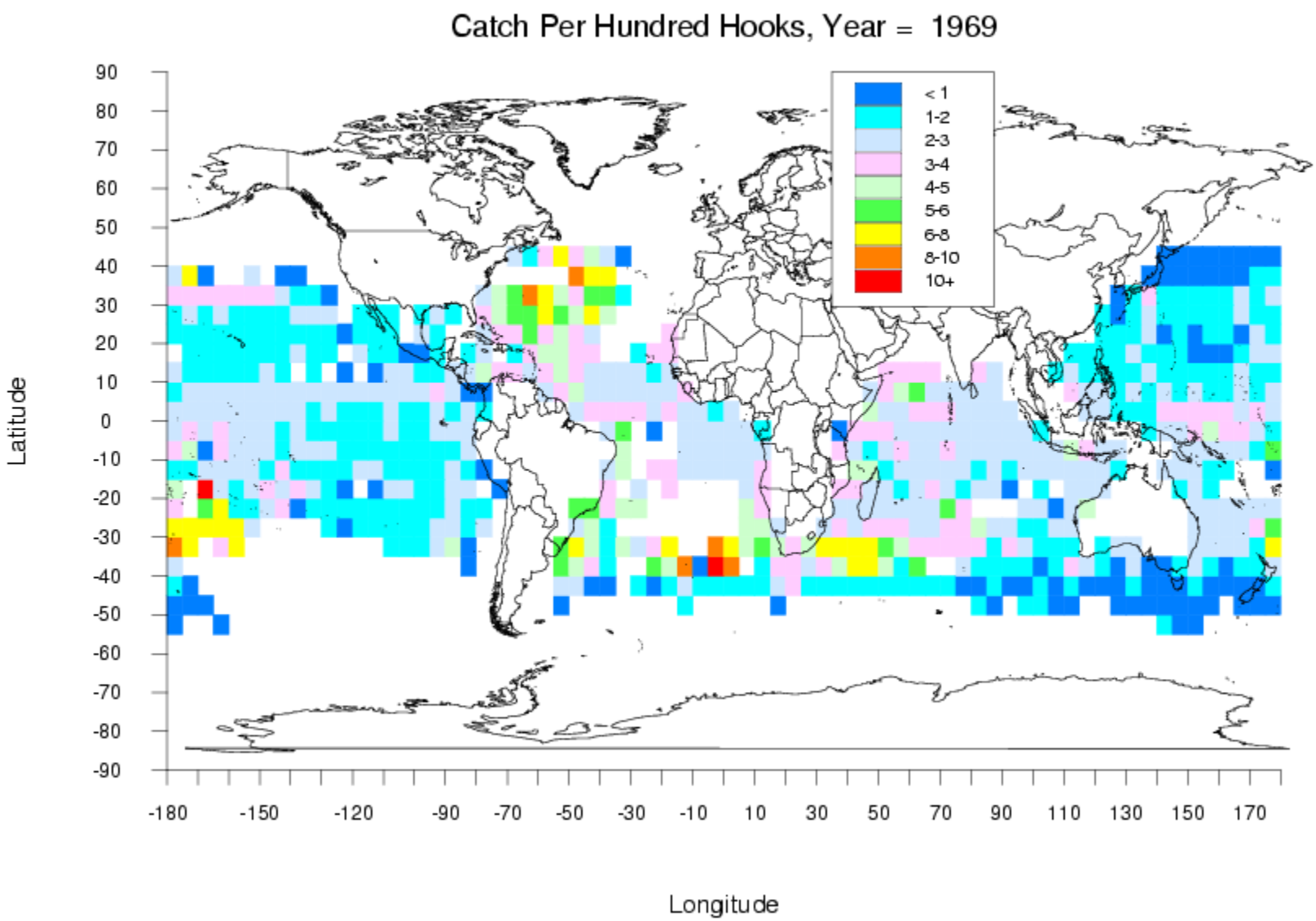
130
150
170
Longitude


Catch Per Hundred Hooks, Year = 1969
< 1
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2-3
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5-6
6-8
8-10
10+
Latitude
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80
70
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40
30
20
10
0
-10
-20
-30
-40
-50
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-70
-80
-90
-180
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-70
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-30
-10
10
30
50
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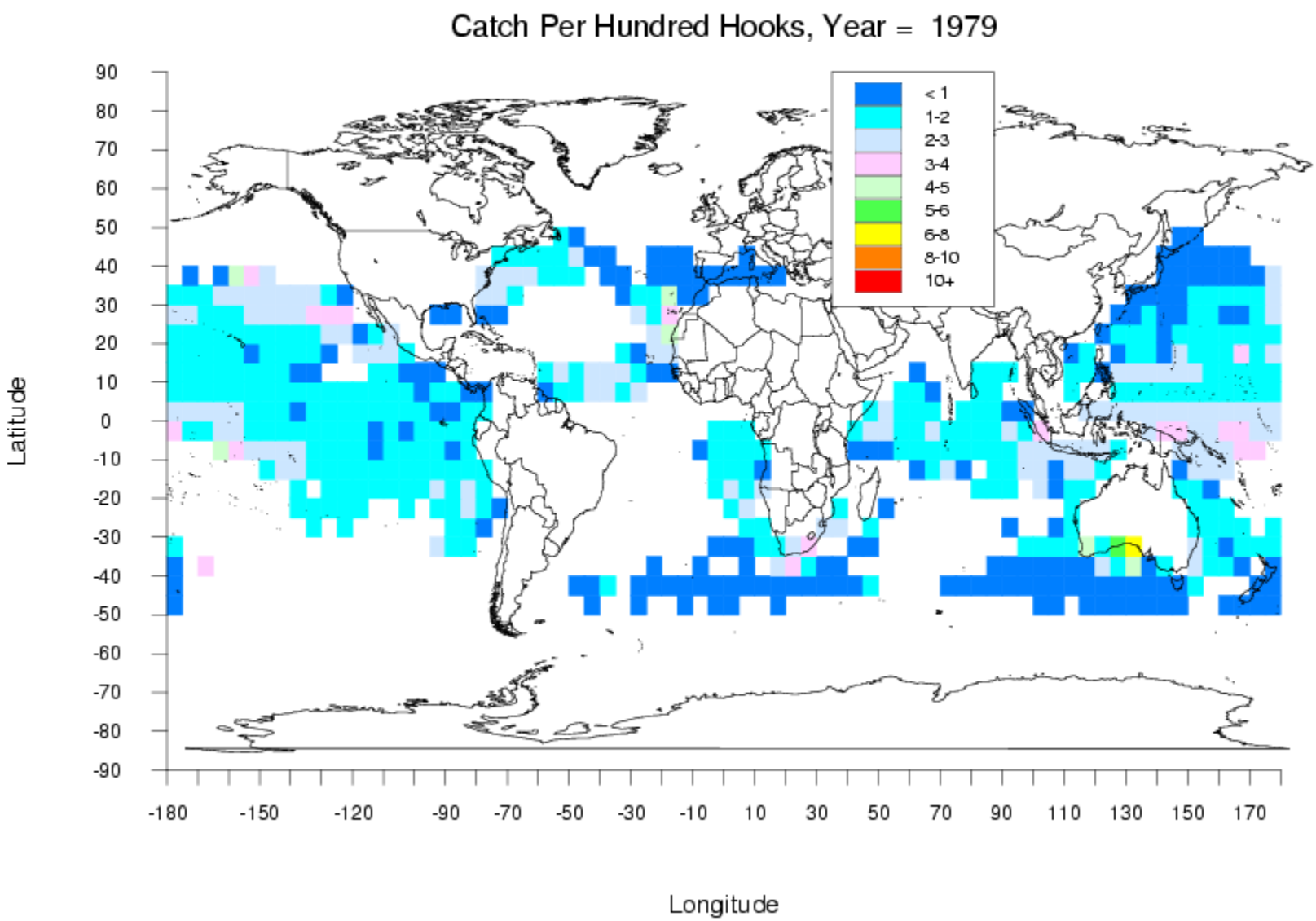
90
110
130
150
170
Longitude


Catch Per Hundred Hooks, Year = 1979
< 1
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2-3
3-4
4-5
5-6
6-8
8-10
10+
Latitude
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
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-70
-80
-90
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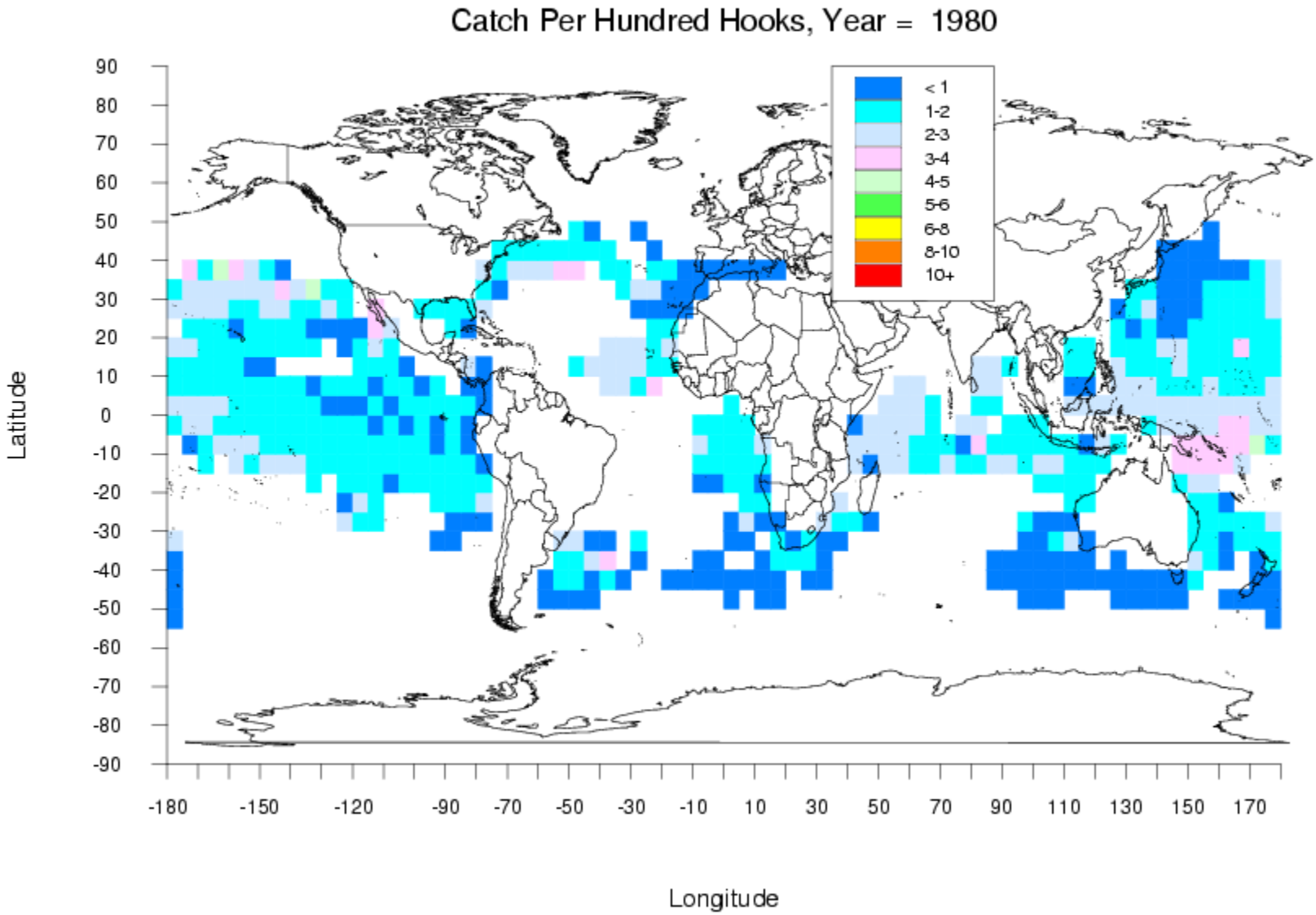
130
150
170
Longitude


Catch Per Hundred Hooks, Year = 1980
< 1
1-2
2-3
3-4
4-5
5-6
6-8
8-10
10+
Latitude
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-180
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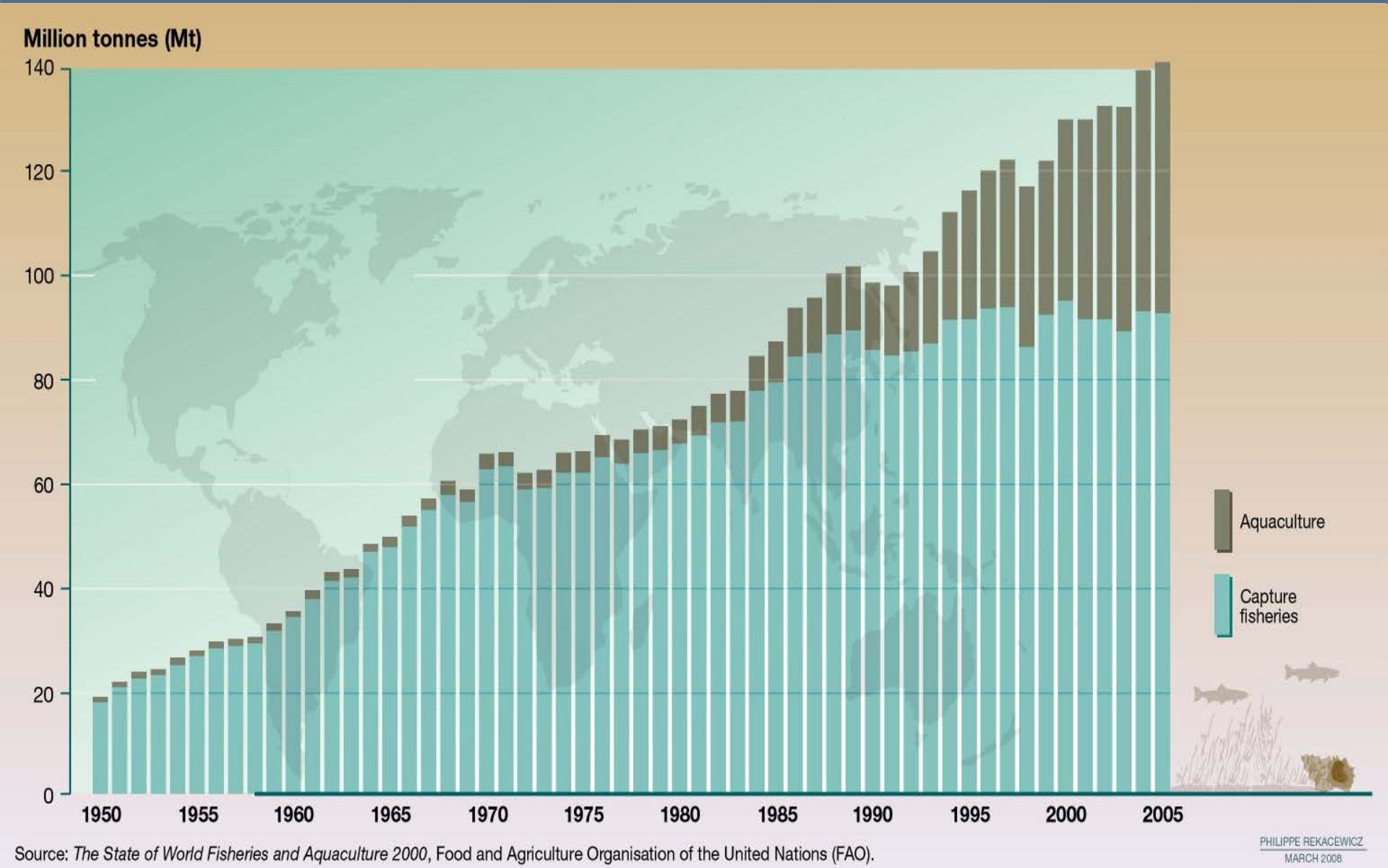
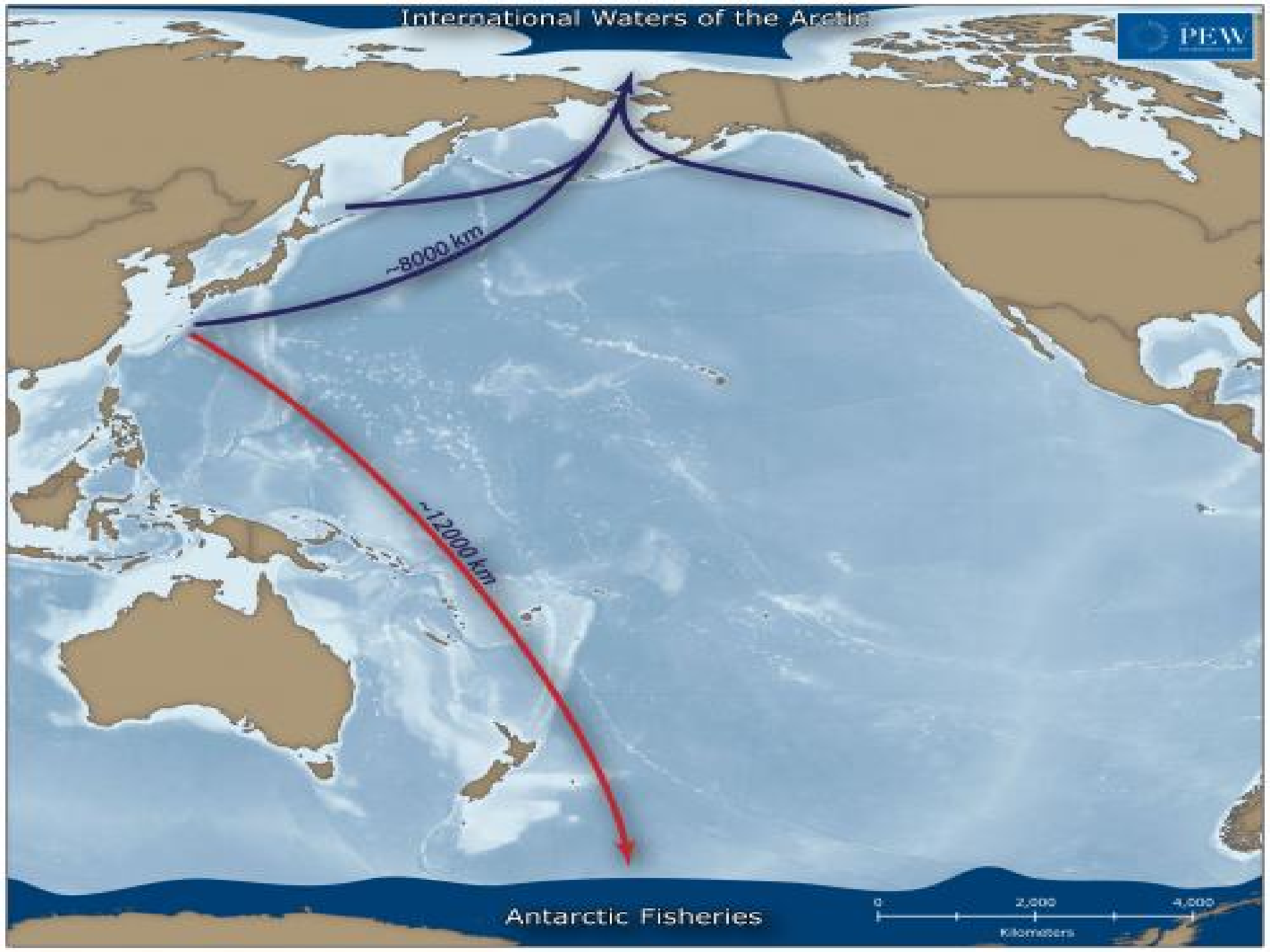
150
170
Longitude



Source: *The State of World Fisheries and Aquaculture 2000*, Food and Agriculture Organisation of the United Nations (FAO).


0
500
1,000
Kilometers
Norway
Greenland
Canada
Russia
USA
EEZ Boundary
International Waters
Fishable Depths (<2000m)
Ice Extent- Sept 16, 2012
THE PEW ENVIRONMENT GROUP

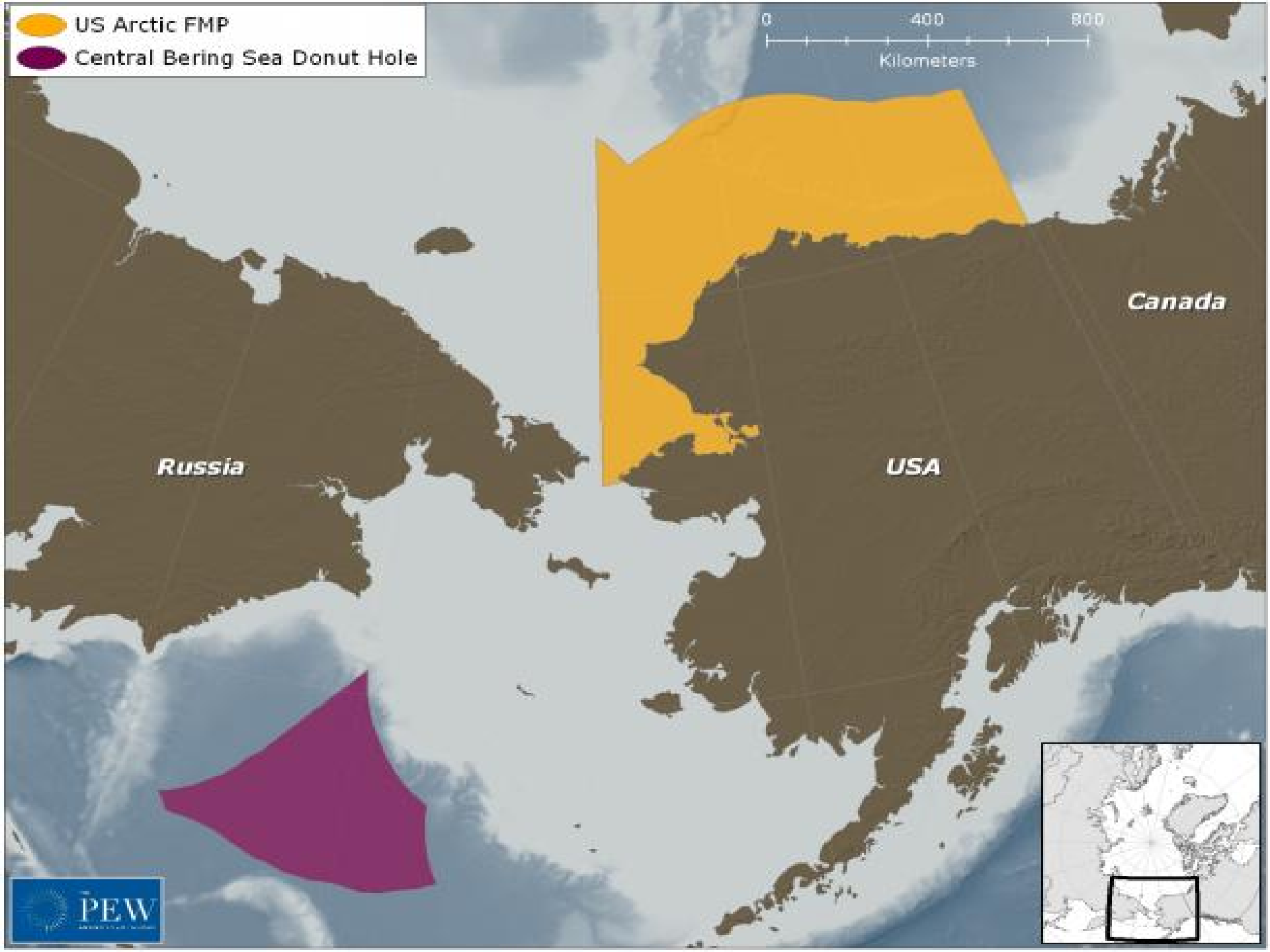

International Waters of the Arctic
PEW
~8000 km
~12000 km
Antarctic Fisheries
0
2,000
4,000
Kilometers

Fishing on ice

The North Pacific Fishery Management Council voted to ban commercial fishing in a vast Arctic Ocean zone from 3 to 200 nautical miles offshore.

Source: North Pacific Fishery Management Council

RON ENGSTROM / Anchorage Daily News


US Arctic FMP
Central Bering Sea Donut Hole
0
400
800
Kilometers
Canada
Russia
USA
PEW

The New York Times

April 16, 2013

Accord Would Regulate Fishing in Arctic Waters

By ANDREW E. KRAMER

MOSCOW — It was once protected by ice. Now regulation will have to do the work.

The governments of the five countries with coastline on the Arctic have concluded that enough of the polar ice cap now melts regularly in the summertime that an agreement regulating commercial fishing near the North Pole is warranted.

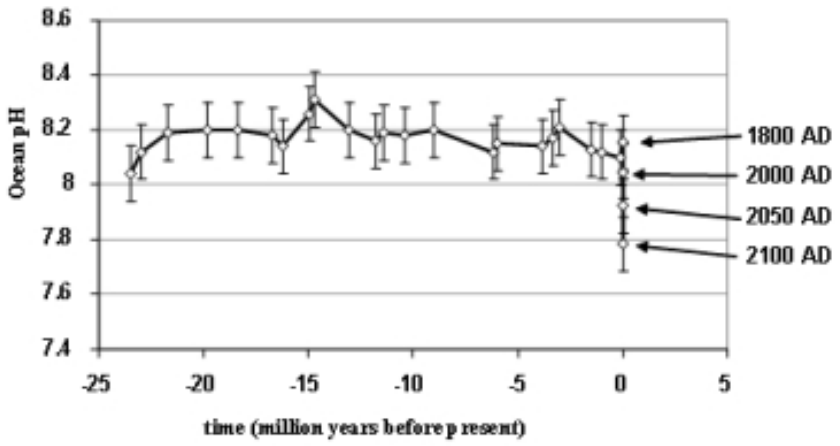
Not aimed at conservation but on management

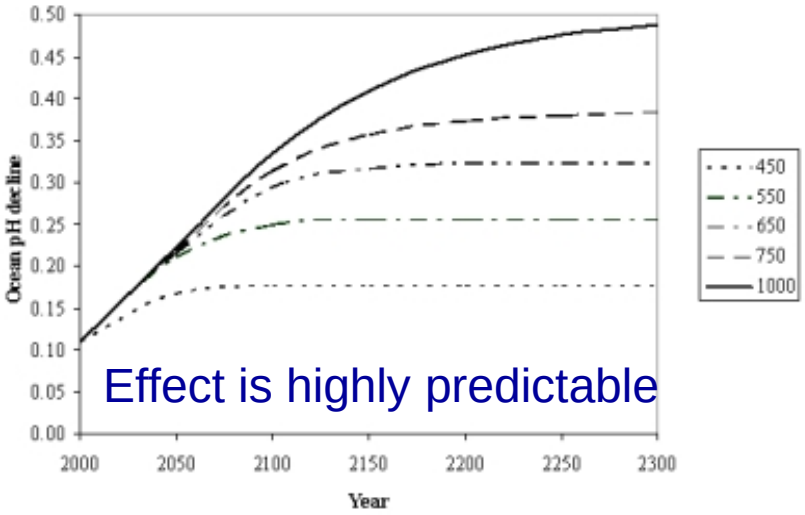

The ocean is now > 0.1 pH units lower than pre-industrial times and contains perhaps 400 billion tons of CO_2 generated from fossil fuel use.

Declining pH of the Ocean: increasing acidity, declining carbonate

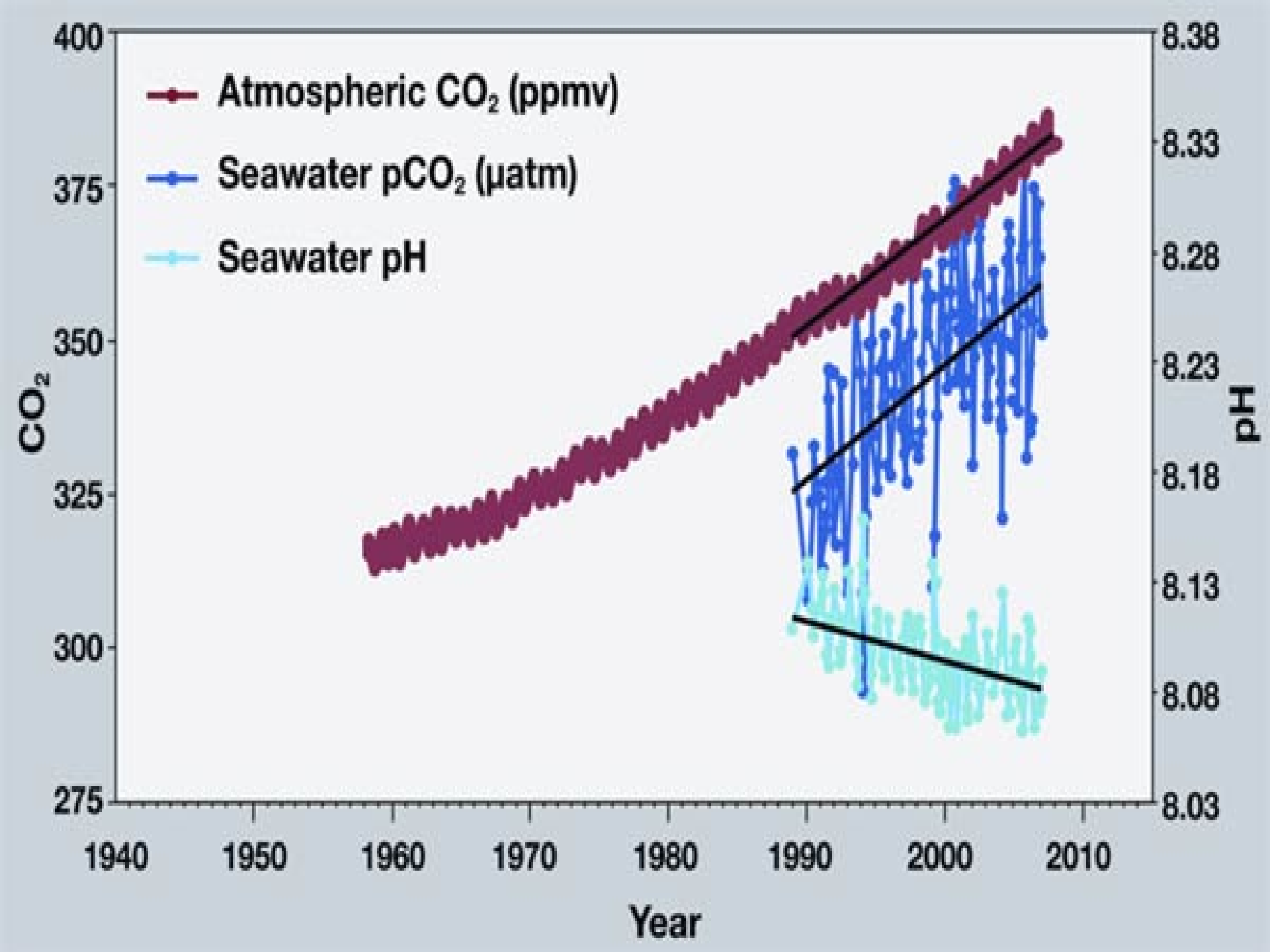
Year	1750	2000	2100?
CO_2 ppm	275	375 (1.36x)	750 (2.73x)
pH of the Ocean	8.24	8.13 (1.29x H^+)	7.87 (2.35x H^+)

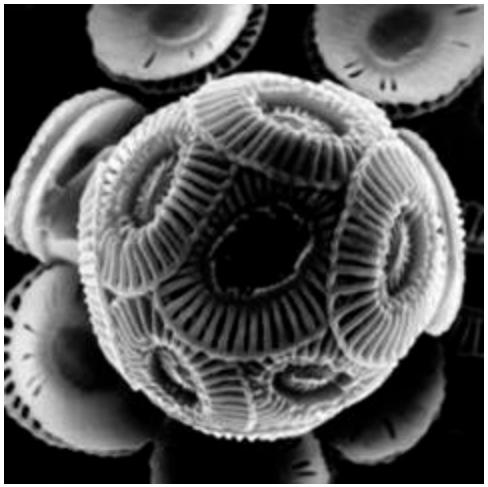
Lowest pH in millions of years

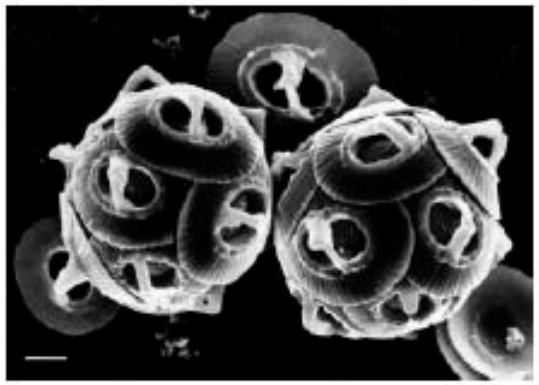


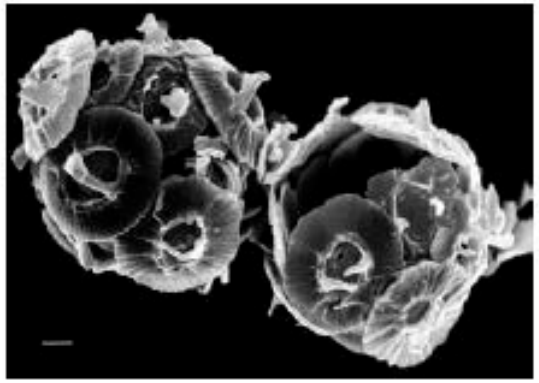


Effect is highly predictable


Atmospheric CO_2 (ppmv)
Seawater pCO_2 (µatm)
Seawater pH
400
375
350
325
300
275
CO_2
8.38
8.33
8.28
8.23
8.18
8.13
8.08
8.03
pH
1940
1950
1960
1970
1980
1990
2000
2010
Year





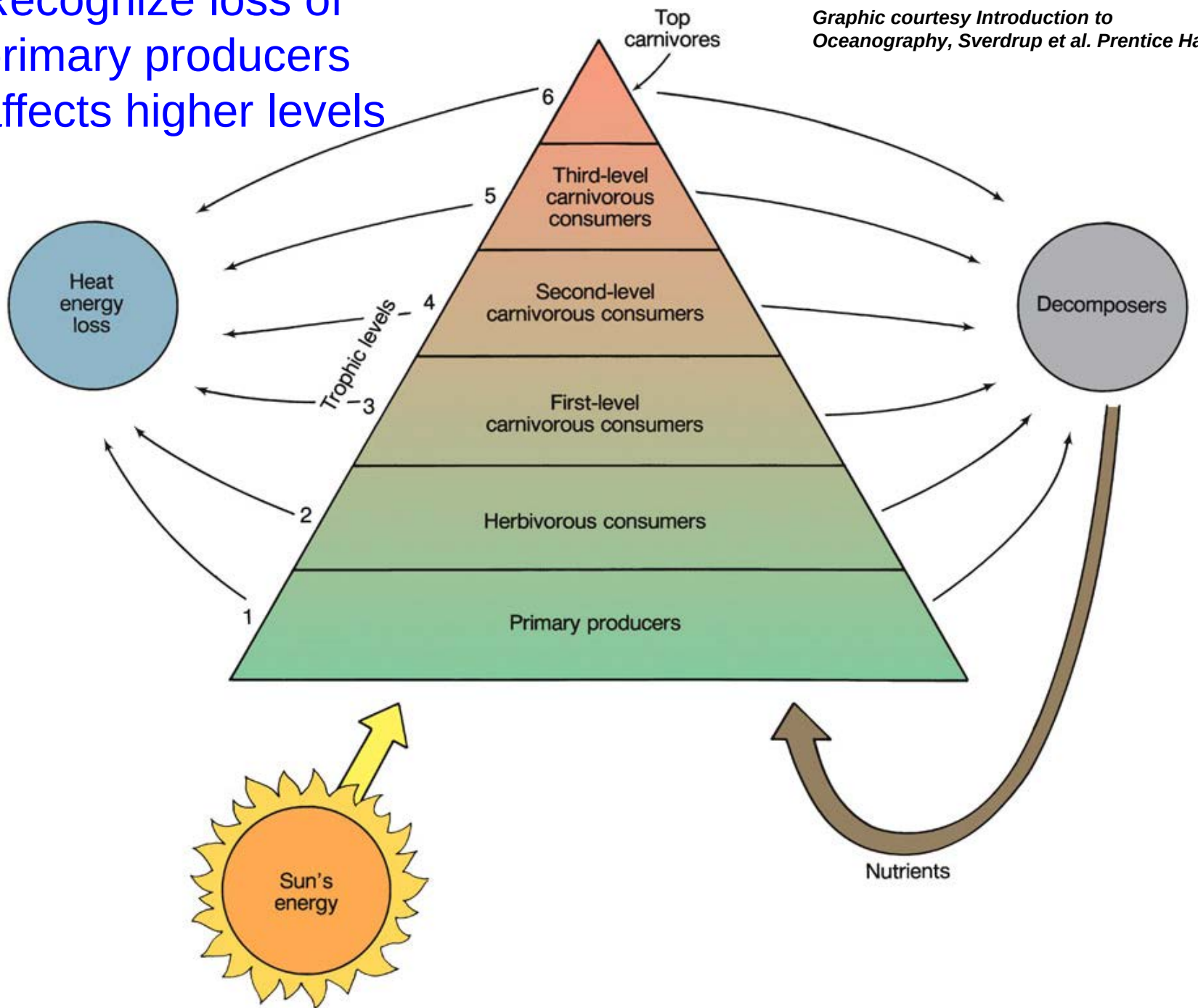


Coccolithophores and Ocean Acidification

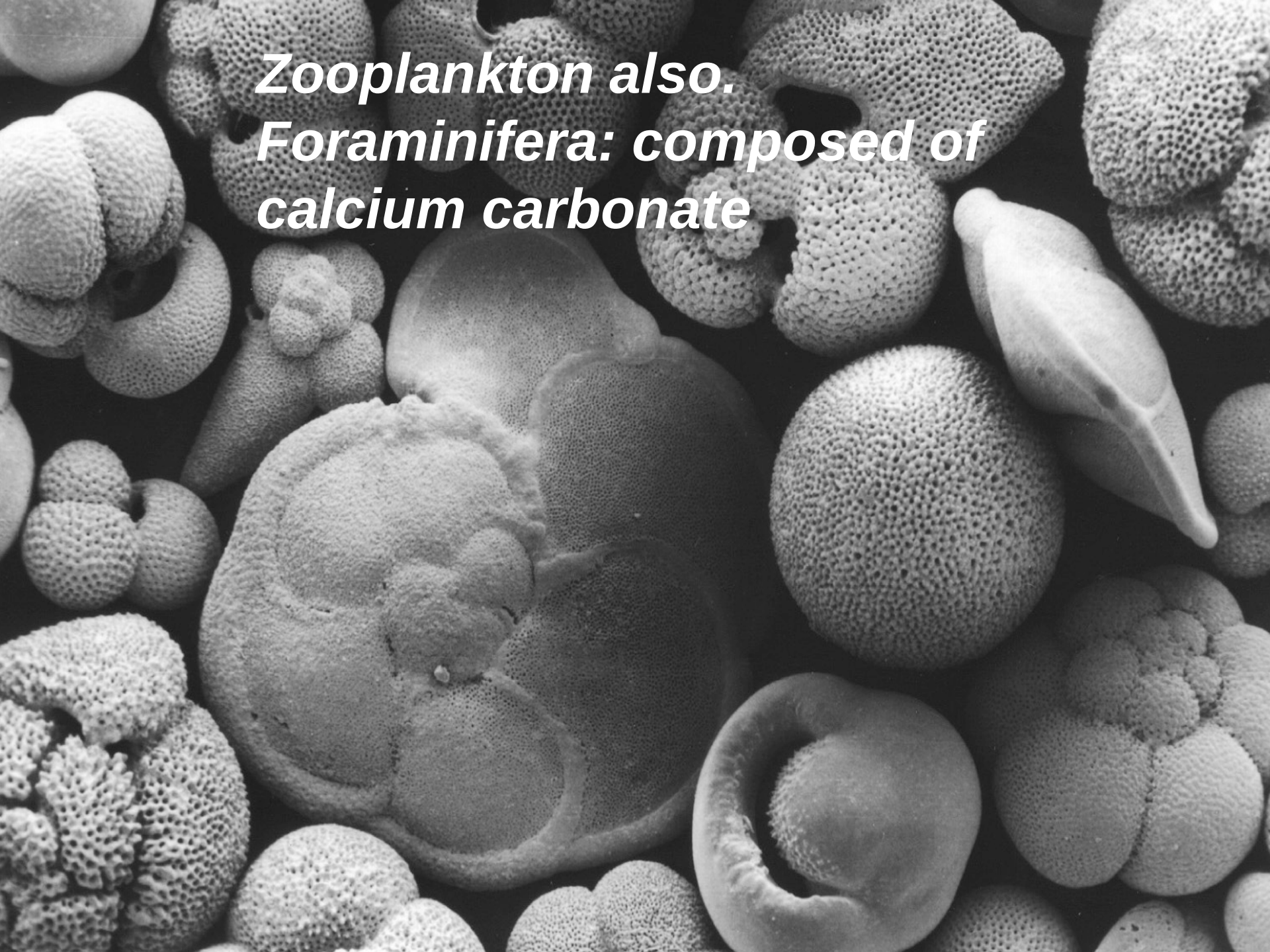
A bloom of coccolithophore plankton recorded near Newfoundland in 1999 by NASA's SeaWiFs satellite

Acidification of the ocean waters means difficulty in calcification by phytoplankton

Recognize loss of primary producers affects higher levels



Graphic courtesy Introduction to Oceanography, Sverdrup et al. Prentice Hall

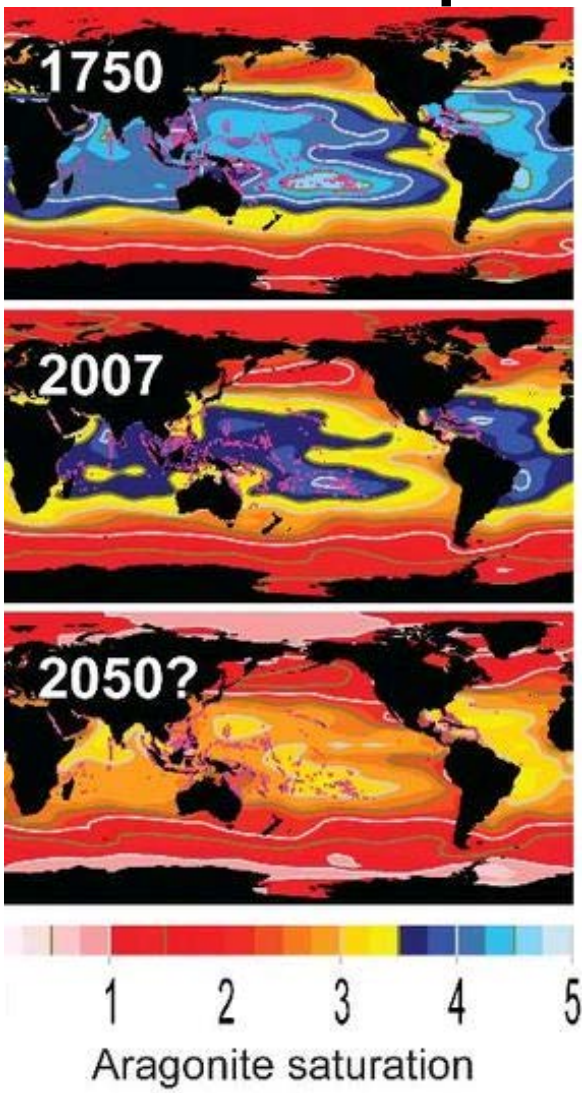

Zooplankton also.
Foraminifera: composed of calcium carbonate

Lower pH negatively affects larval stages of planktonic stages: increased mortality, affects hardening of chitin with calcite formation

Blue king crab zoea

Juvenile blue king crab

Ocean Acidification: the “other” carbon dioxide problem



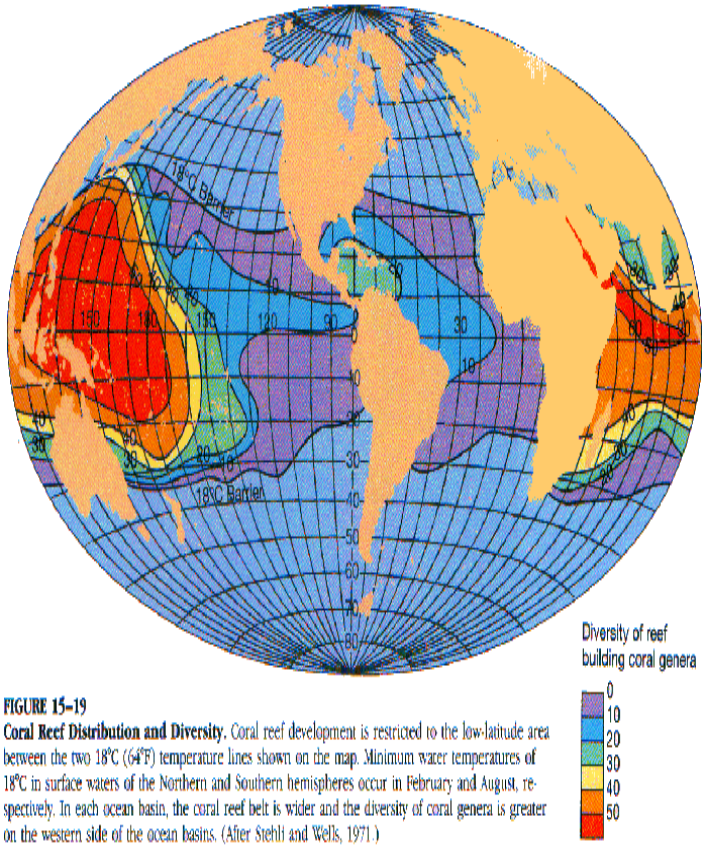
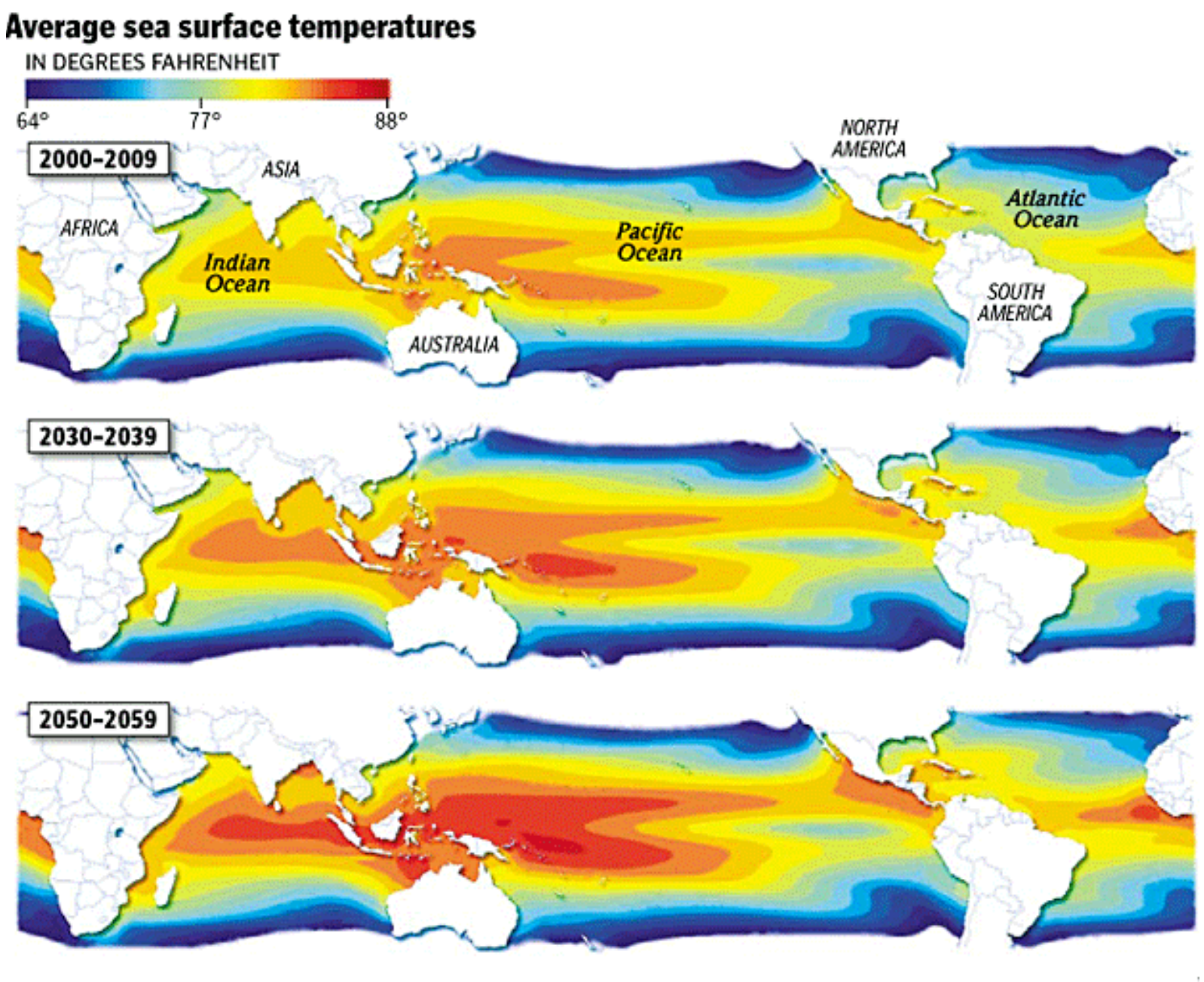
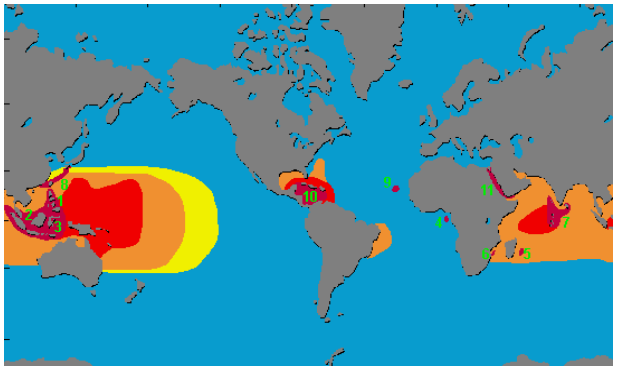


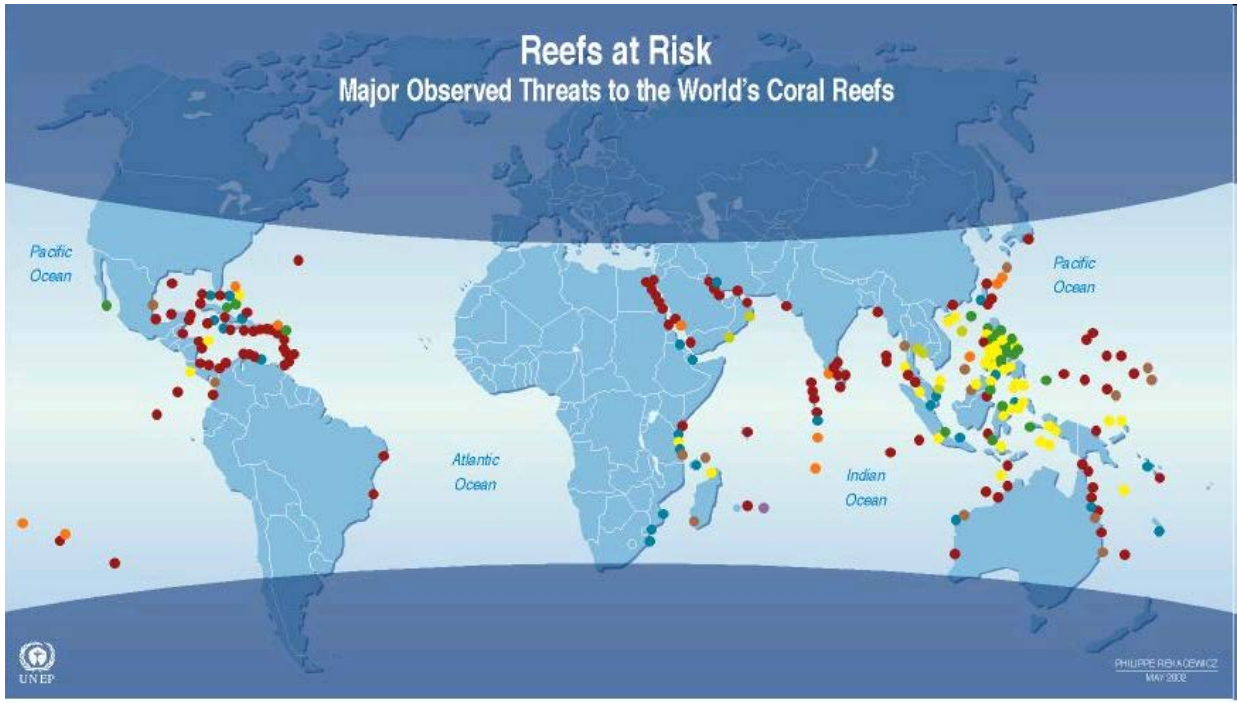
FIGURE 15–19
Coral Reef Distribution and Diversity. Coral reef development is restricted to the low-latitude area between the two 18°C (64°F) temperature lines shown on the map. Minimum water temperatures of 18°C in surface waters of the Northern and Southern hemispheres occur in February and August, respectively. In each ocean basin, the coral reef belt is wider and the diversity of coral genera is greater on the western side of the ocean basins. (After Stehli and Wells, 1971.)

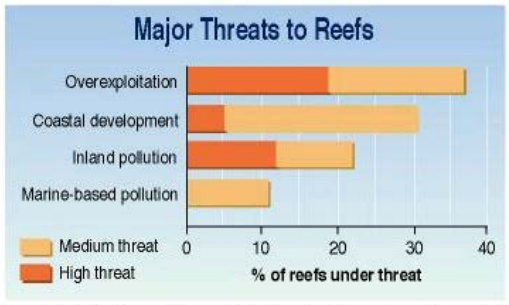


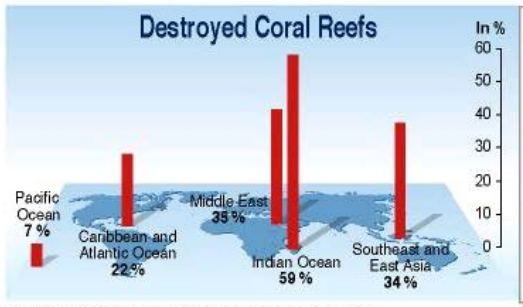
SOURCE: Lauren Franck, Andrew Baker and Amy Clement, Rosenstiel School of Marine and Atmospheric Science, University of Miami

Threatened Coral Reefs



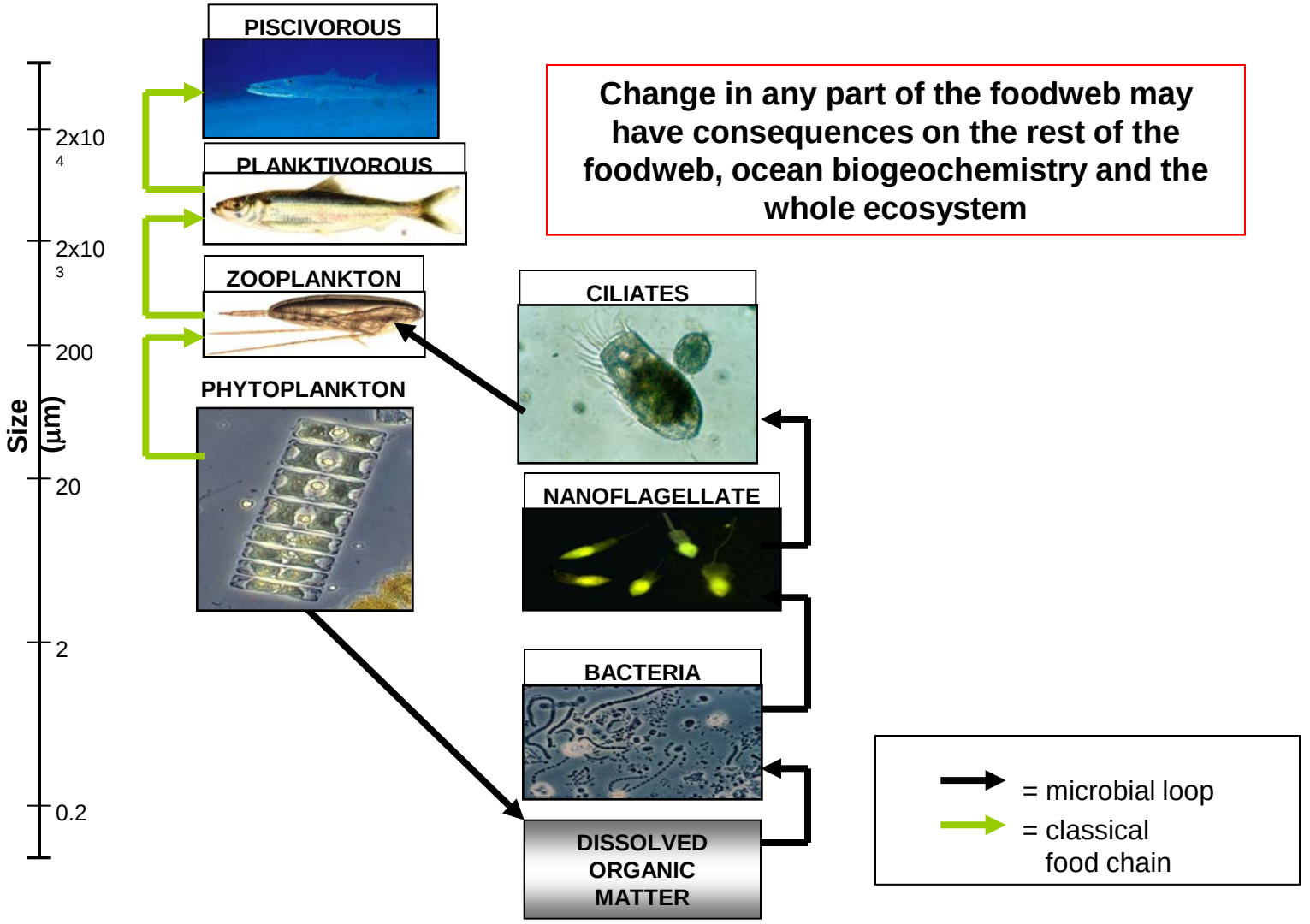






Source: Bryant et al., *Reefs at Risk; a Map-Based Indicator of Threats to the World's Coral Reefs*, World Resources Institute (WRI), Washington DC, 1998.

Whole Ecosystem Effects

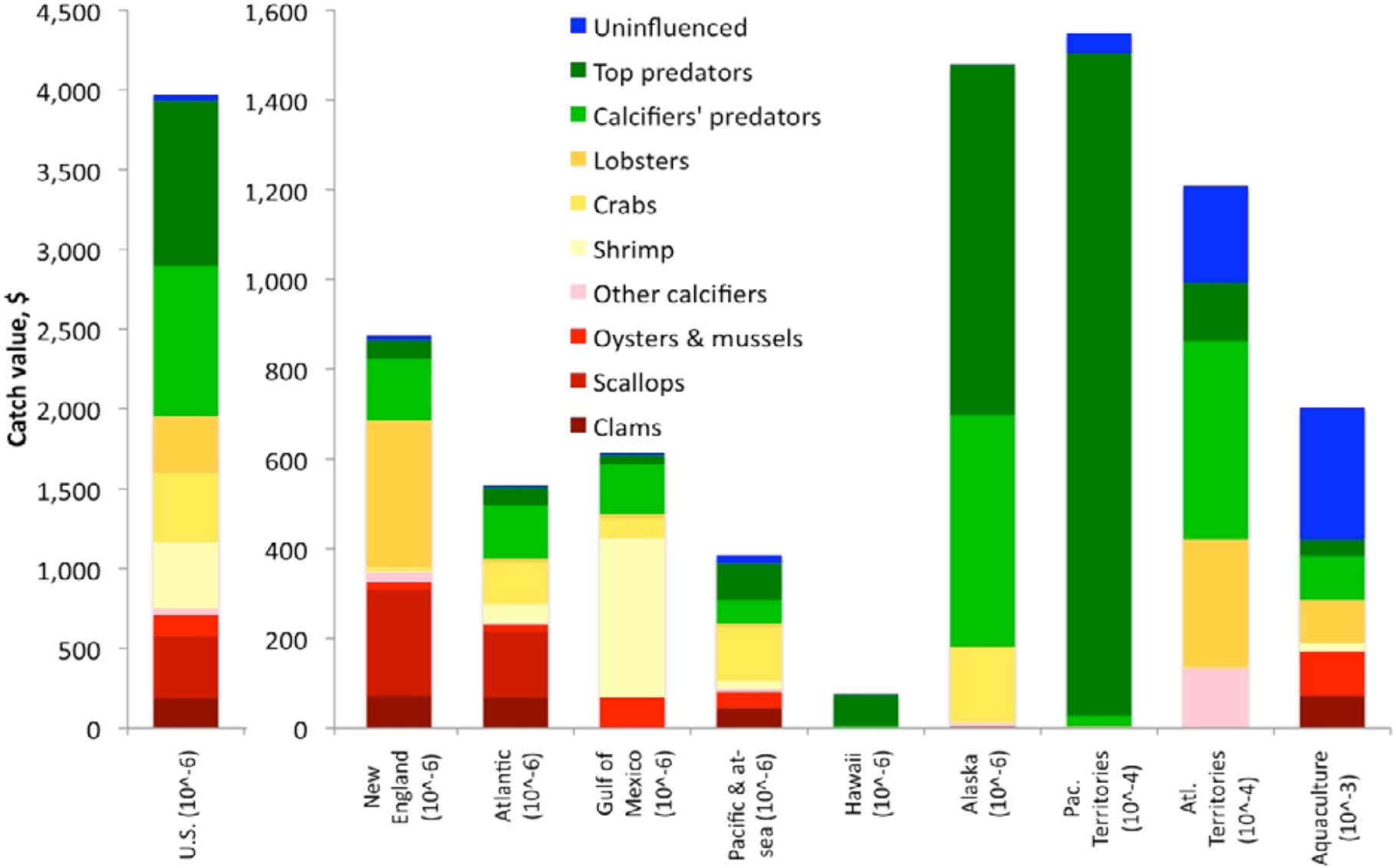


Graphics Eileen Hoffman, Old Dominion University

Probable effects on fisheries by rising CO_2 and acidification

- Loss of carbonate-containing phytoplankton
- Loss of carbonate-containing zooplankton
- Effects on carbonate-containing benthos
- Effects on chitin-containing zooplankton
- Effects on chitin-containing benthos
- Effects on fish themselves
- Whole ecosystem effects

Potential economic impact of ocean acidification on US fisheries *(Cooley and Doney, 2009)*

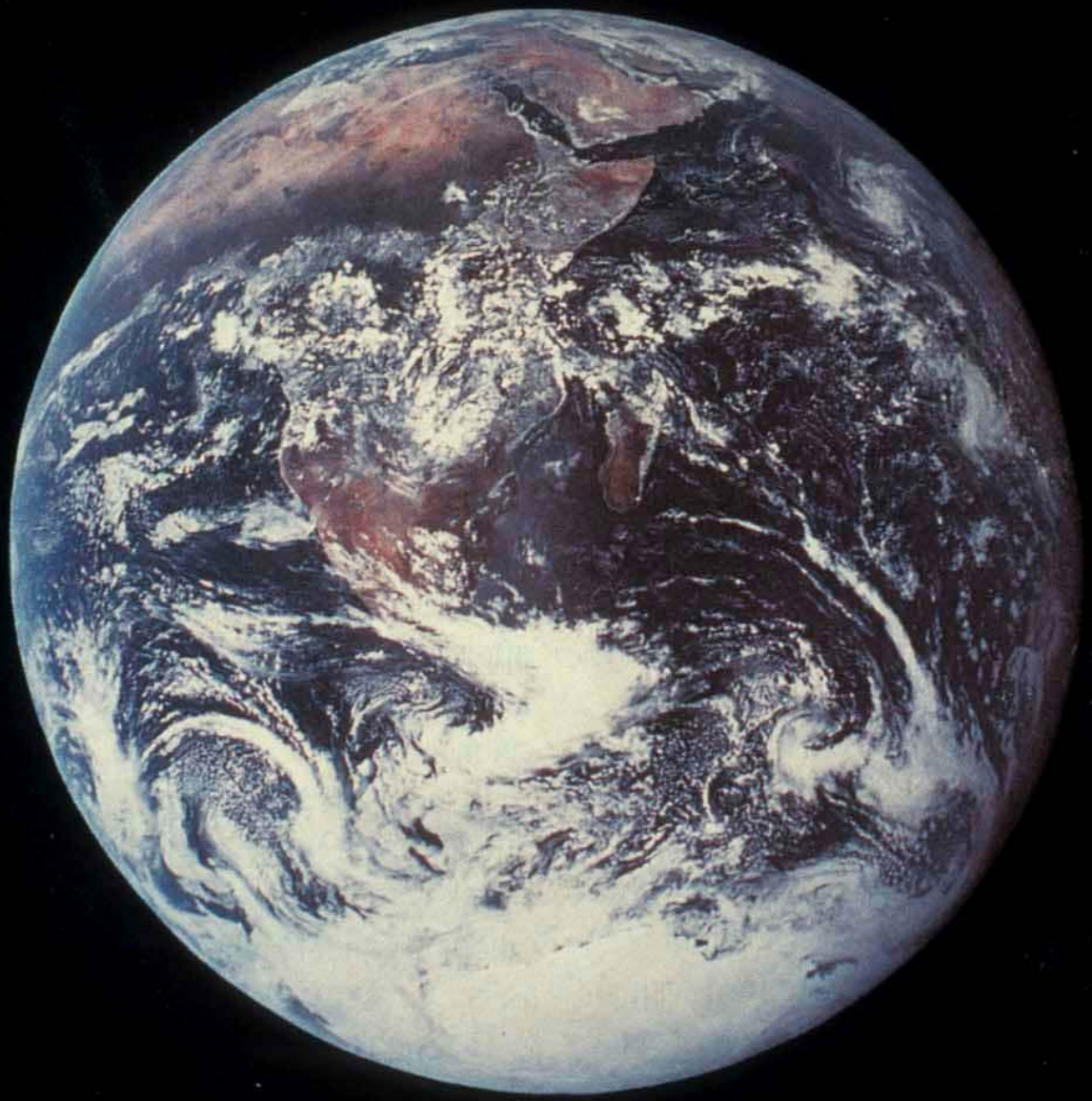



The way forward will not be easy

An unprecedented need for international environmental cooperation

Photo Stephen Macko

We depend on you



There is no other option *Winston Churchill*