Local Adaptation:
the Dark Matter of Fisheries Genetics

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Dark Matter?

- **Dark matter**

  – **Hypothetical matter in universe**

  – **Does not interact with the electromagnetic force**

  – **Can be inferred from gravitational effects on visible matter**

  – **Accounts for more mass in the universe than visible matter**

  – **Important in galaxy formation**

- **Adaptive genetic variation**

  – **Can be measured, but genetic mechanisms complex**

  – **Does not (much) interact with neutral molecular markers**

  – **Can be inferred from phenotypes**

  – **Accounts for most of evolution**

  – **Important for local adaptation, biocomplexity and speciation**

Synopsis

- **Importance of stock structure**

- **Some simulations**

    – **Effective population size**

    – **Dispersal / gene flow**

    – **Selection**

- **Atlantic cod as a case study**

    – **Phenotypic differentiation**

    – **Molecular differentiation**

- **Adaptive differentiation**

    – **Significance**

    – **Detection**

    – **Application**

Why is population structure important?

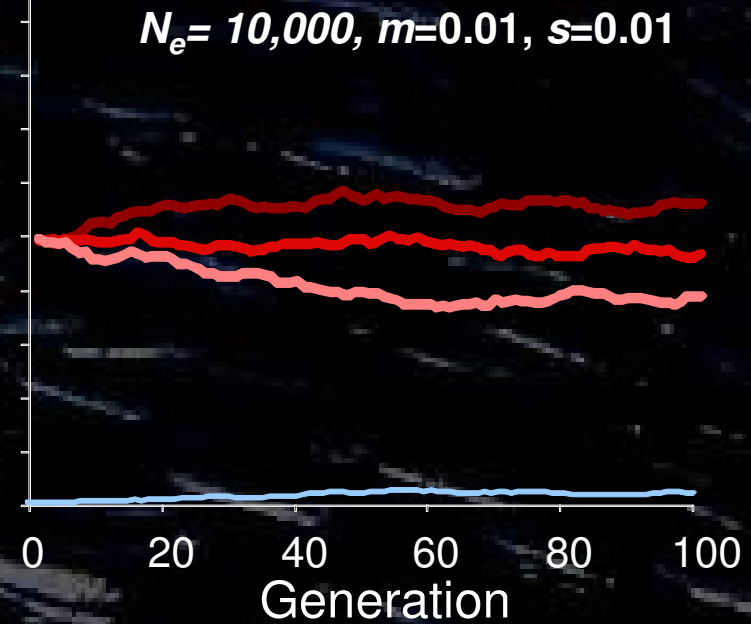- **Unit of management**
  - Does local perturbation affect other stocks?

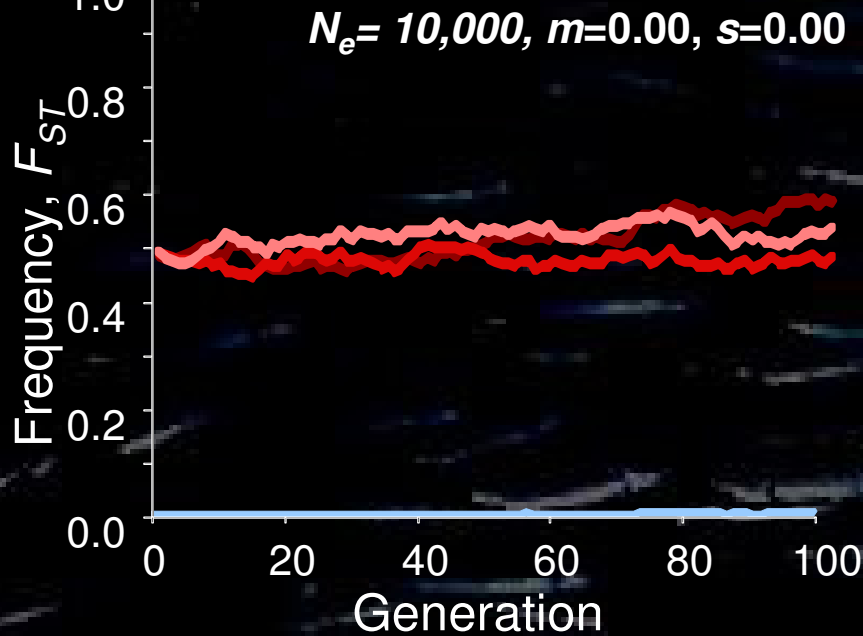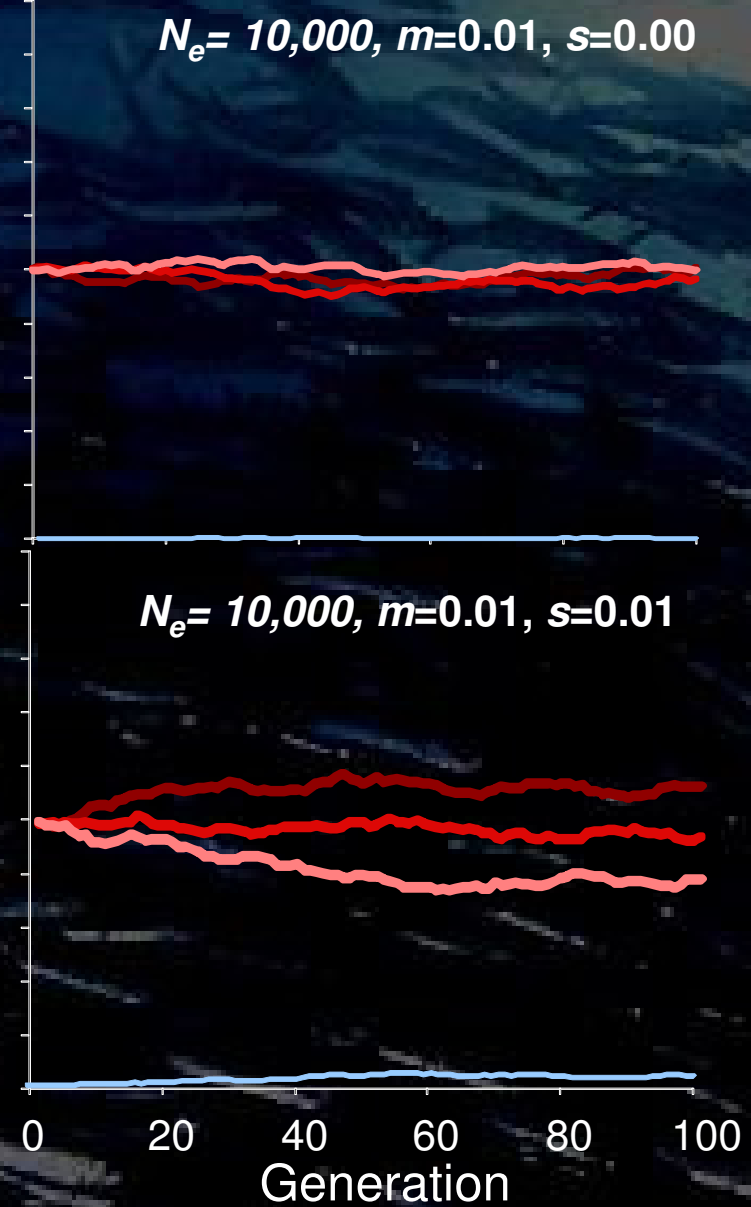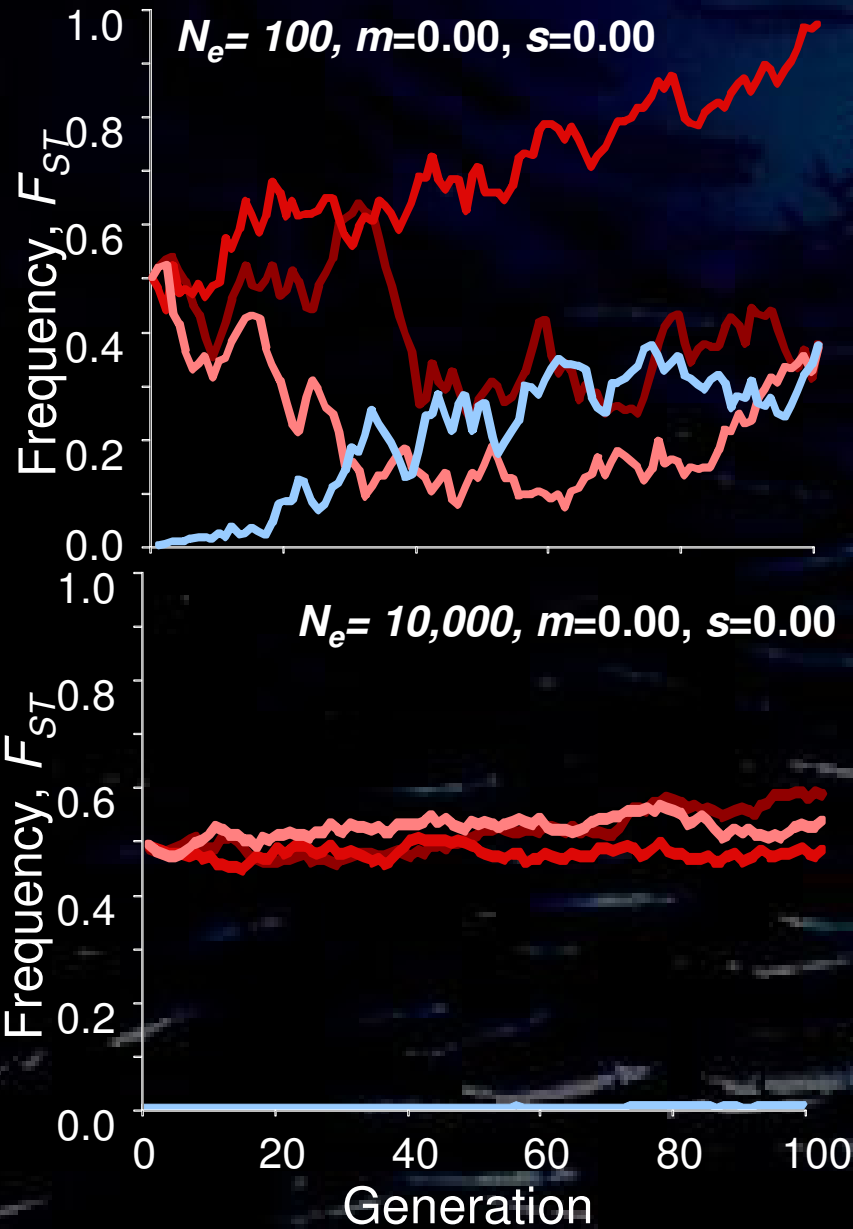# Why is population structure important?

- **Unit of management**
  - Does local perturbation affect other stocks?

- **Adaptive differentiation**
  - Different biological parameters
    - Life history
    - Migration
  - Local adaptation
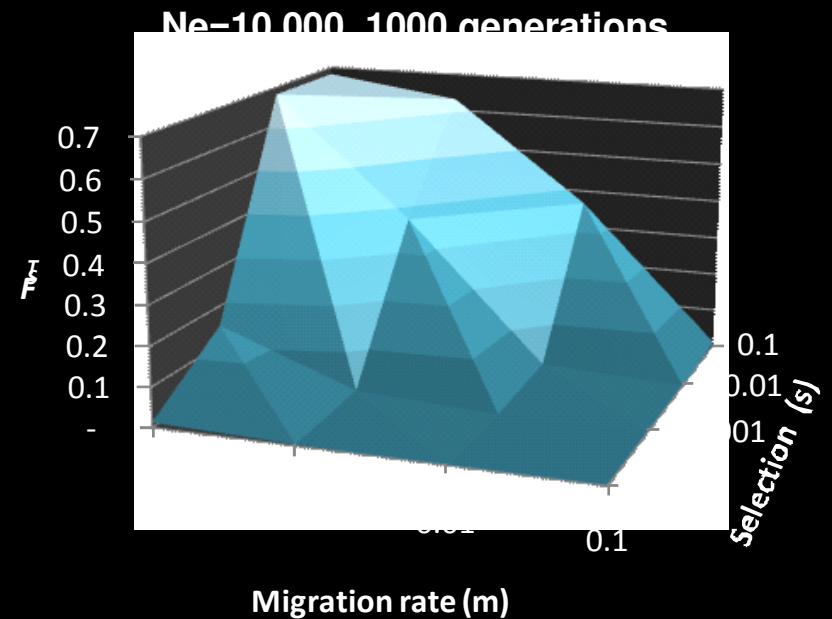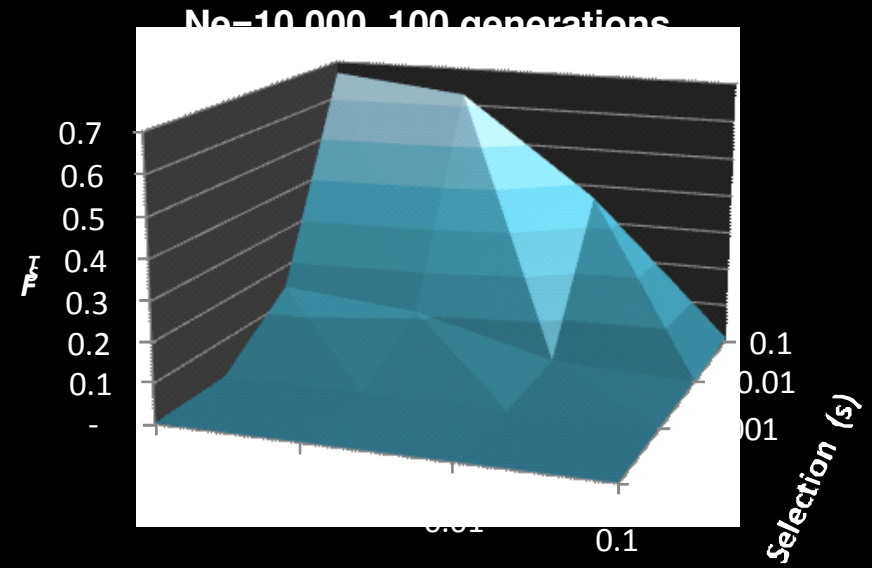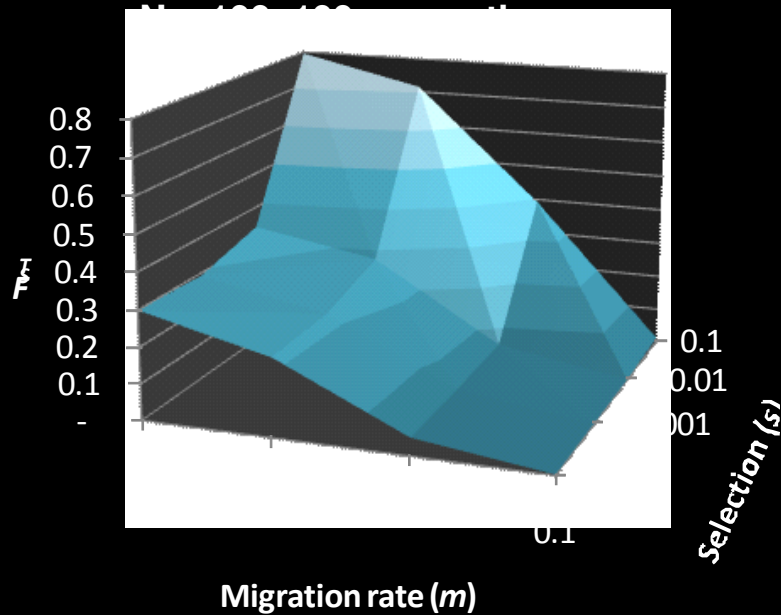 - Biodiversity / biocomplexity

Neutral vs. selective differentiation
population size, migration, selection

Top-left panel: $N_e = 100$, $m = 0.00$, $s = 0.00$

Top-right panel: $N_e = 10,000$, $m = 0.01$, $s = 0.00$

Bottom-left panel: $N_e = 10,000$, $m = 0.00$, $s = 0.00$

Bottom-right panel: $N_e = 10,000$, $m = 0.01$, $s = 0.01$

Y-axis: Frequency, F_{ST}

X-axis: Generation

Adaptive genetic variation

Ne=10,000, 100 generations
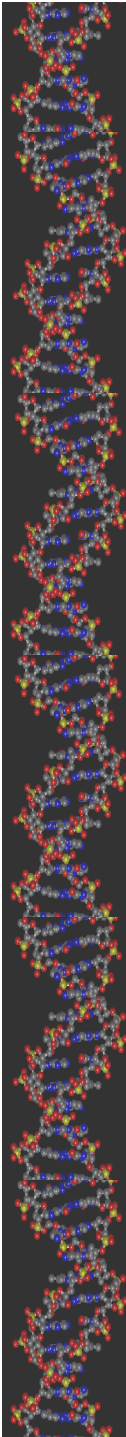
Migration rate (*m*)

- Depends on migration rate (*m*), not number of migrants ($N_e m$)
  - **Not affected by population size**
- Less sensitive to low levels of gene flow
- Reaches equilibrium faster
  - **Less dependent on demographic history**

Ne=10,000, 1000 generations

Migration rate (m)

What does this mean?

- **Neutral molecular markers vastly underestimate adaptive genetic differentiation of large populations**
  - Very conservative estimate
  - Much undetected population structure
- **Selective differentiation**
  - May often be higher
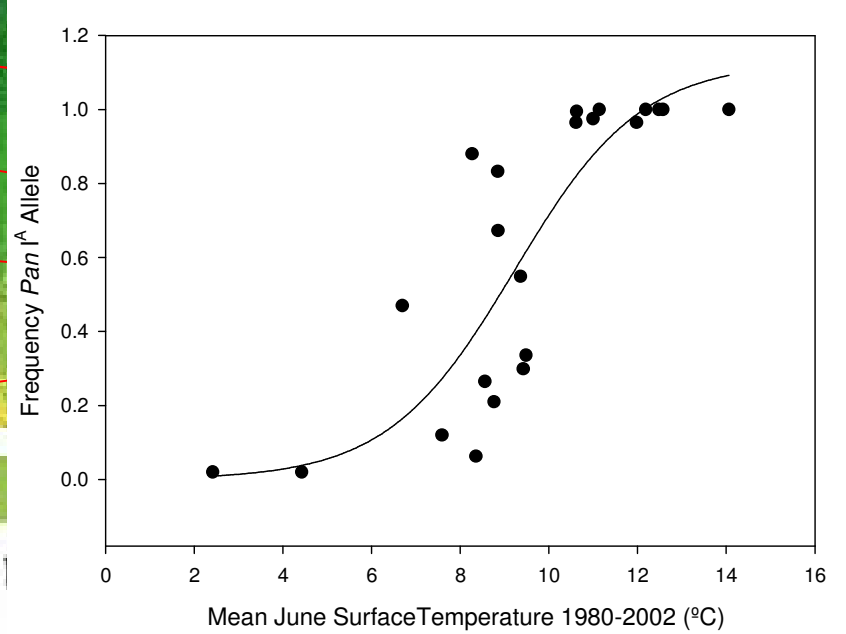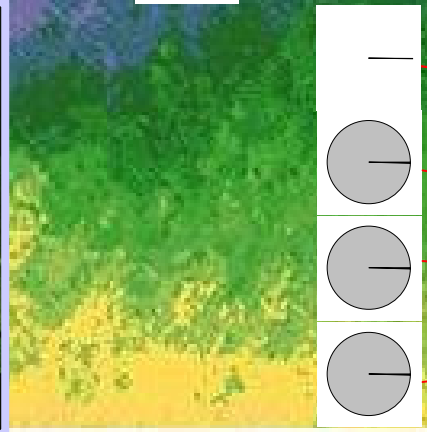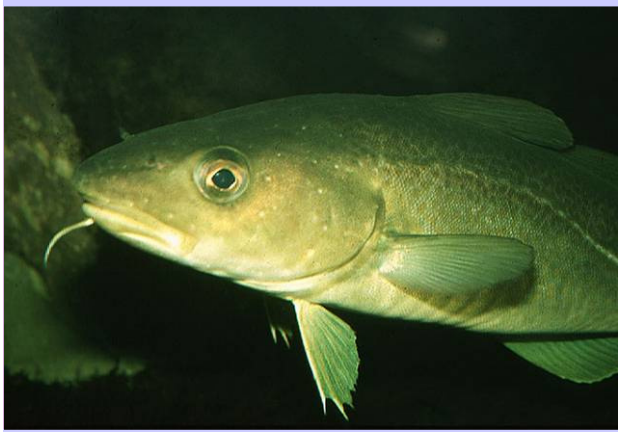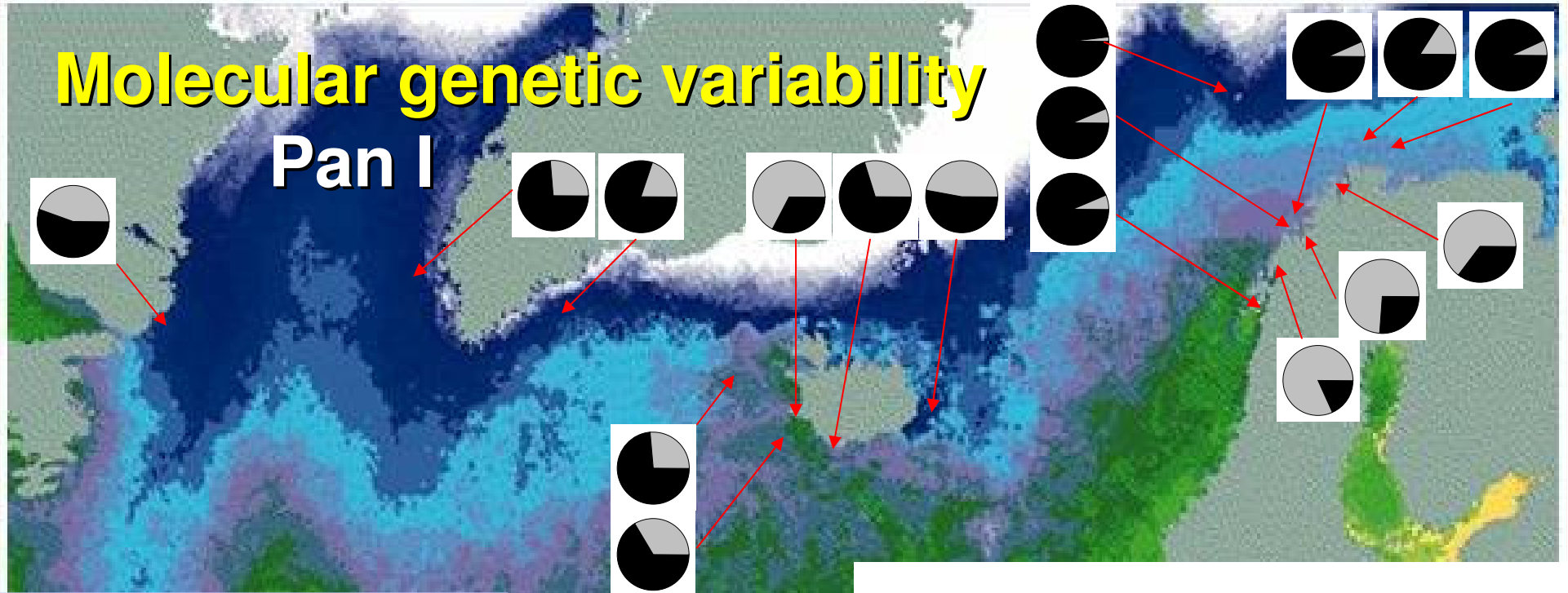 - Less affected by demographic history

- **Any evidence?**

Phenotypic variation in Atlantic cod

- **Migratory tendency**
  – **Robichaud & Rose 2004**

- **Survival**
  – **Hutchings et al. 2007**

- **Egg buoyancy**
  – **Nissling & Westin 1997**

Sedentary
Homing
Dispersing
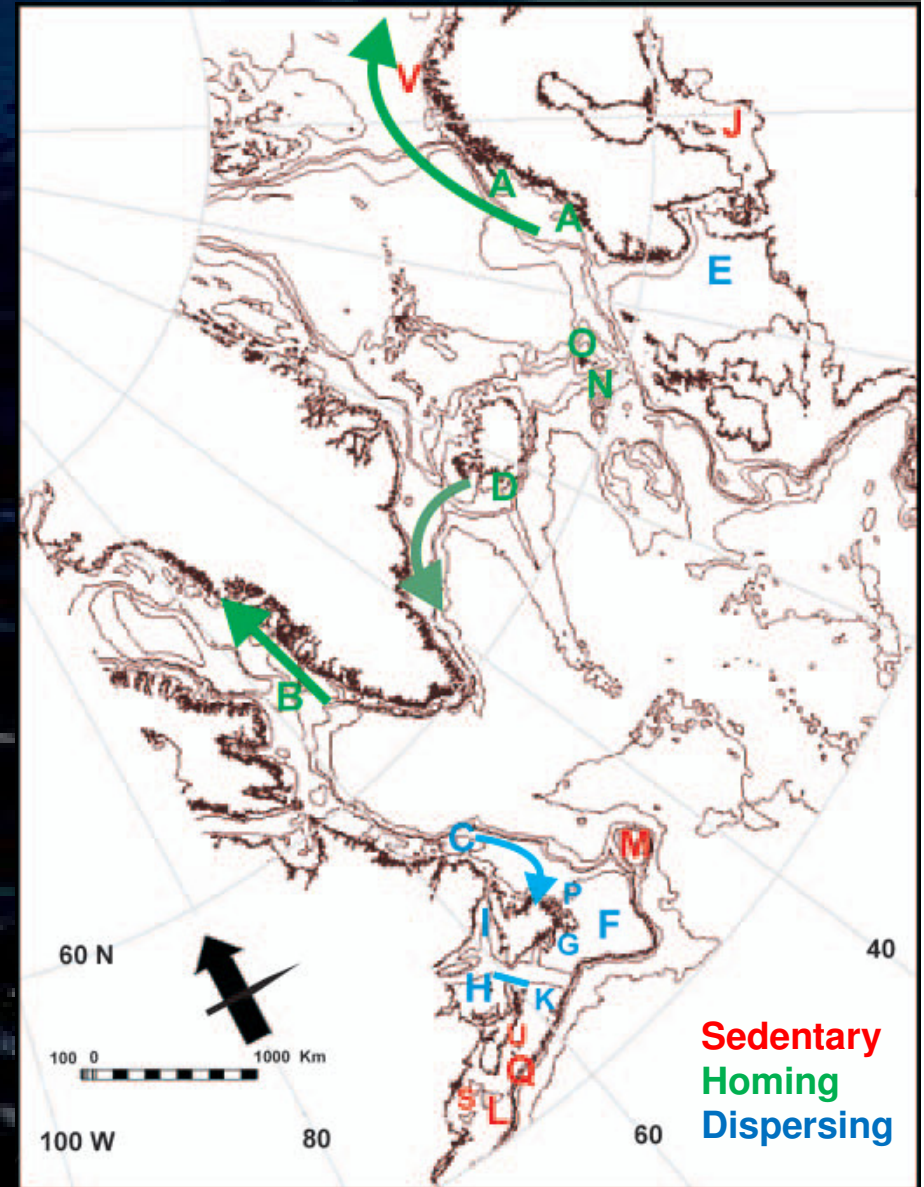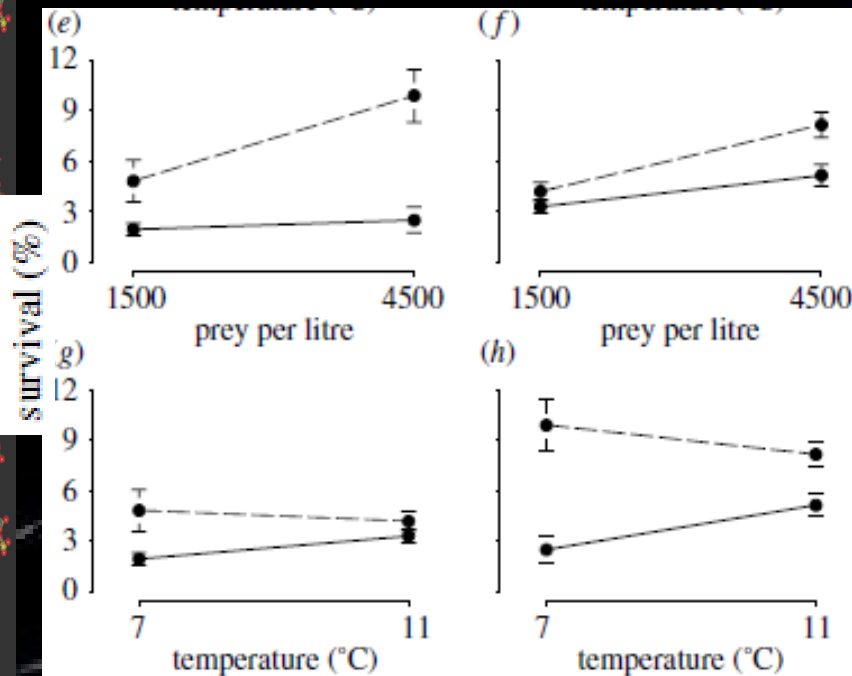
Molecular genetic variability
Pan I

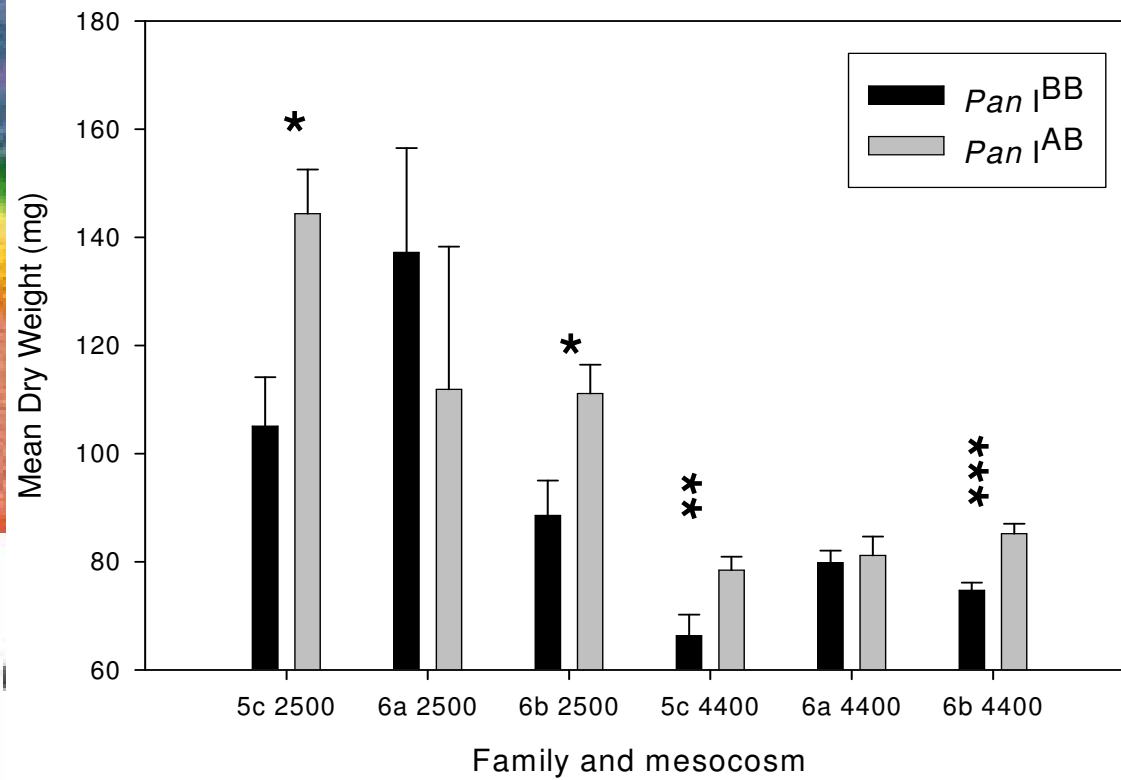Frequency Pan I^A Allele

Mean June SurfaceTemperature 1980-2002 (ºC)

Mean sea surface temperature in July 1987-1994

Case et al., 2005

Case et al 2005

Mean Dry Weight (mg) vs Family and mesocosm. Legend: $Pan\ I^{BB}$ (black), $Pan\ I^{AB}$ (grey). Categories: 5c 2500, 6a 2500, 6b 2500, 5c 4400, 6a 4400, 6b 4400.

20 22 24 26 deg. C.

87-1994
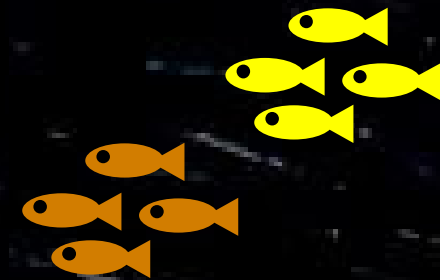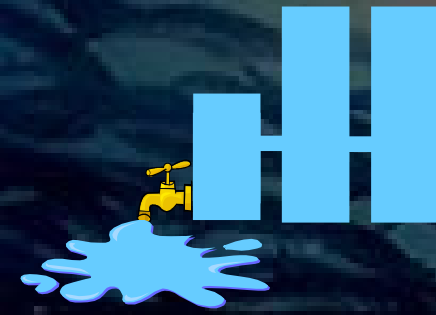
Why is population structure important?

- **Unit of management**
  - Does local perturbation affect other stocks?

- **Adaptive differentiation**
  - Different biological parameters
    - Life history
    - Migration
  - Local adaptation
  - Biodiversity / biocomplexity

Genetic stock identification

- **2 populations**
  - **Norwegian coastal cod**
  - **Northeast Arctic cod**
- **Patterns of differentiation**
  - **Microsatellites**
    - **Isolation by distance**
  - **PanI**
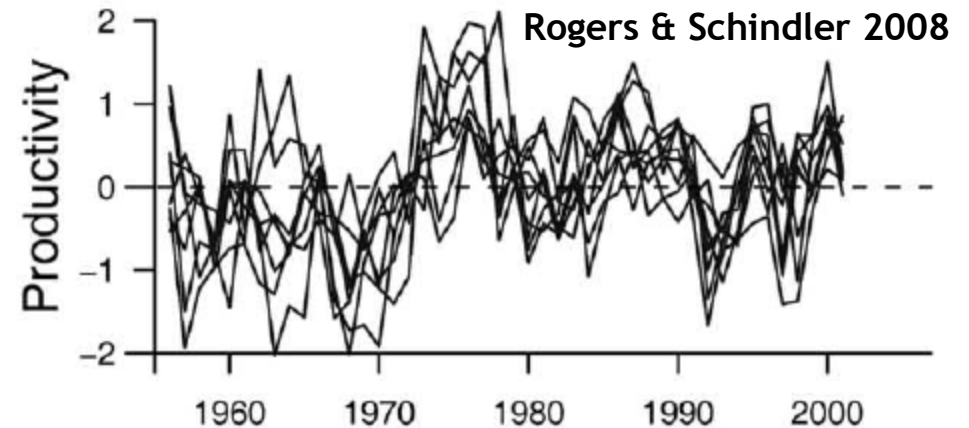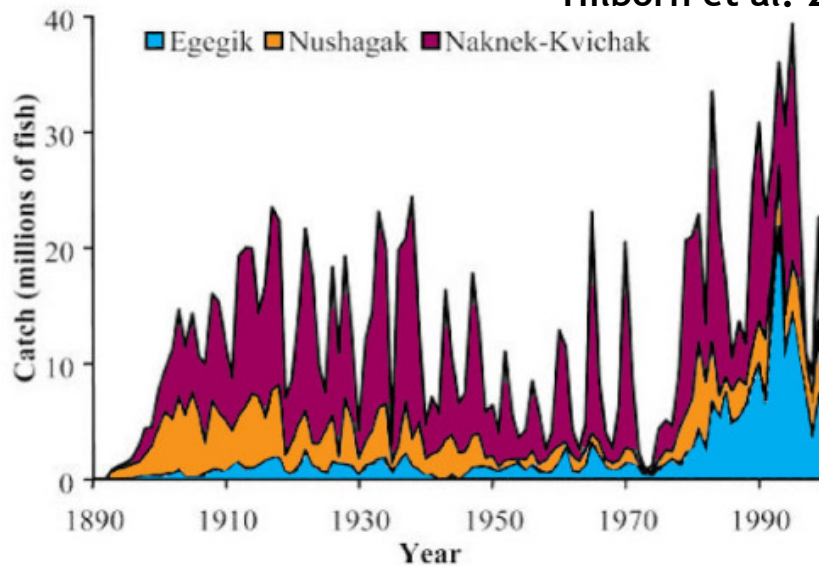   - **Clear differentiation**
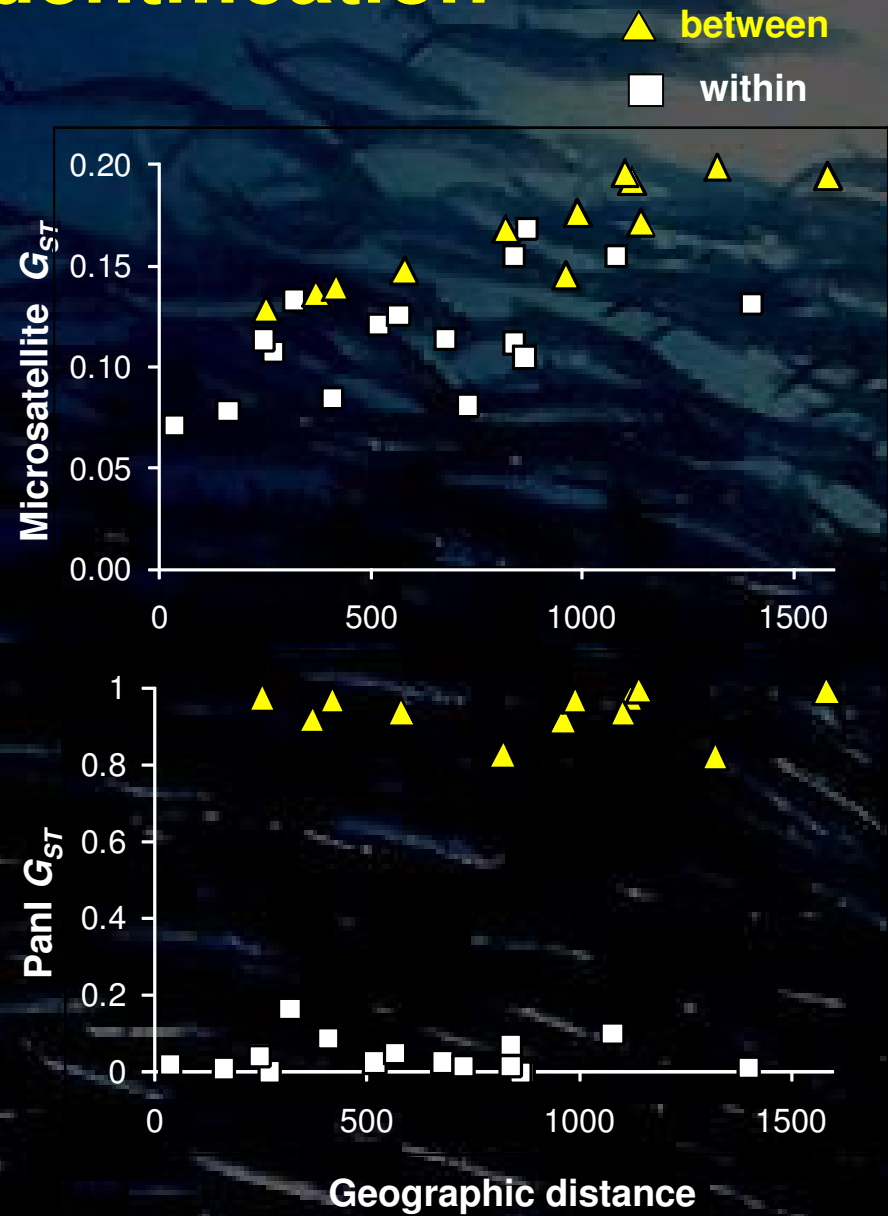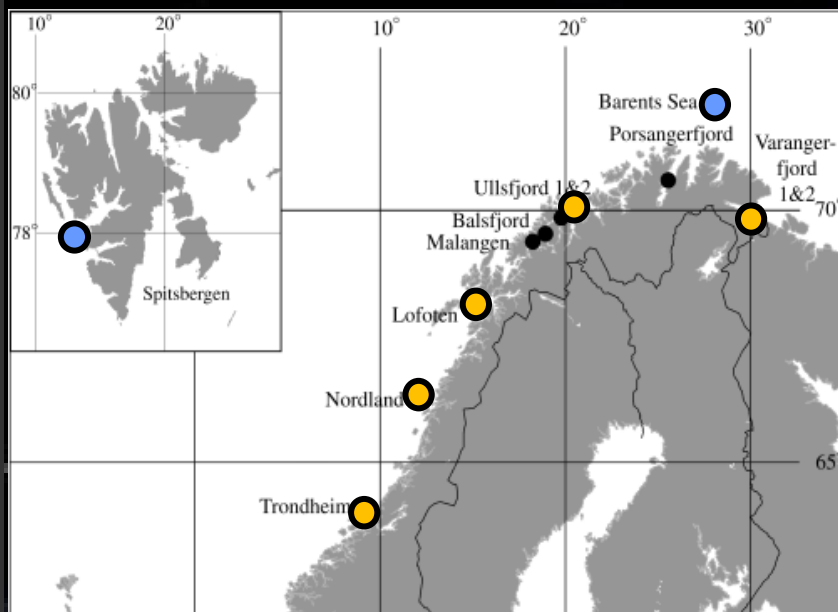
Data from Skarstein *et al.* (2007)

Biocomplexity

- **Interaction of local adaptation and environmental variation**
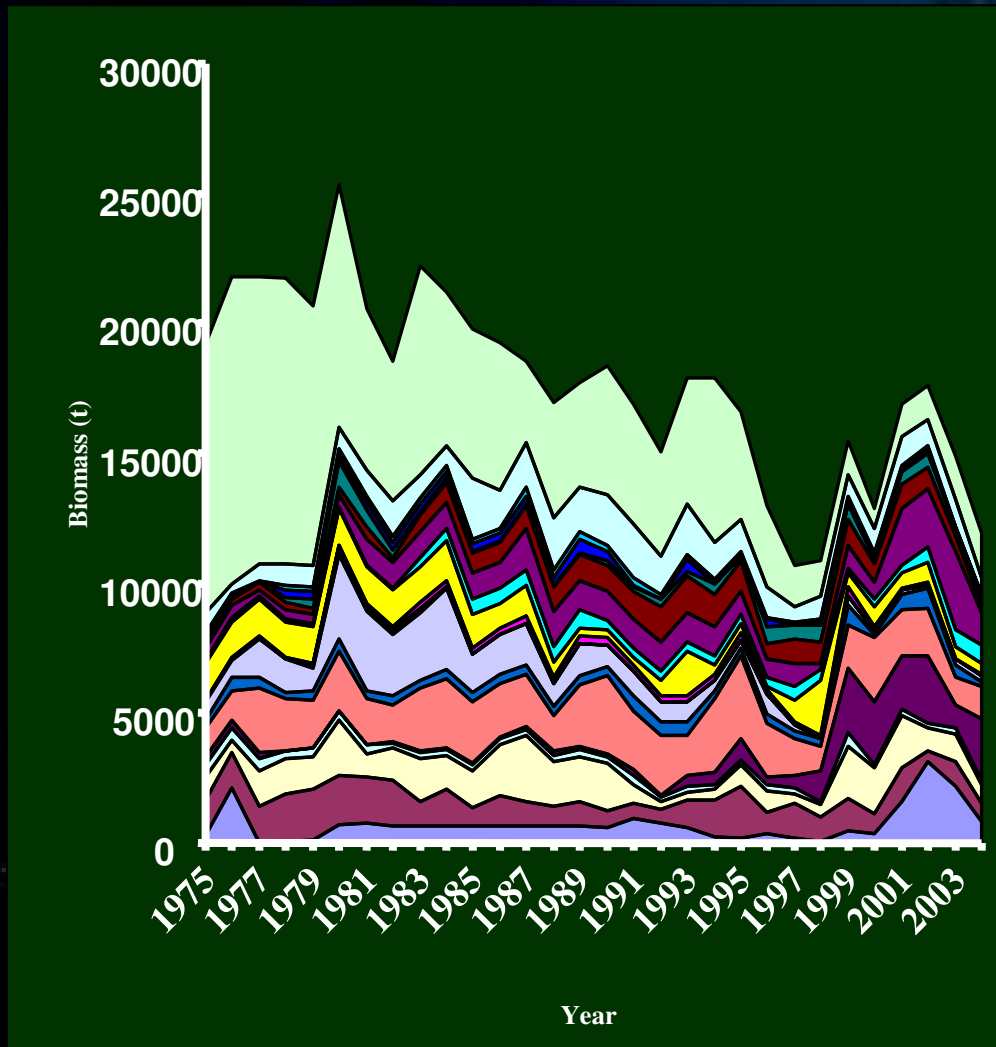- **Sustainability of stock complexes**
  - **Bristol Bay sockeye salmon**
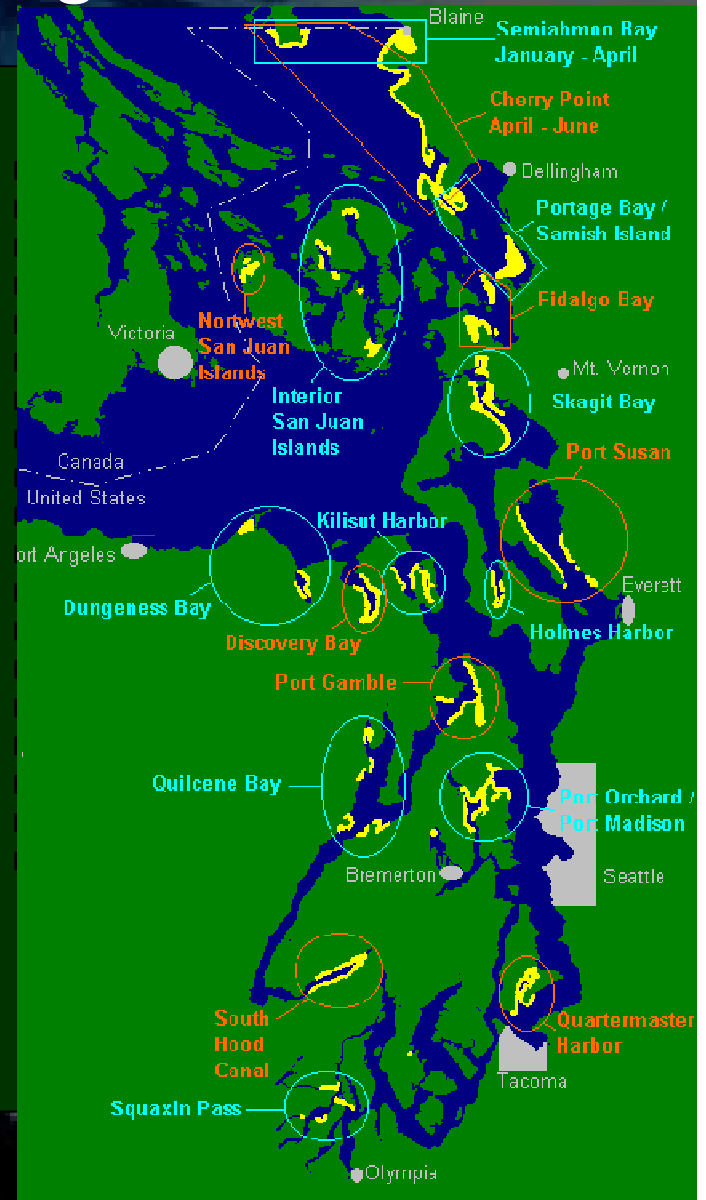
Hilborn et al. 2003

Rogers & Schindler 2008
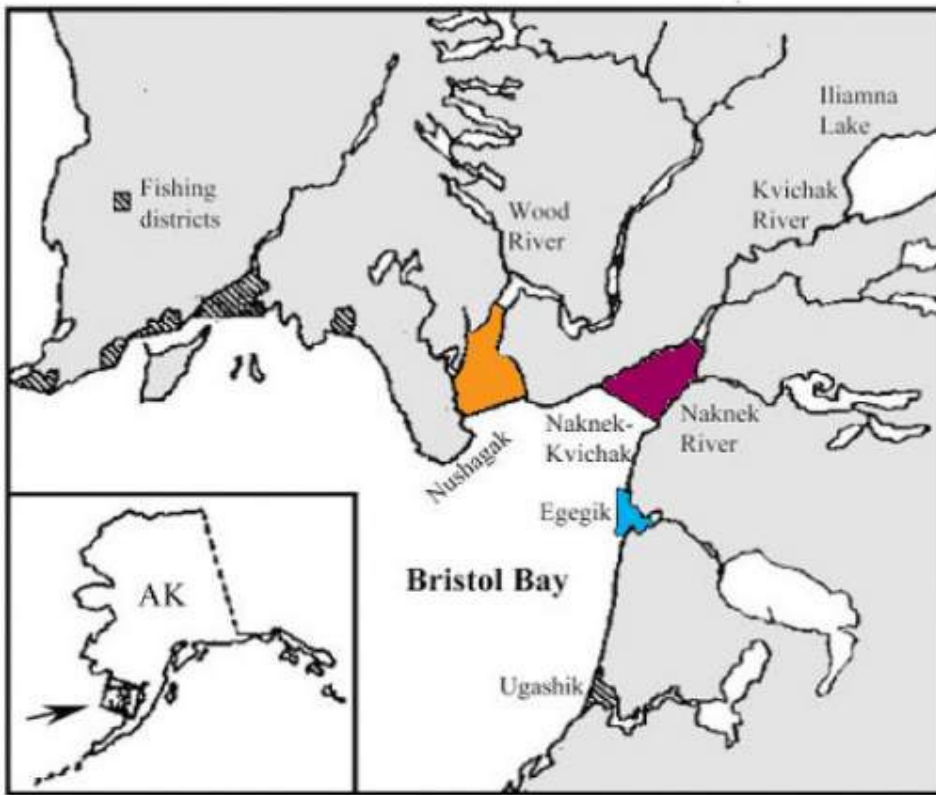
Biocomplexity in a marine fish
Puget Sound herring

WDFW data, in prep

How can we detect selective differentiation?

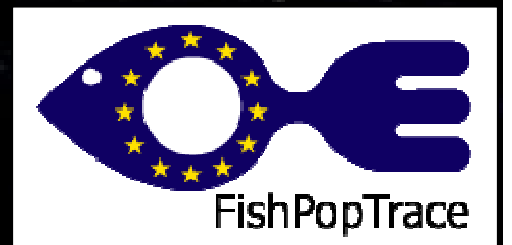- **Sequencing expressed genes (EST)**
  - **Annotate function**
  - **Develop markers**
    - **Microsatellites**
    - **SNPs**

- **Atlantic genome project**
  - **158,000 EST**
  - **>4700 SNPs**
  - **> 700 microsatellites**

- **EU project FishPopTrace**
  - **Detect adaptive population differentiation**
  - **Identify source of fish products**

Moen *et al.* 2008
Norwegian cod
17,000 ESTs
318 SNPs
26 SNPs positive selection

CGP
Atlantic Cod Genomics and Broodstock Development

FishPopTrace
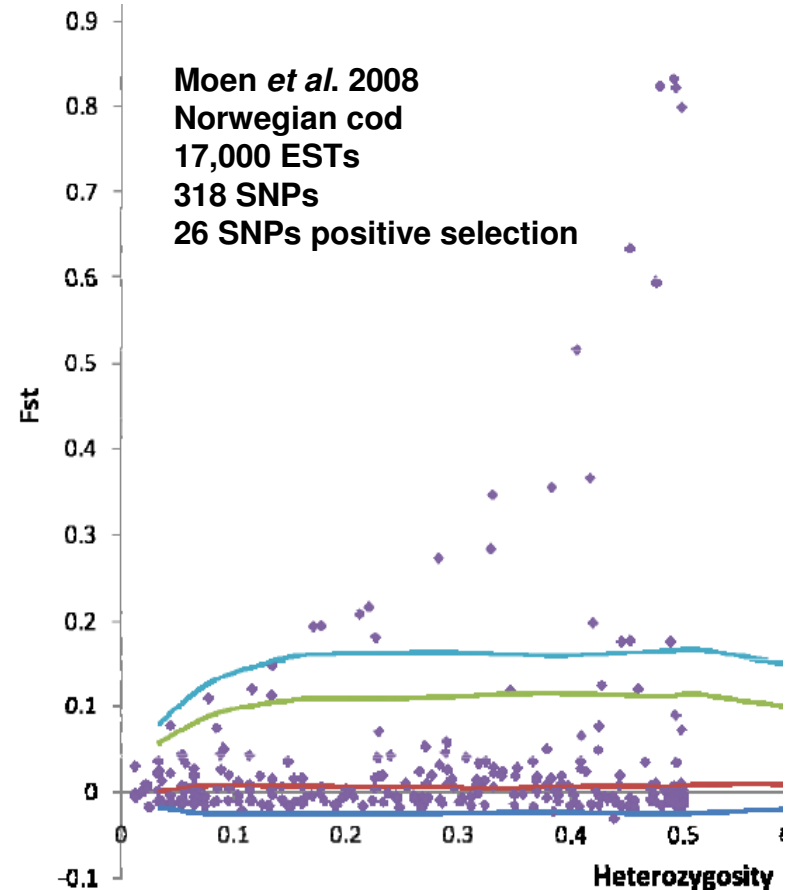
Estimation of migration rates / dispersal distances

- **Cannot use basic population genetics**
  - **Ignores selection**
  - **Cannot infer m directly from F_{ST}**
    - **Assume ranges of s**
- **Can use for mixed stock analysis**
- **Often sharp clines at environmental gradients**
  - **Homogenizing gene flow**
  - **Diversifying selection**
  - **Width of cline**
    - **estimate dispersal distances**
    - **Assume or measure selection**
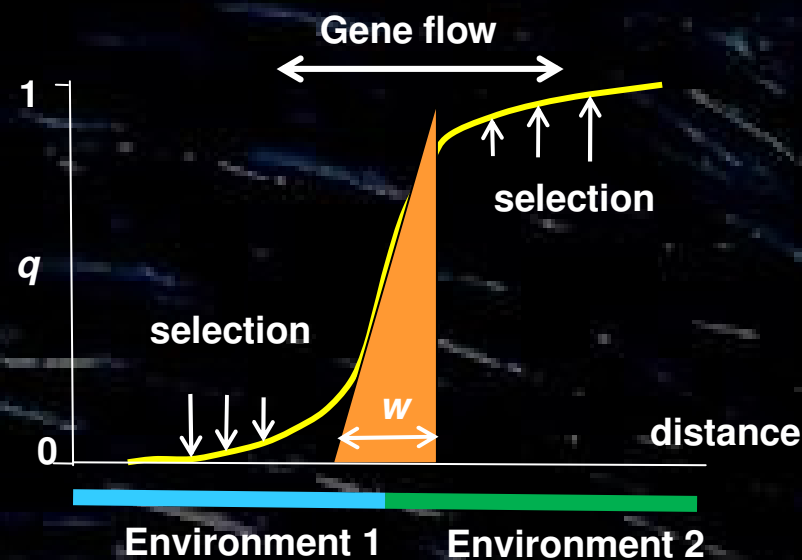
Estimation of migration rates / dispersal distances

- **Linkage disequilibrium**
    - **Higher if selection is stronger**
    - **~ selection**
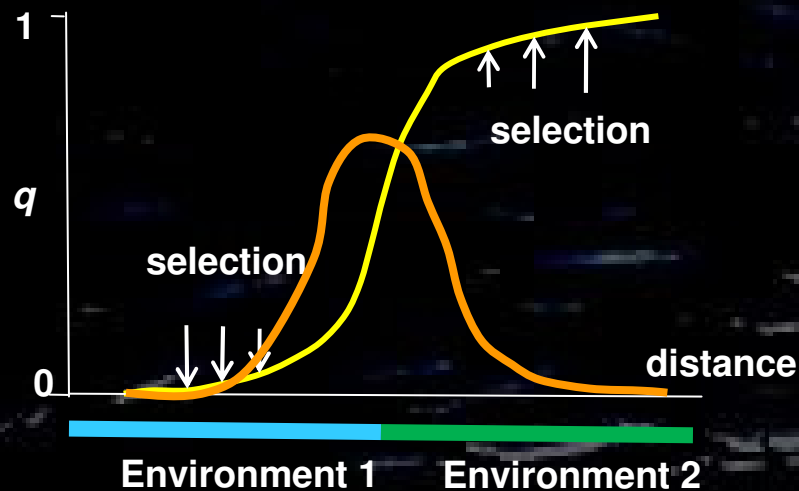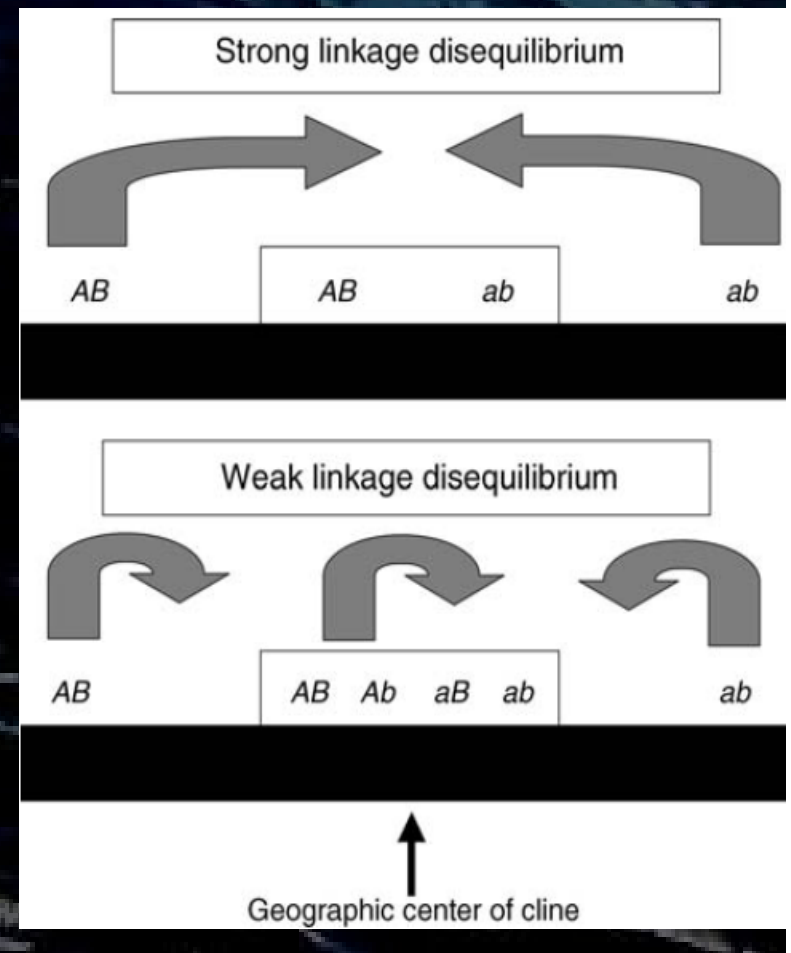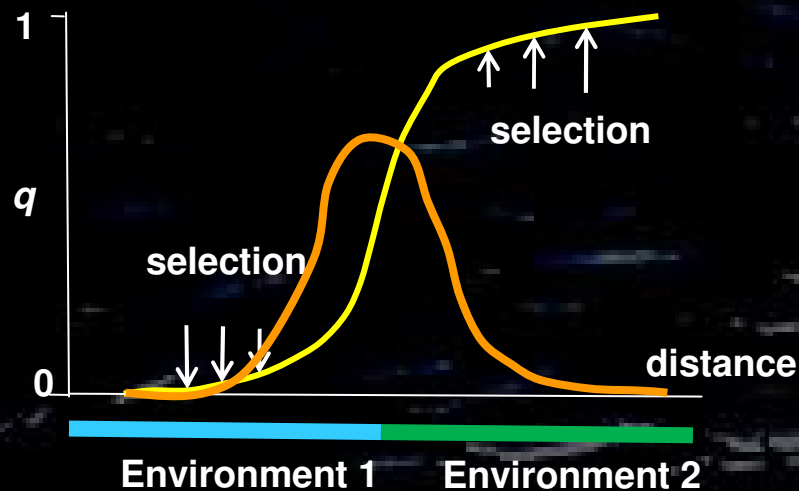   - **➔ dispersal**
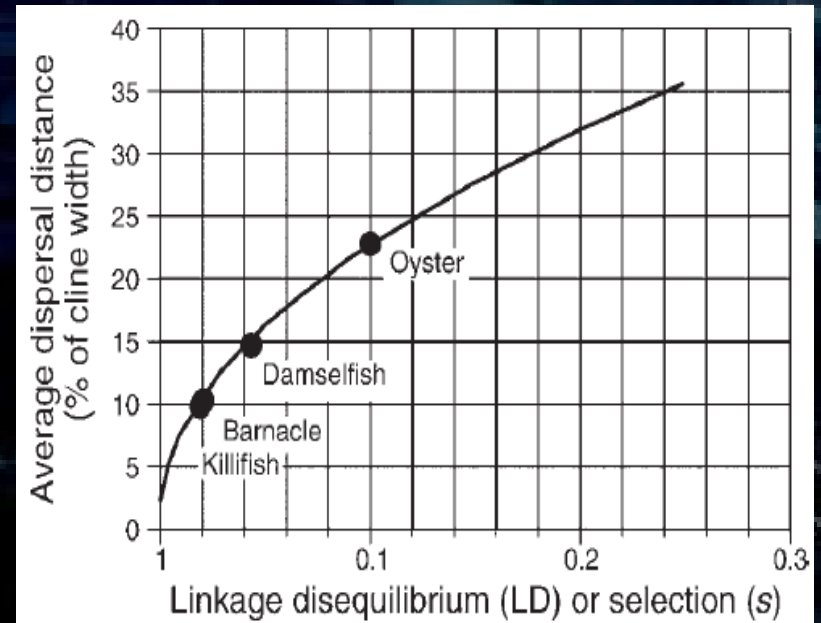
Sotka & Palumbi 2006

Estimation of migration rates / dispersal distances

- **Linkage disequilibrium**
  - **Higher if selection is stronger**
  - **~ selection**
    - **➜ dispersal**

Sotka & Palumbi 2006

$$D_{AB} = p_{AB} - p_A p_B$$

Conclusions
making Dark Matter visible

- **Neutral molecular marker underestimate biodiversity in marine species**
  - **Genetic drift low**
  - **Selection efficient**
- **Evidence in Atlantic cod**
  - **Phenotypic variation**
  - **Molecular variation**
    - **Environmental correlations**
    - **Growth differences between genotypes**
- **Significance**
  - **Biodiversity / Biocomplexity**
  - **Stock deliniation**

- **Detection**
  - **Novel technological developments**
  - **Statistical approaches**
- **Advantages**
  - **Higher levels of differentiation**
  - **Less affected by long-term history**
- **Applications**
  - **Delineation of populations**
  - **Mixed stock analysis**
  - **Estimation of dispersal**

Acknowledgements

- **Atlantic cod**
  - Gary Carvalho
  - Richard Case
  - Bill Hutchinson
  - MACOM partners

- **Pacific cod / pollock**
  - Mike Canino
  - Ingrid Spies
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  - Isadora Jimenez-Hidalgo
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  - Sampling support

- **Funding**
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