Sustainable Strategies in a Warming Climate:
Salmon in the Arctic

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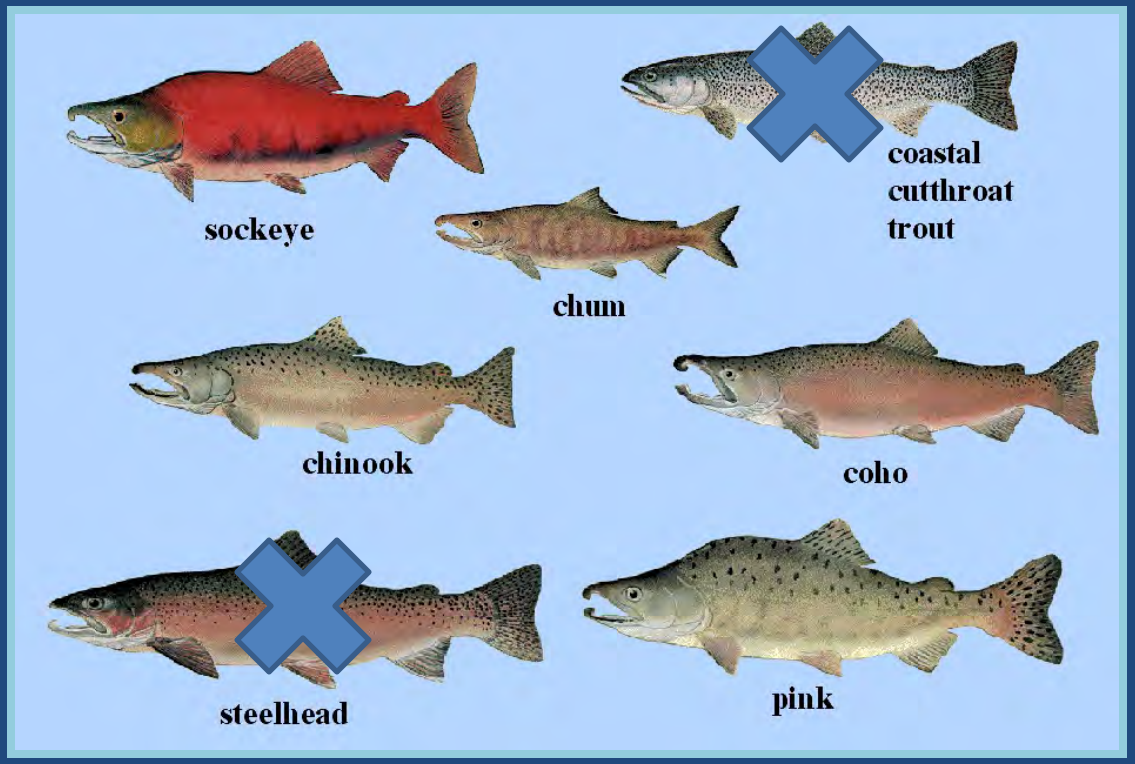
Defining the Arctic for Salmon?

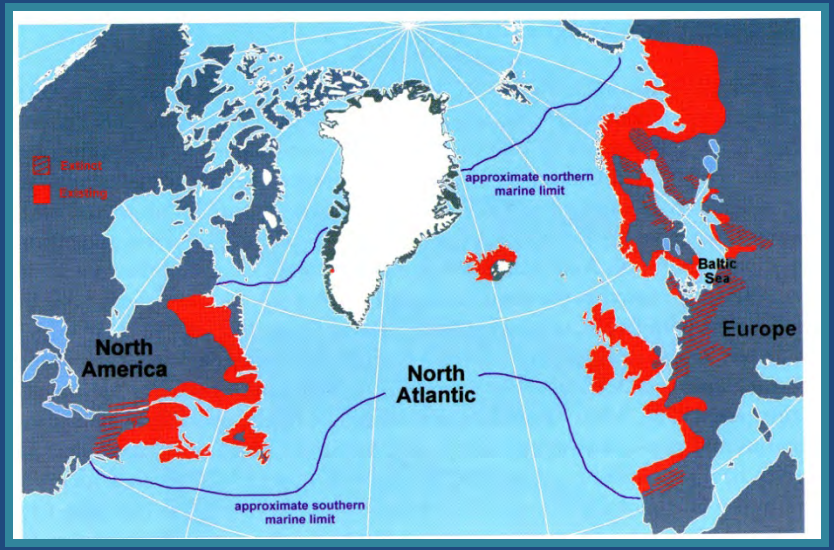
Atlantic salmon (*Salmo salar*)



Pacific salmon (*Oncorhynchus* spp.)

Not pictured anadromous *O. Masou* also not found in the Arctic

Northern Anadromous Range



Atlantic salmon distribution
from Verspoor et al. 2007

Pacific salmon distribution
from Quinn 2005

Documented Arctic Distributions

Atlantic Salmon

- Hundreds of populations in the Arctic coastal rivers in Russia, Norway and Finland
- Small anadromous population in Unagava Bay, Canada

Pink salmon

- Most abundant species of Pacific salmon documented in Arctic
- Russia – populations in Yana and Lena rivers
- Canada - population in Mackenzie River
- Reports of juveniles and adults along Alaska's northern coasts
- Recent catches in Iceland, Norway and Scotland

Chum salmon

- Second most abundant Pacific salmon species in Arctic
- Siberian Arctic – populations from Providence Bay to Kolyma and Lena rivers
- Canada – Mackenzie River has a small natal population
  Mark-recapture abundance estimate 1979 on Laird River = 400 fish
- Reports of juveniles and adults along Alaska's northern coasts

Documented Arctic Distributions

Sockeye salmon

- Northern seacoast of Russia – Anadyr and Cape Chaolina
- Small numbers reported in several tributaries on Mackenzie River

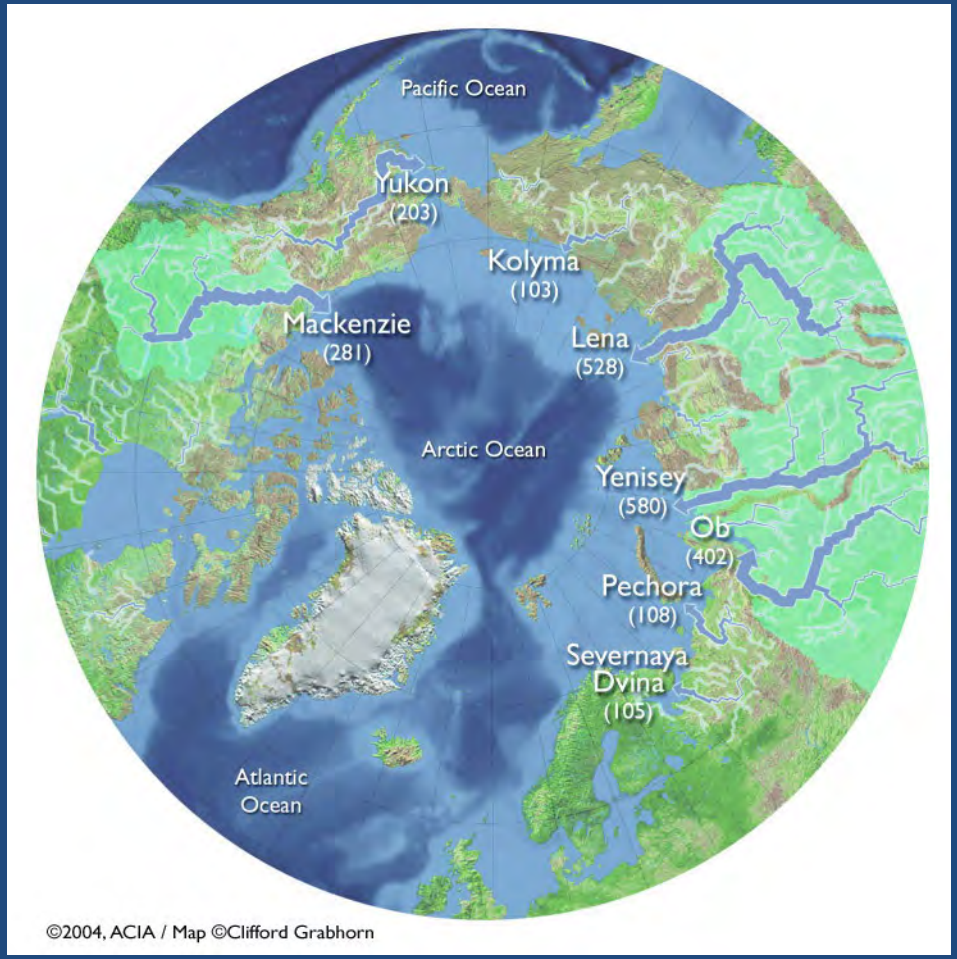
Chinook Salmon

- Rare in Canadian Arctic, but adults found in subsistence fishery
- Confirmed adult captured at Fort Laird, Canada 1979
- Reports from subsistence fishers from the Beaufort Sea, Alaska

Coho Salmon

- Least frequently reported Pacific salmon in Arctic waters
- Single coho in Great Bear Lake 1987 on Mackenzie River, Canada
- Hook-and-line capture of adult coho near Inuvik, Canada 1998

Large Rivers with Deep North/South Drainage
Latitudinal Colonization Threshold?

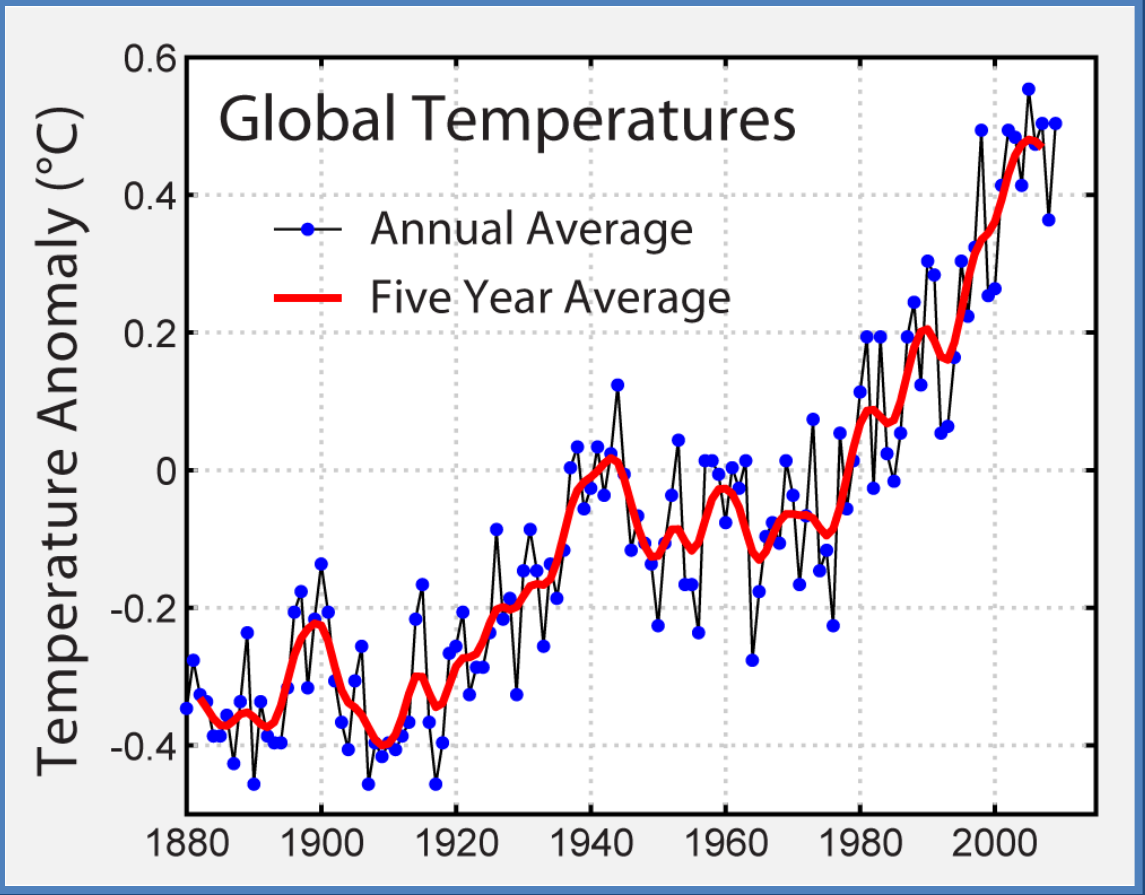


Map from Arctic Climate Impact Assessment Report 2005 (discharge km^3/yr)

Limitations to Salmon Arctic Expansion

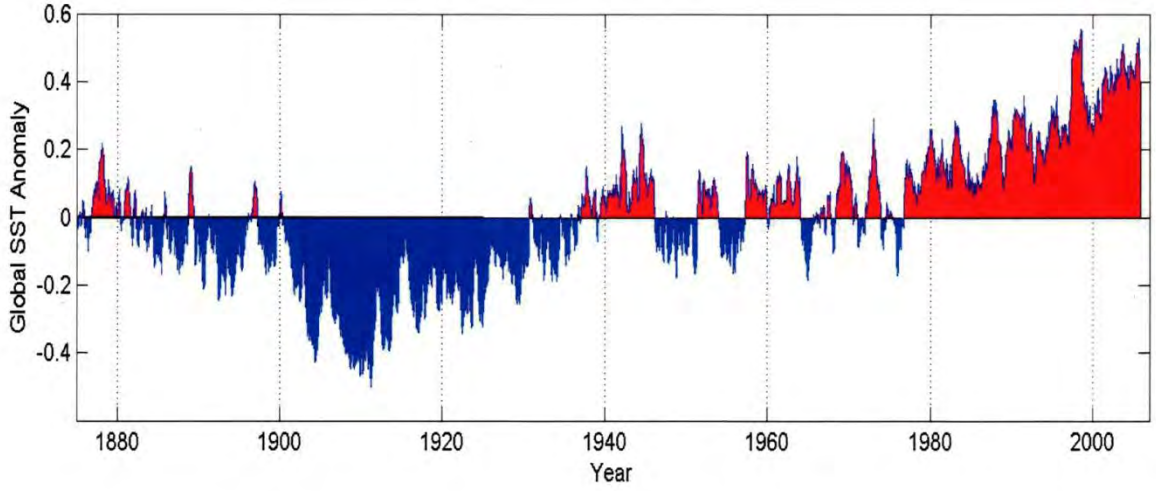
- Thermal migration barriers
- Limited source populations as colonizers
- Poor spawning habitats
- Inadequate incubation temperatures and O^2
- Juvenile overwinter habitat – freshwater and marine
- Limited food availability – all life stages
- Novel predators
- Novel pathogens
- Limited anadromous dispersal routes
- Short growing season
- Small population size and low population viability
- Unanticipated interactions and outcomes

Environment is Changing Rapidly



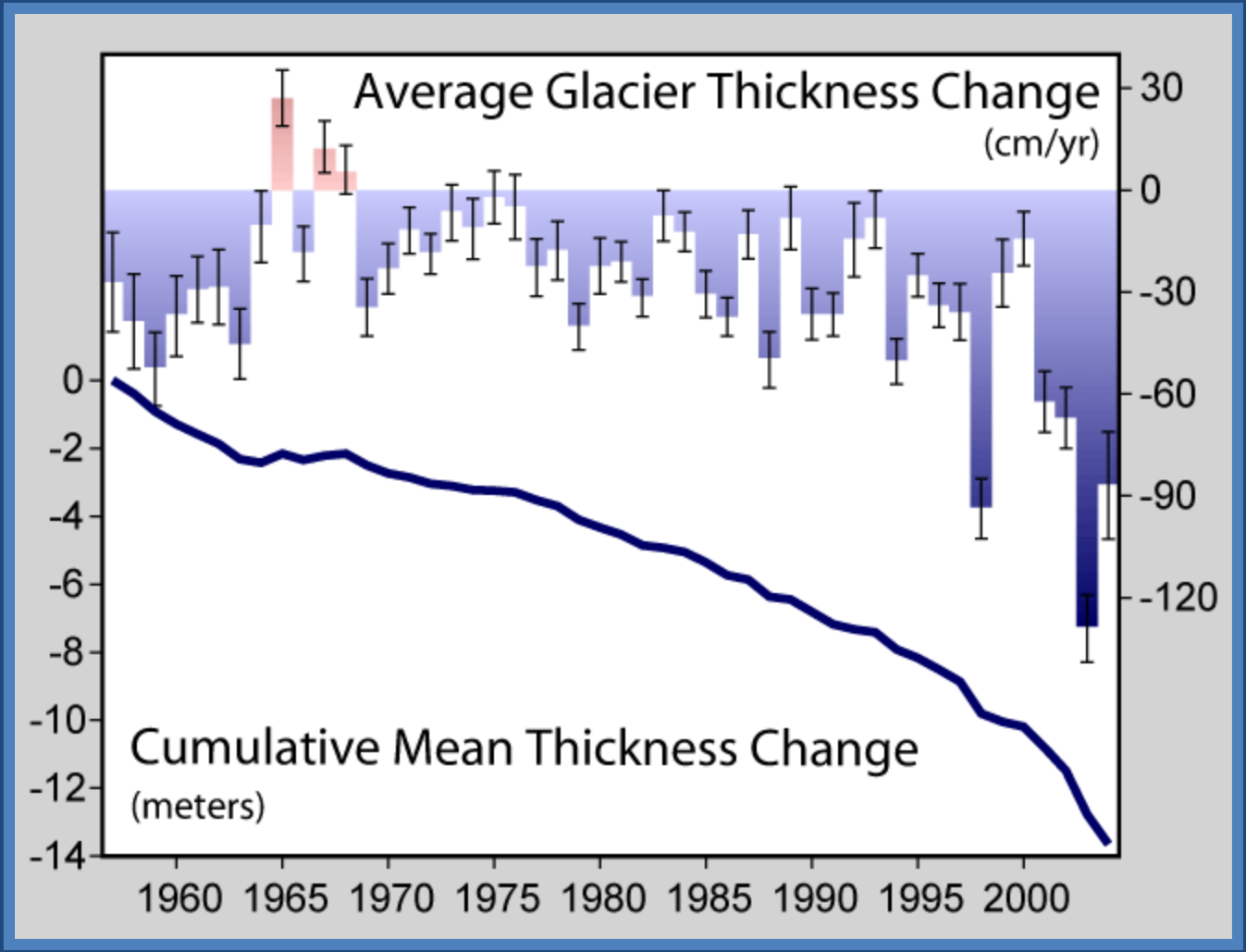
IPCC (2007) anticipated increase of 1.1 °C to 6.4 °C by 2100

Global Sea Surface Temperature Anomaly, 1880-2005



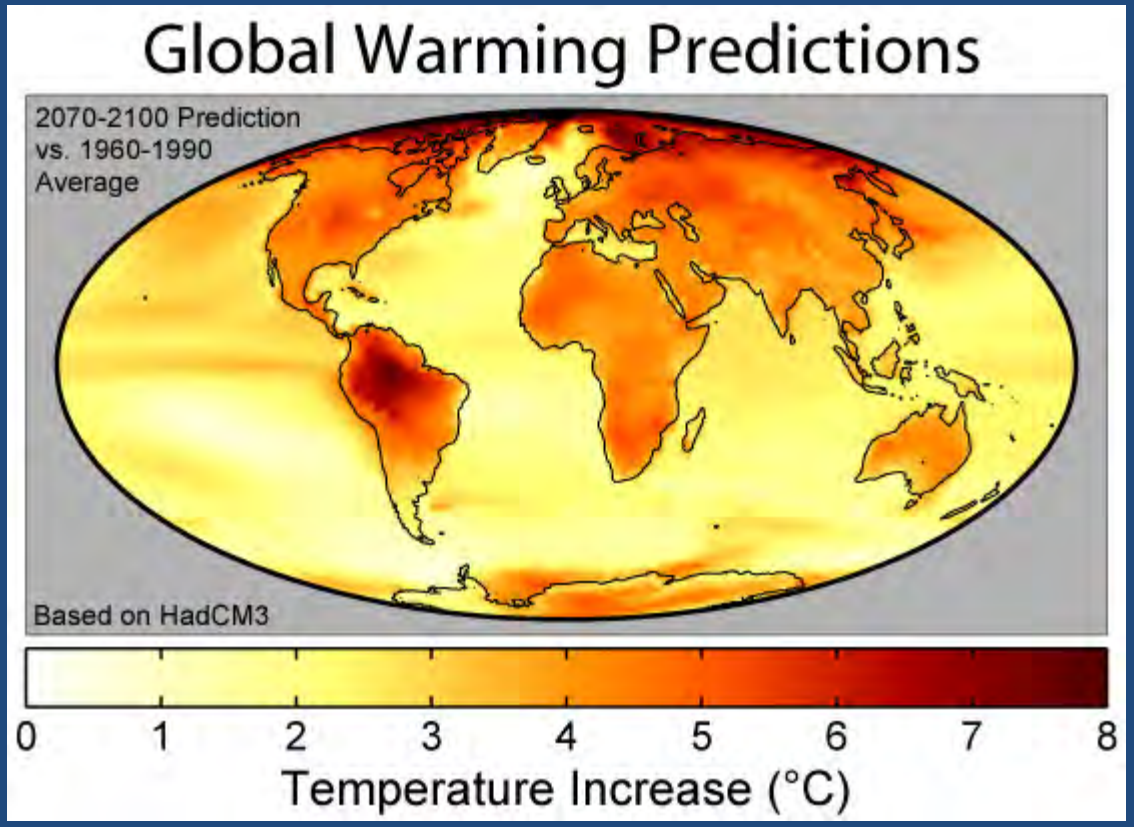
Courtesy Francisco Chavez, MBARI

Changes in Freshwater Discharge and Sea Surface Levels



National Snow and Ice Data Center http://nsidc.org

Estimated Average Arctic Warming 5.6 °C



HadCM3 climate model Collins et al. 2000

Short-term Climate Effects - Negative

- Loss of sea ice may change juvenile ocean refugia (brackish slush) for chum and pink salmon in the Arctic
- Increased commercial fishing (cod, whitefish, capelin) may have negative impacts due to salmon by-catch
- Increased hatchery production impacts on carrying capacity
- Increased marine traffic and contamination potential
- Coastal erosion contributes to negative impacts in near shore habitats
- Development of extractive resources (oil and gas) increases probability of Arctic pollution events
- Competition for food and habitats with locally adapted species
- Ocean acidification effects

Salmon in the Arctic
Short-term (40 years) Climate Effects - Positive

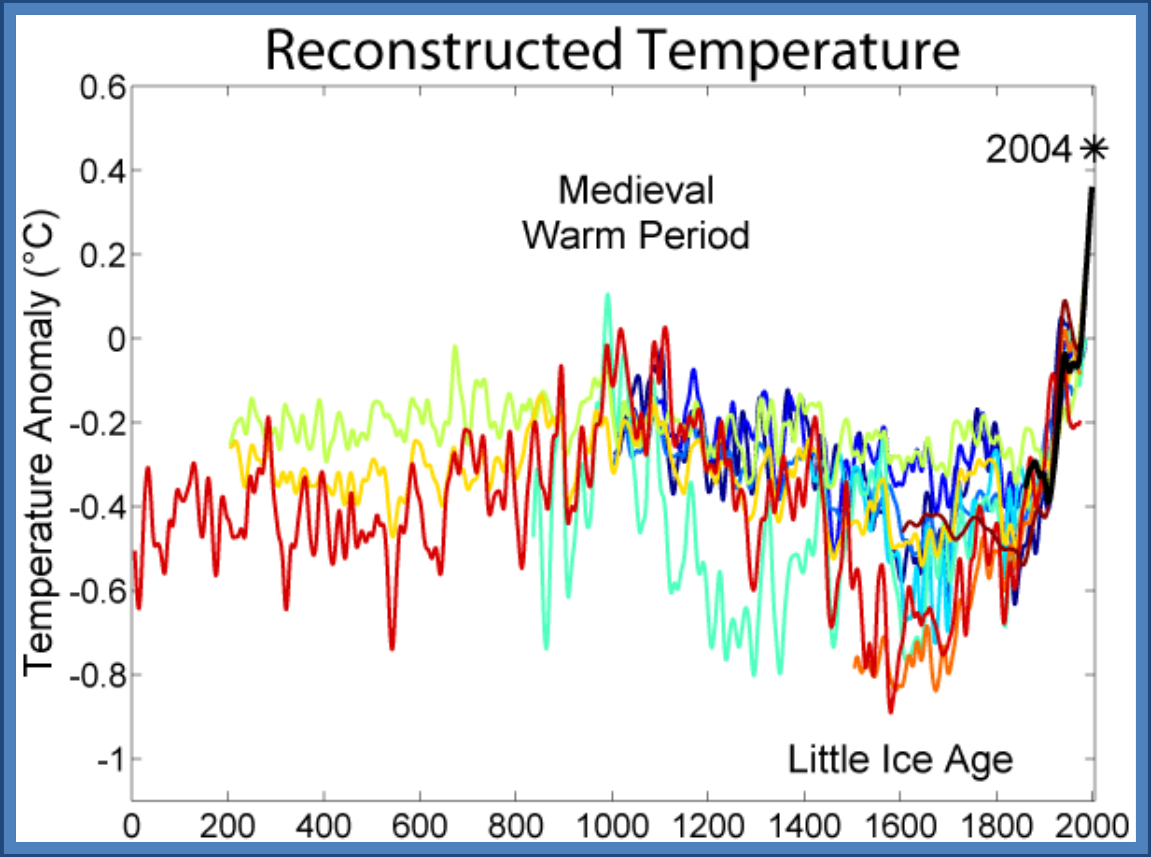
- Warming ocean temperature may break down thermal barriers and open new anadromous migration routes
- Changes in groundwater contribution may increase distribution and abundance of freshwater habitats, esp. chum salmon
- Changing air temperatures could increase quality and quantity of ice-free habitats
- Increased stream flow due to melting permafrost and glaciers may provide additional in-river and near shore habitat
- Changes in channel morphology and discharge could add additional spawning gravels and juvenile habitat
- Changing prey resources (capelin in the Arctic) linked to growth and survival at sea

Salmonidae Evolutionary History

Significant Adaptive Variation

- **Oldest fossil record middle Eocene**
  - *Eosalmo driftwoodensis* - Driftwood Creek BC
  - Coregoninae type morphology
- **Split between *Oncorhynchus* and *Salmo* predates early Micene**
  - 20 MYA
- **Gap in record to late Miocene**
  - 7 MYA, *Oncorhynchus* - Clarkia Lake beds
- **Split between *O. mykiss* and *O. Clarki* predates beginning of Pliocene**
  - 5-6 MYA

Salmon have survived a wide range of climate change



Changes in mean surface temperature over time reconstructed using different climate models and smoothed on a decadal scale (IPCC 2007).

Different Scales of Adaptation

- Does the evolutionary history of salmon hold the key to future adaptation in the Arctic?

- How flexible are the critical physiological thresholds documented for salmon in the literature – role of gene expression and physiological genomics?

- Is colonization by small numbers a threat to long-term population stability – role of multiple colonizations on diversity and viability?

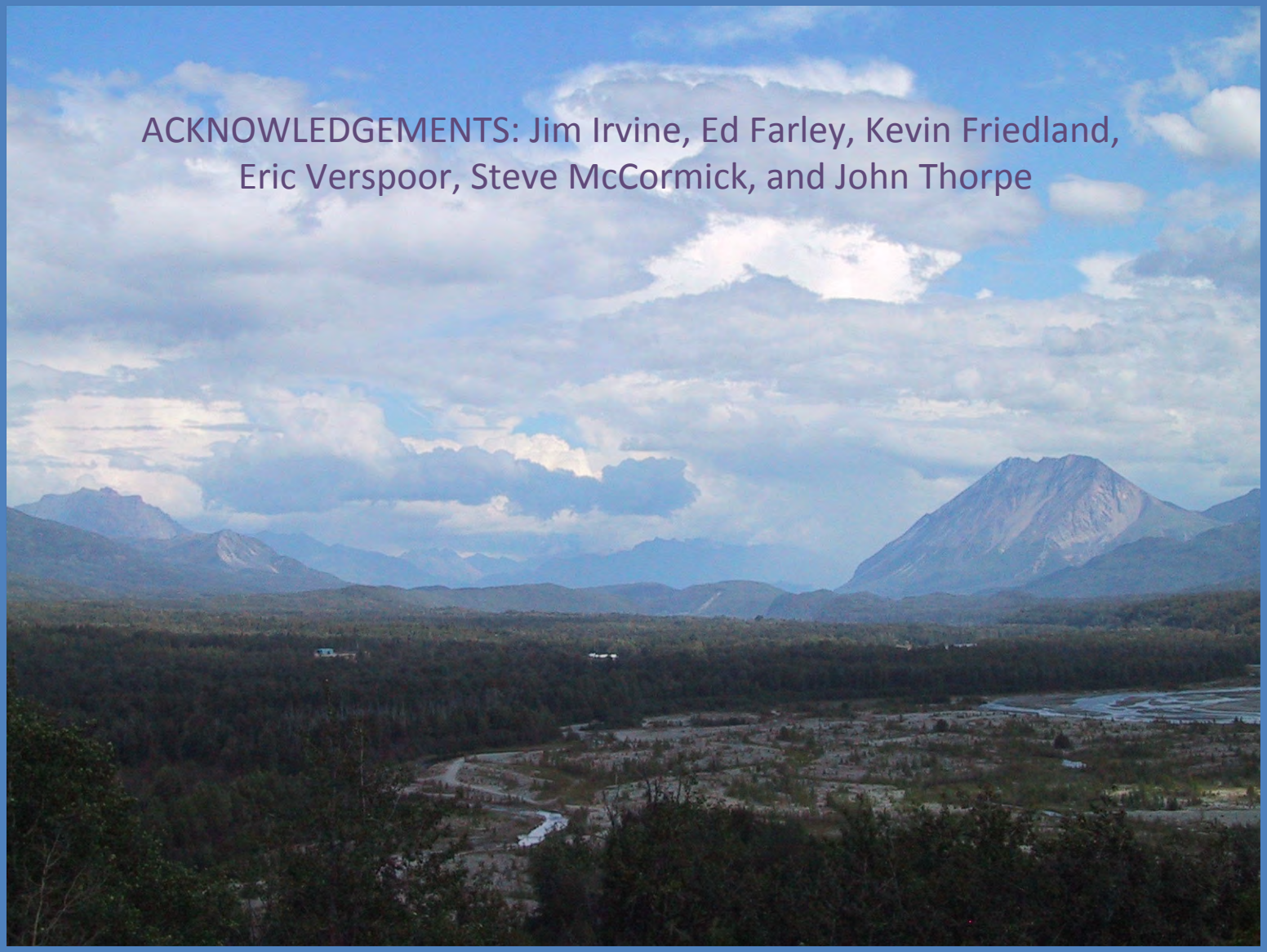
Summary

- Under current conditions, we do not expect a rapid increase of colonization by salmon in the Arctic, primarily due to limited juvenile survival in freshwater and near-shore marine environments.

- Predictive models of environmental changes over the next 40 years under conditions of climate change may facilitate additional colonization and expanded marine migrations.

- Evolutionary history of salmon suggest a broad adaptive potential, but we know little about limitations of current genomic function.

- The physiological adaptive potential of the Pacific and Atlantic salmon genomes may increase range expansion in an unpredicted timeline.

- Opportunistic use of Arctic waters by salmon will continue, but significant change needs to take place at the landscape level before viable populations of some salmon species can colonize Arctic habitats.

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