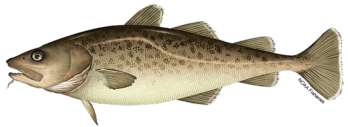
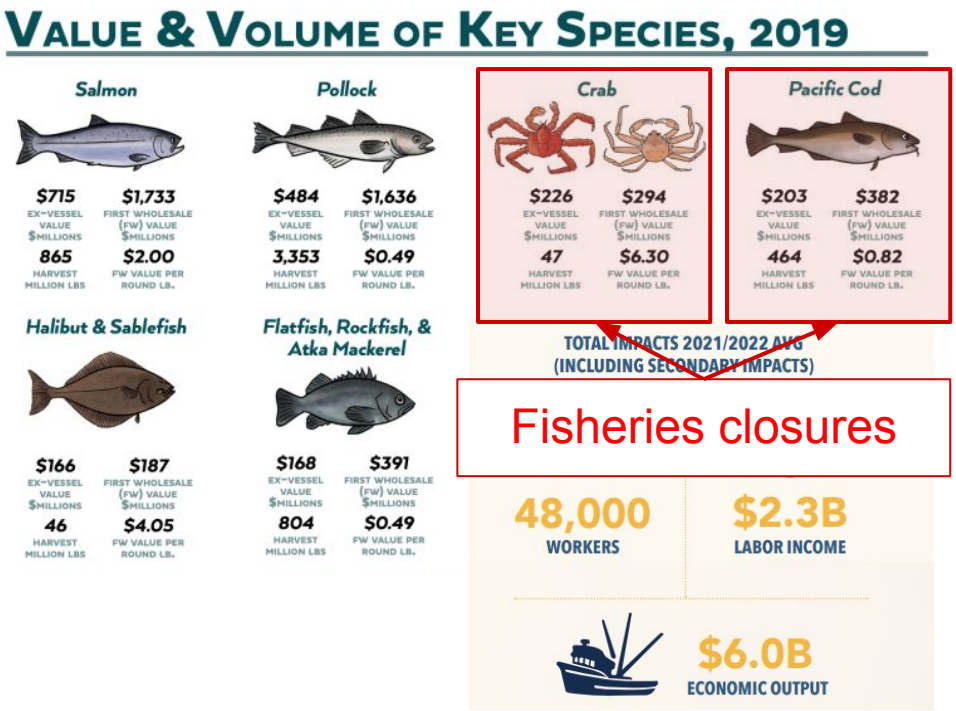
Molecular indicators of performance in a marine fish exposed to temperature stress



Laura Spencer, NOAA AFSC Affiliate

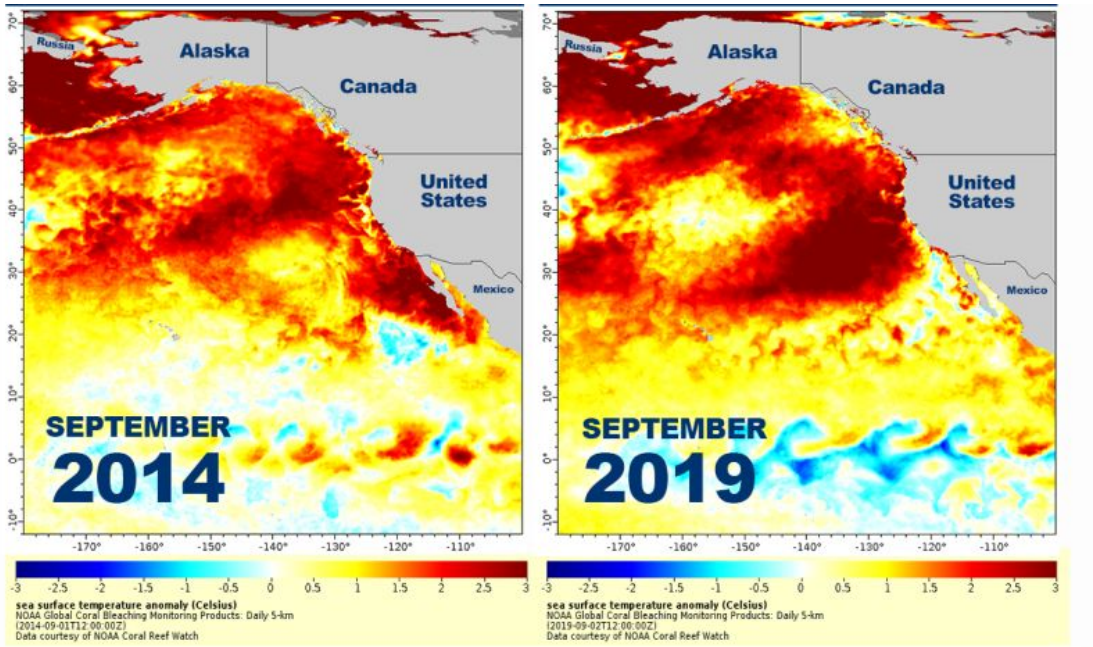
University of Washington SAFS & CICOES

NOAA surveys & manages Alaskan fisheries (AFSC)



ASMI (industry report), 2022

Heatwaves!



NOAA feature story, September 05, 2019

NOAA surveys & manages Alaskan fisheries (AFSC)

VALUE & VOLUME OF KEY SPECIES, 2019

Salmon

$715	$1,733
EX-VESSEL VALUE $MILLIONS	FIRST WHOLESALE (FW) VALUE $MILLIONS
865	$2.00
HARVEST MILLION LBS	FW VALUE PER ROUND LB.

Pollock

$484	$1,636
EX-VESSEL VALUE $MILLIONS	FIRST WHOLESALE (FW) VALUE $MILLIONS
3,353	$0.49
HARVEST MILLION LBS	FW VALUE PER ROUND LB.

Crab

$226	$294
EX-VESSEL VALUE $MILLIONS	FIRST WHOLESALE (FW) VALUE $MILLIONS
47	$6.30
HARVEST MILLION LBS	FW VALUE PER ROUND LB.

Pacific Cod

$203	$382
EX-VESSEL VALUE $MILLIONS	FIRST WHOLESALE (FW) VALUE $MILLIONS
464	$0.82
HARVEST MILLION LBS	FW VALUE PER ROUND LB.

Halibut & Sablefish

$166	$187
EX-VESSEL VALUE $MILLIONS	FIRST WHOLESALE (FW) VALUE $MILLIONS
46	$4.05
HARVEST MILLION LBS	FW VALUE PER ROUND LB.

Flatfish, Rockfish, & Atka Mackerel

$168	$391
EX-VESSEL VALUE $MILLIONS	FIRST WHOLESALE (FW) VALUE $MILLIONS
804	$0.49
HARVEST MILLION LBS	FW VALUE PER ROUND LB.

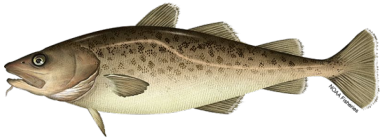
TOTAL IMPACTS 2021/2022 AVG (INCLUDING SECONDARY IMPACTS)

48,000
WORKERS

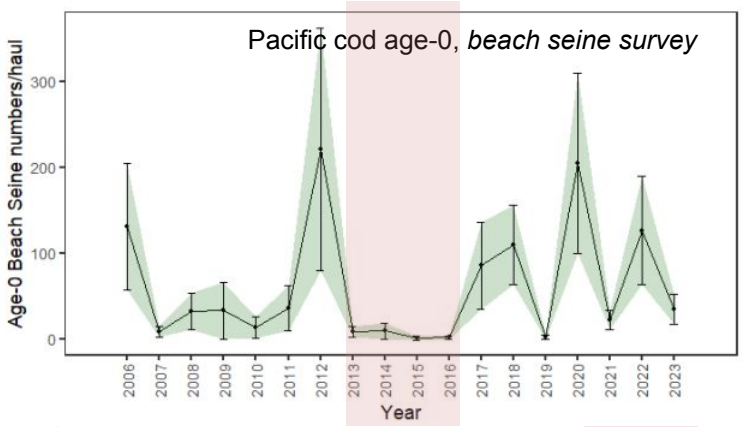
$2.3B
LABOR INCOME

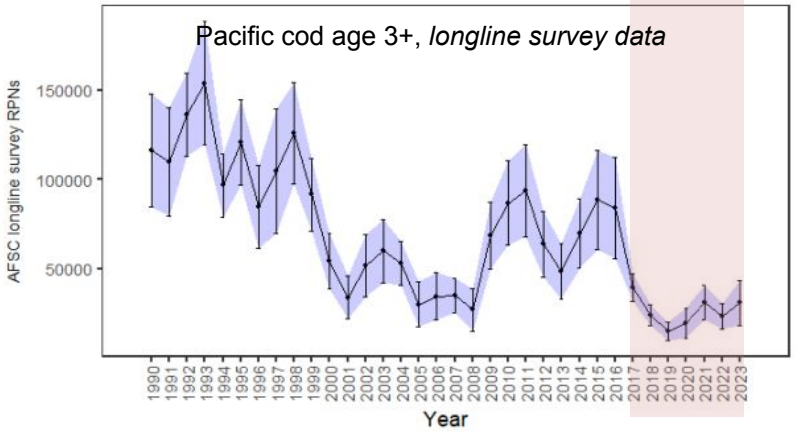
$6.0B
ECONOMIC OUTPUT

ASMI (industry report), 2022

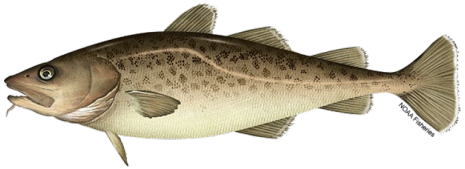


Pacific cod, *Gadus macrocephalus*





Stock Assessment Report, 2023, Gulf of Alaska,

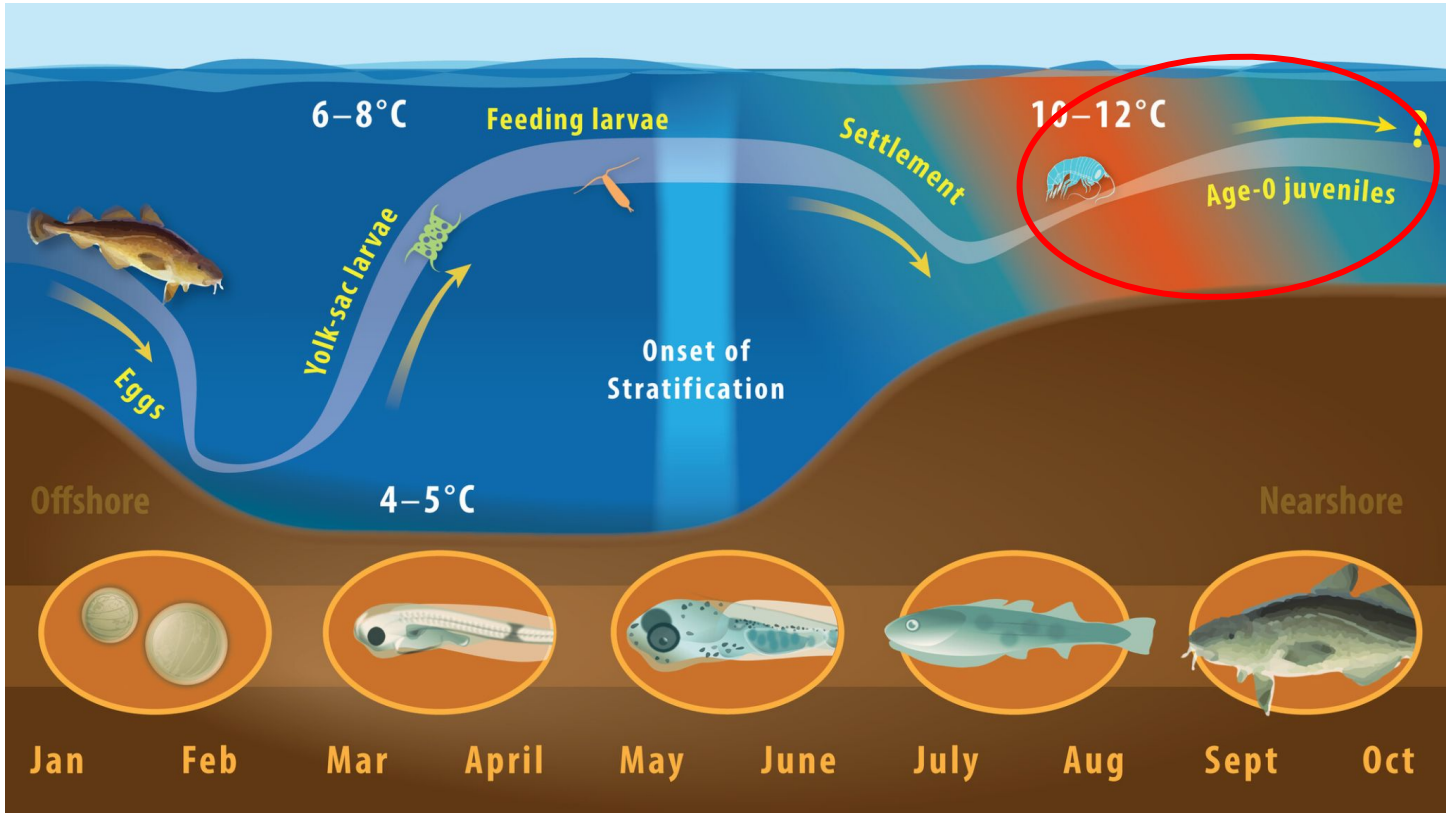


Big Questions

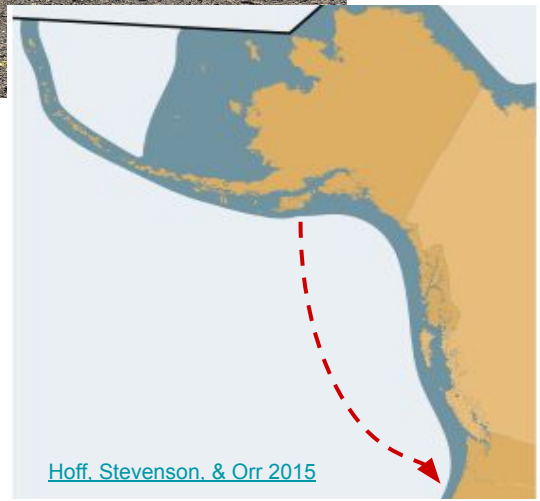
- Why & how does warming affect Pacific cod recruitment?

- Do stock assessment reference points need to be updated?
  - *E.g. natural mortality rates*

- How resilient are Pacific cod populations in Alaska to warming?



Laurel et al. 2023, *in Fish & Fisheries*



How does temperature affect **juvenile** Pacific cod **growth, survival, & energy allocation** in the pre-winter period?

- Wild juveniles (age-0) caught off Kodiak, AK late summer
- Transported to Newport, OR wet lab
- ~6 weeks experiment (age-0)

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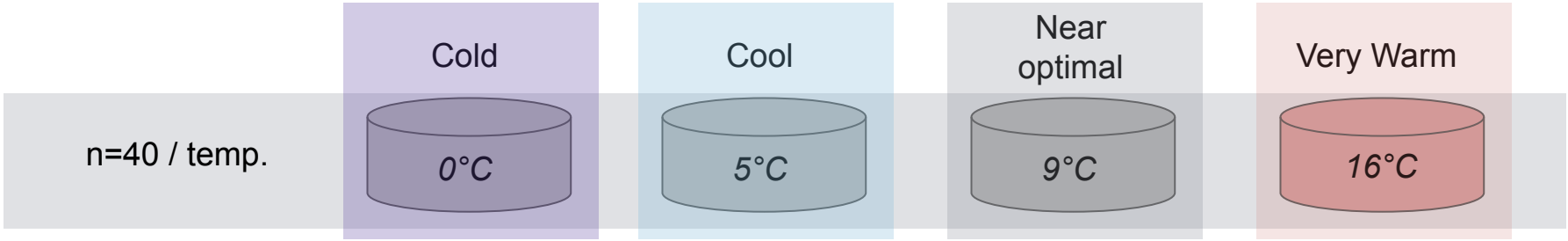
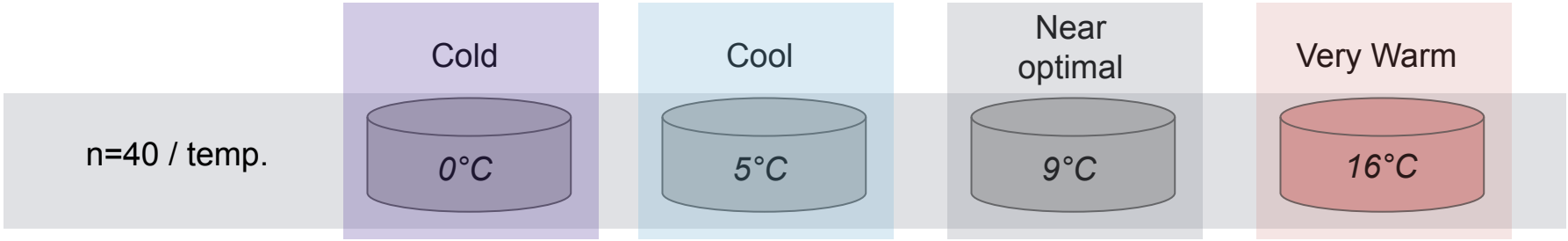
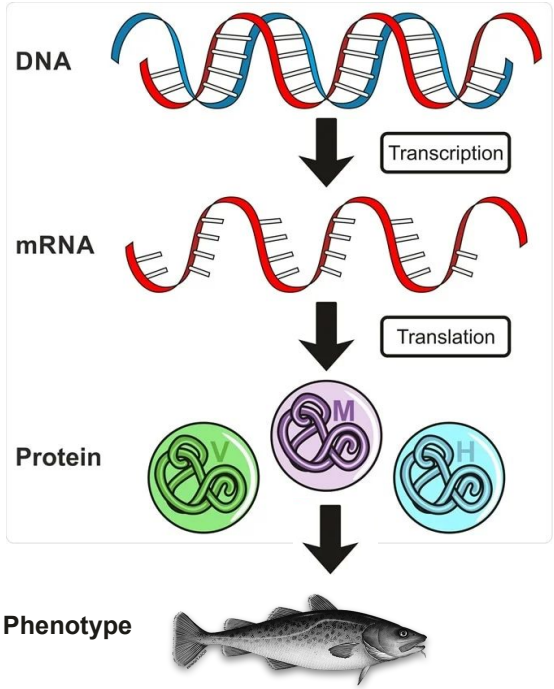


Individuals tagged, collected:

a. Genetics with fin clips, n=40/temp (lcWGS)
b. Growth rates (length & wet weight) during acclimation, treatment
c. Body condition (Kwet)
d. Liver condition (HSI)
e. Survival
f. Liver lipid components (n=25/temp)
g. Gene expression with liver, n=18/temp (RNASeq)



“Genome-to-Phenome” dataset, Pacific cod juvenile temperature response



Adapted from: udaix/Shutterstock.com

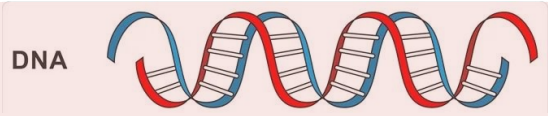
1. Genetics –
   Who are they?

2. Phenotypes –
   How does warming affect key traits?

3. Integrate datasets –
   Why are some fish less sensitive?

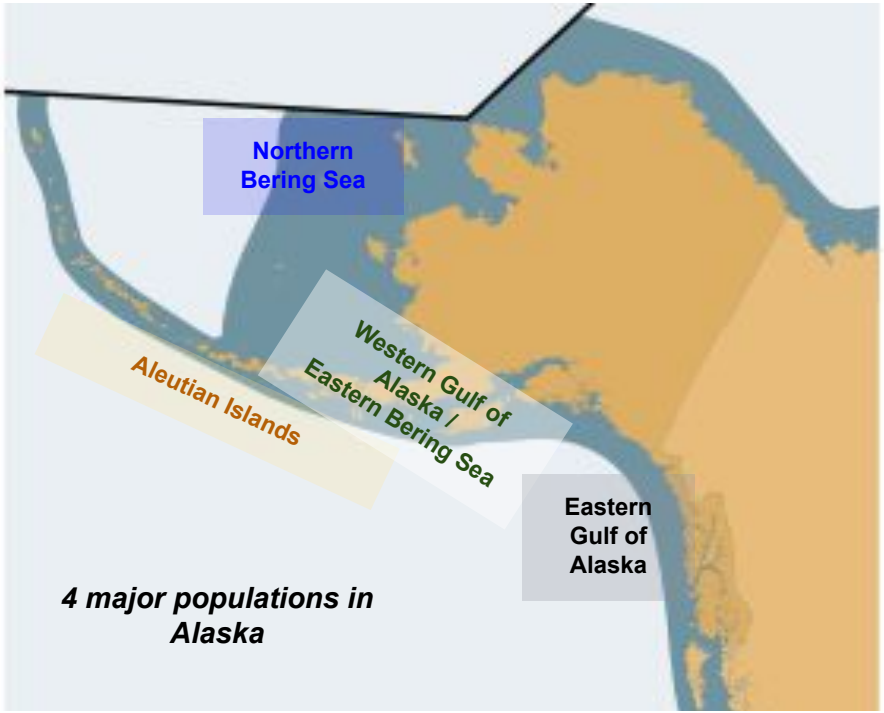
"Genome-to-Phenome" dataset, Pacific cod juvenile temperature response

1. Genetics – Who are they (wild caught)?

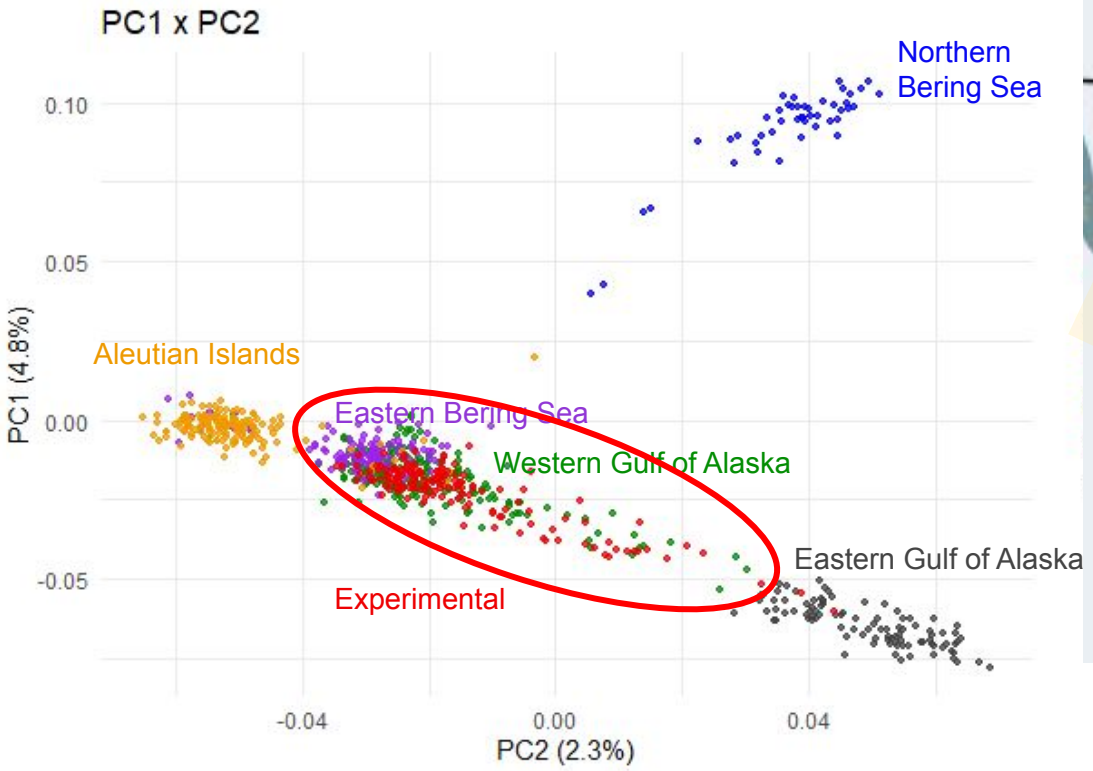


Tools used:

- Sequence whole genome ~3x (i.e. "low-coverage"), n=160
- ~$100/fish, genome size ~500Mb (similar to pacific oyster)
- High-quality reference genome for alignment & genotype data (`bwa mem` & `angsd`)
- More data from ~55 reference fish per population, assign our fish (`wgsassign`)
- 6,101 sites used to **predict population of origin of experimental fish,** 96% accurate



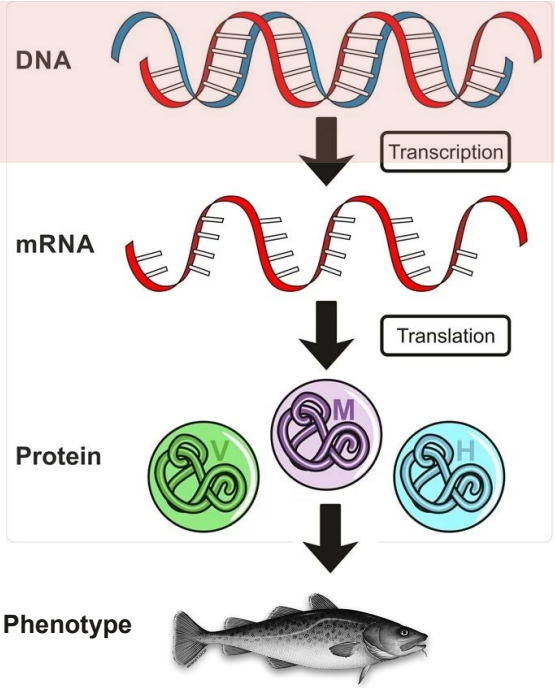
Genetics - They are the Western GOA / Eastern Bering Sea group



“Genome-to-Phenome” dataset, Pacific cod juvenile temperature response

✓ Genetics – **they are one population**

western Gulf of Alaska / Eastern Bering Sea



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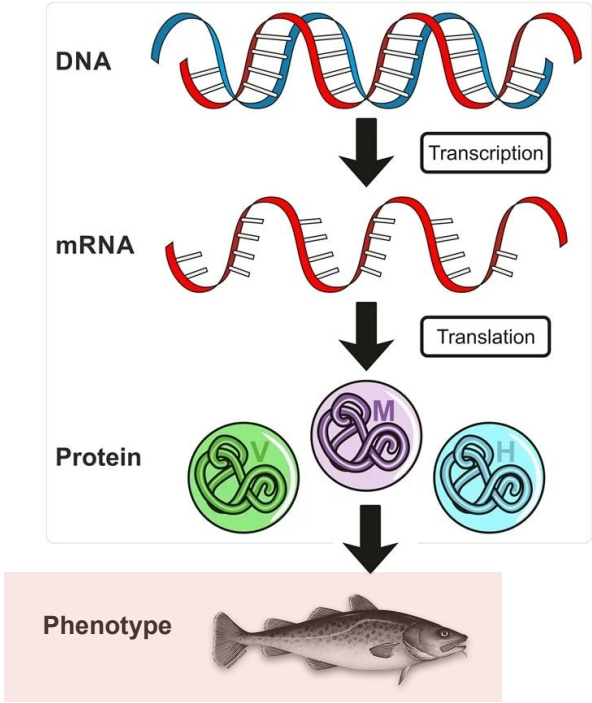
“Genome-to-Phenome” dataset, Pacific cod juvenile temperature response

✓ Genetics – **they are one population**

western Gulf of Alaska / Eastern Bering Sea

- Phenotypes – <u>how</u> are survival-associated biometrics affected?



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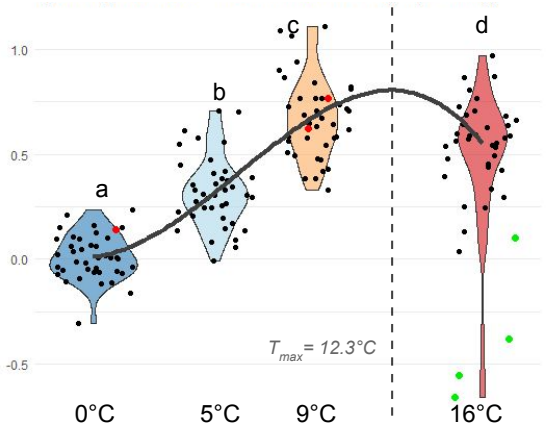
Warming decreased lipid reserves

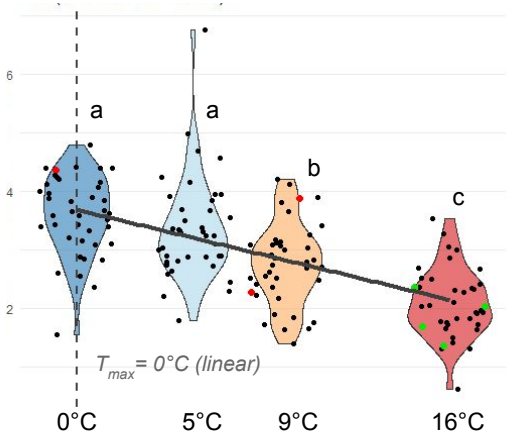
Growth Rate (weight)

Faster growth 👍



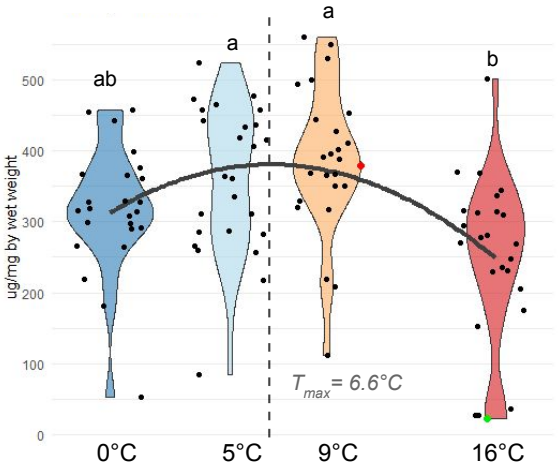
Hepatosomatic index (liver size)

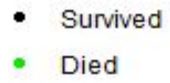
Larger liver👍



Total Lipid Content in liver

More lipid 👍



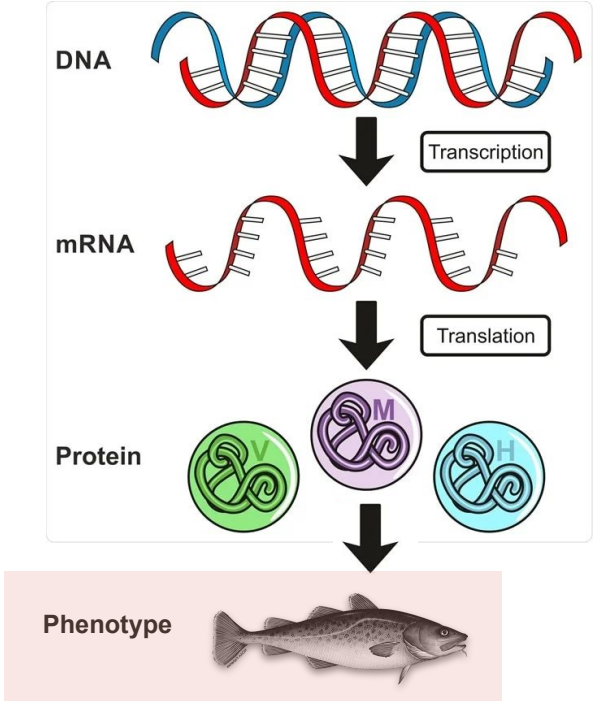


“Genome-to-Phenome” dataset for juvenile Pacific cod

✓ Genetics – **they are one population**

western Gulf of Alaska / Eastern Bering Sea

✓ Phenotypes – **Fewer lipid reserves in warming, slightly slower growth** - juvenile overwinter survival likely lower during heatwave years.



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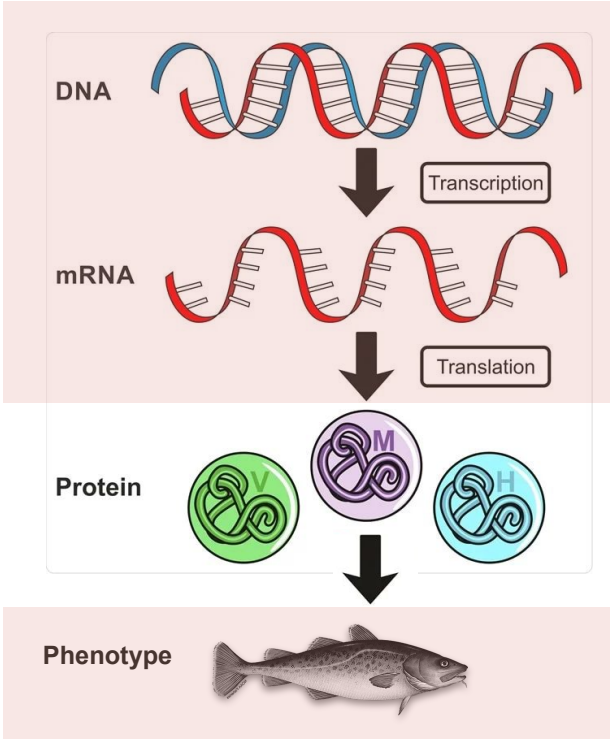
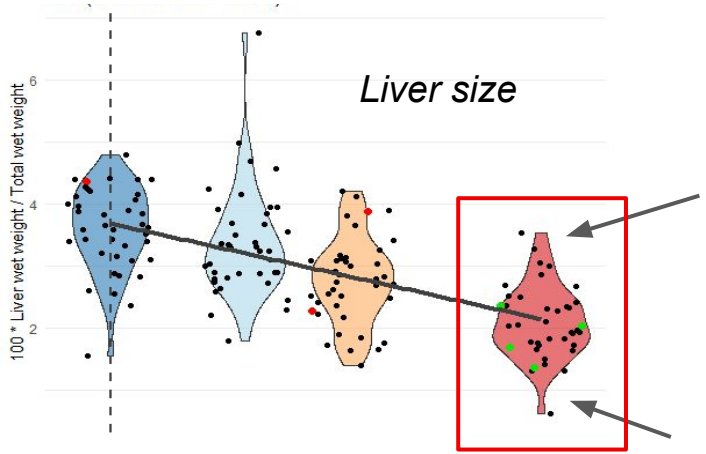
- Integrate datasets – Performance indicators!
  a. Genetic variants
  b. Expression patterns



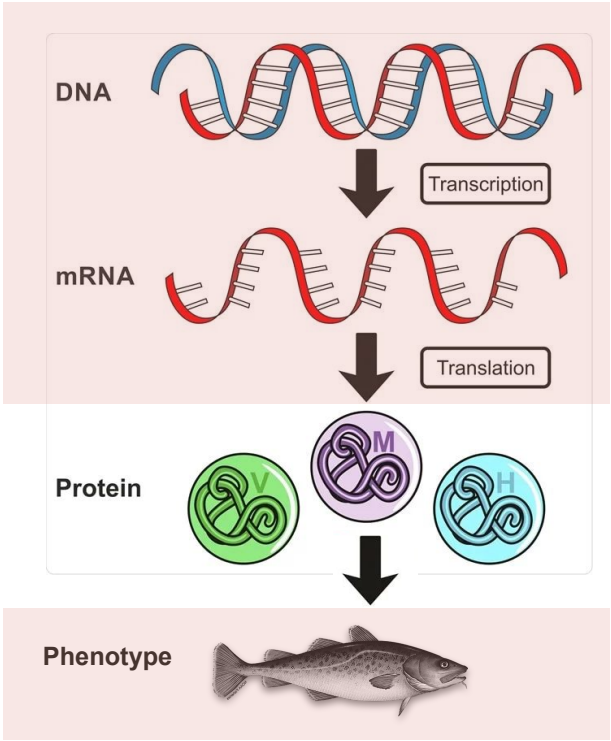
Adapted from: udaix/Shutterstock.com

Variation within each temperature - opportunity!



1. Identified <u>sites on genome</u> associated with liver size, lipid content, & growth in warming
2. Identified best sites/genotypes that **predict performance in warming, are adaptive**

Genome-Wide Association Studies (GWAS) within each treatment



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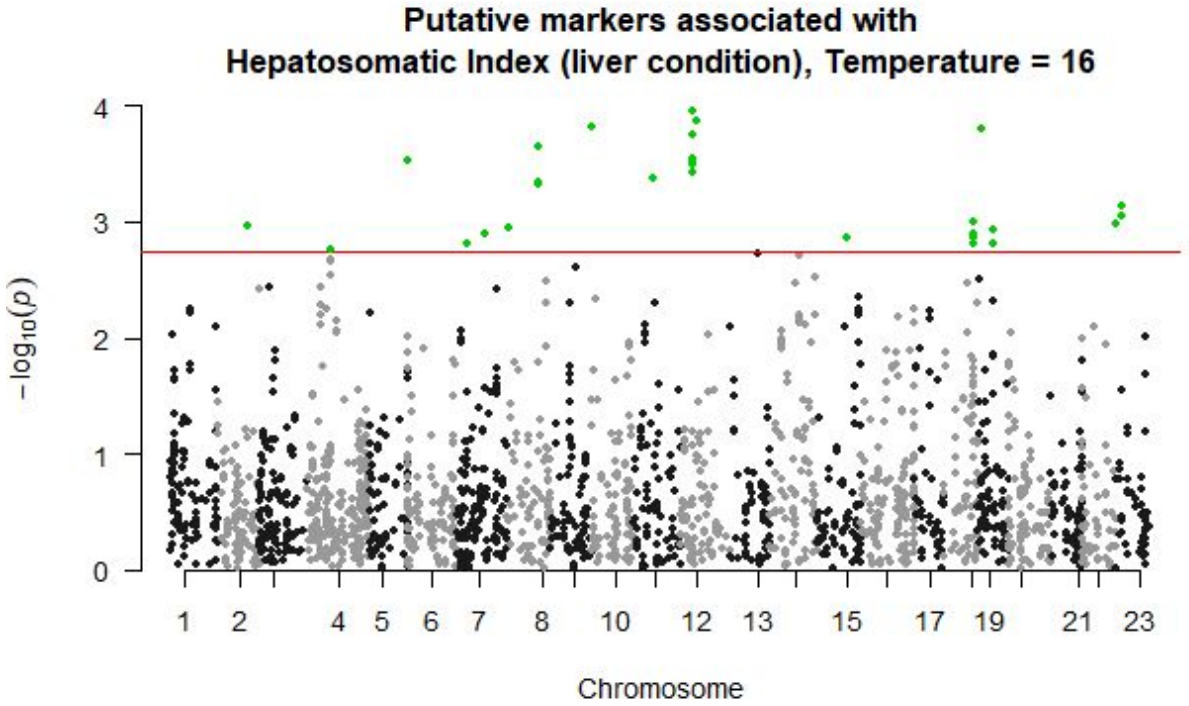
~100 markers putatively associated with liver size in Pacific cod juveniles exposed to warming



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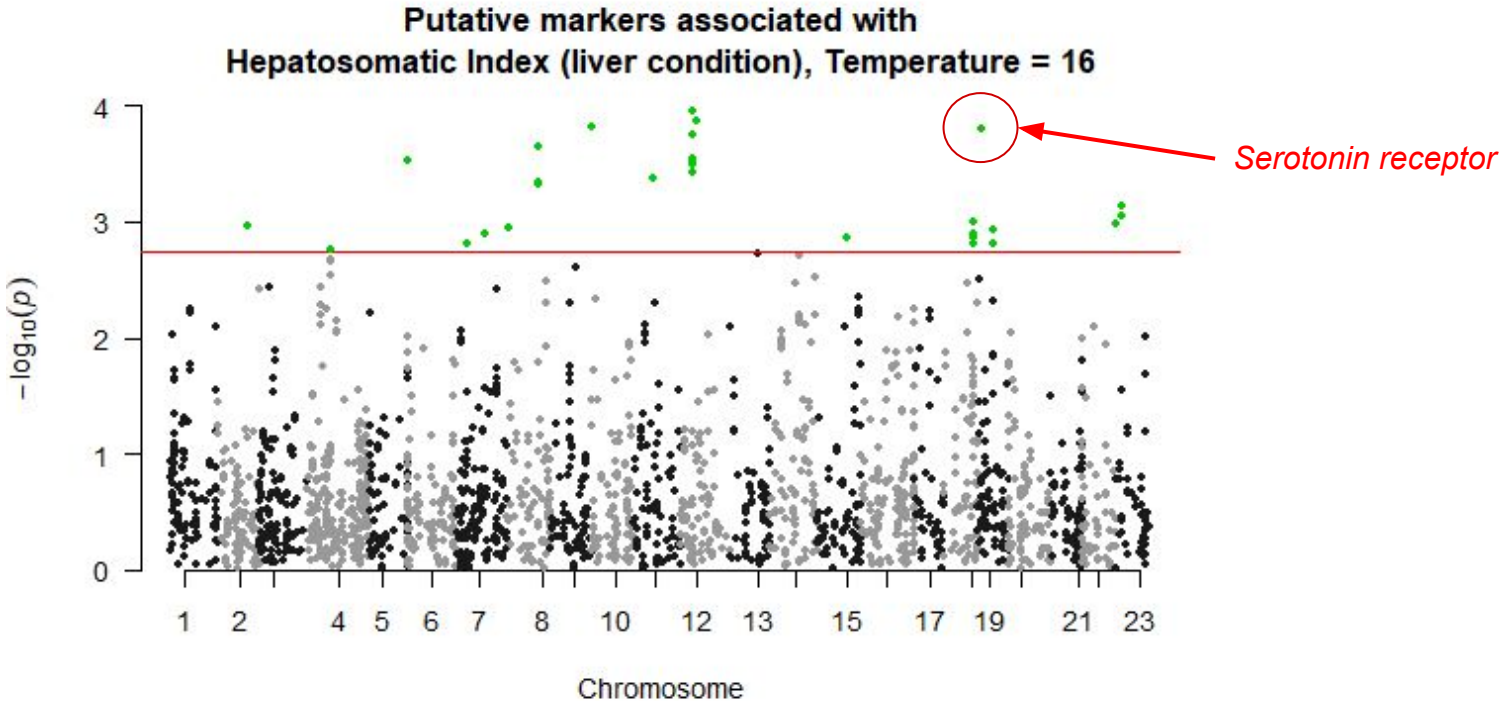

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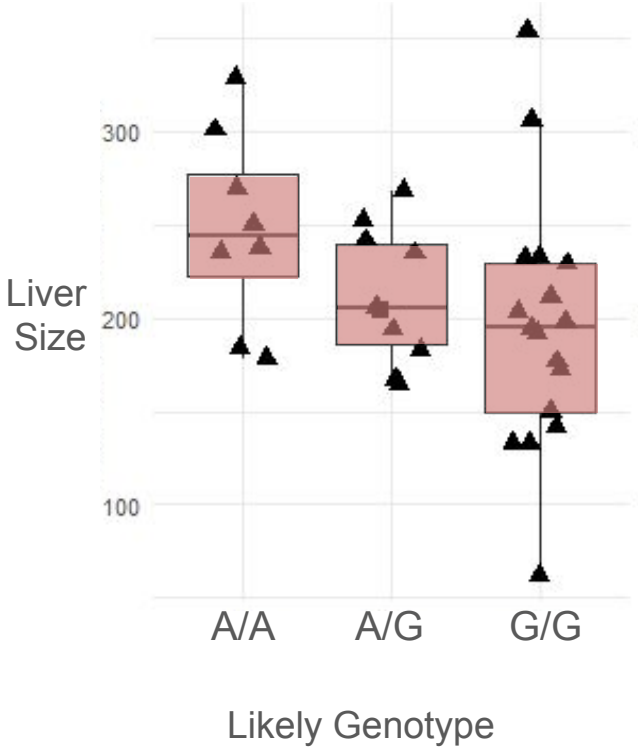


*Marker in a gene coding for a **receptor for serotonin** (5-HT4) which regulates appetite*

“Genome-to-Phenome” dataset for juvenile Pacific cod

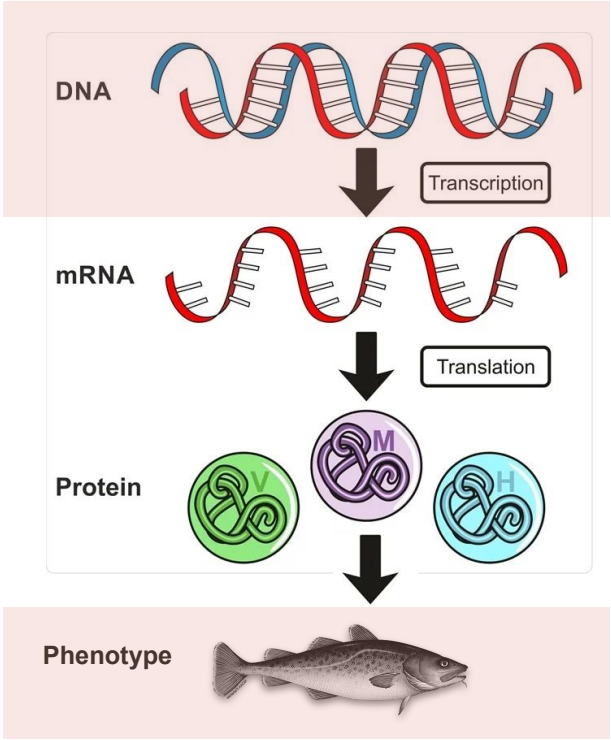
✓ Genetics – **they are one population**

western Gulf of Alaska / Eastern Bering Sea

✓ Phenotypes – **Fewer lipid reserves in warming, slightly slower growth**

✓ Gene expression – **Lipid usage, immune activity, & damage control may deplete energy reserves**

1. Integrate datasets – Performance indicators!
   - ✓ **~100 genetic markers** of liver size in warming
   - a. Expression patterns



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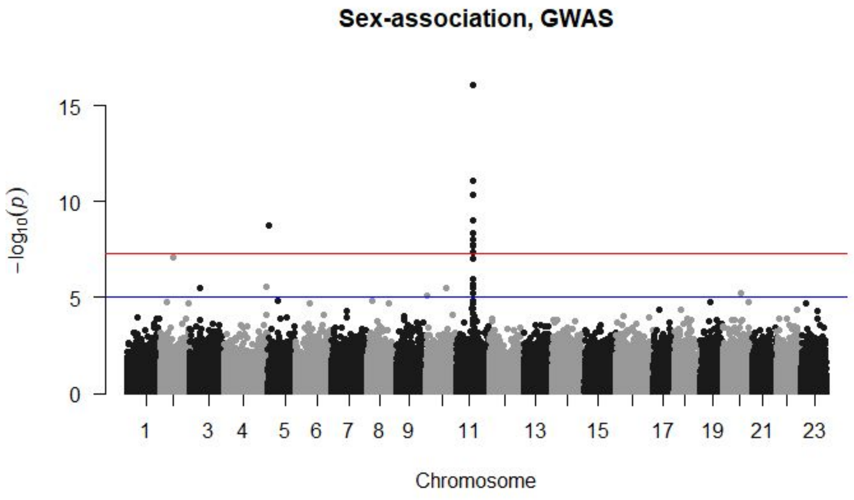
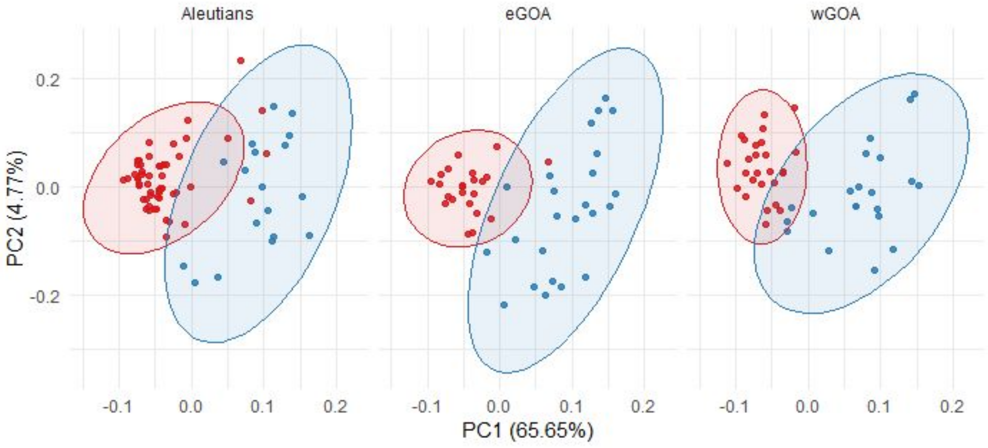
Example Genome Wide Association Study – Sex markers discovery (preliminary)



PCAs with ~50 sex-associated sites



Female = Male

Tangent –
Sex marker discovery (preliminary) using Genome Wide Association Study

Also Chromosome 11 in Atlantic cod

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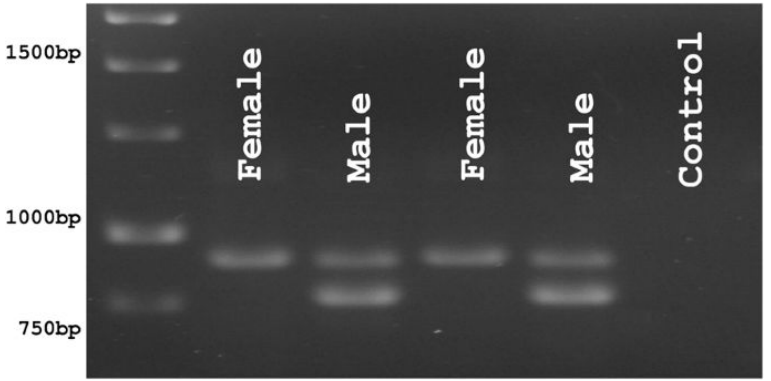
Article | Open access | Published: 15 January 2019

Characterization of a male specific region containing a candidate sex determining gene in Atlantic cod

Tina Graceline Kirubakaran, Øivind Andersen, Maria Cristina De Rosa, Terese Andersstuen, Kristina Hallan, Matthew Peter Kent & Sigbjørn Lien

Scientific Reports **9**, Article number: 116 (2019) | Cite this article

Benchtop sex assay in Atlantic cod



Pacific halibut assessment uses sex data based on DNA sample

“Genome-to-Phenome” dataset for juvenile Pacific cod

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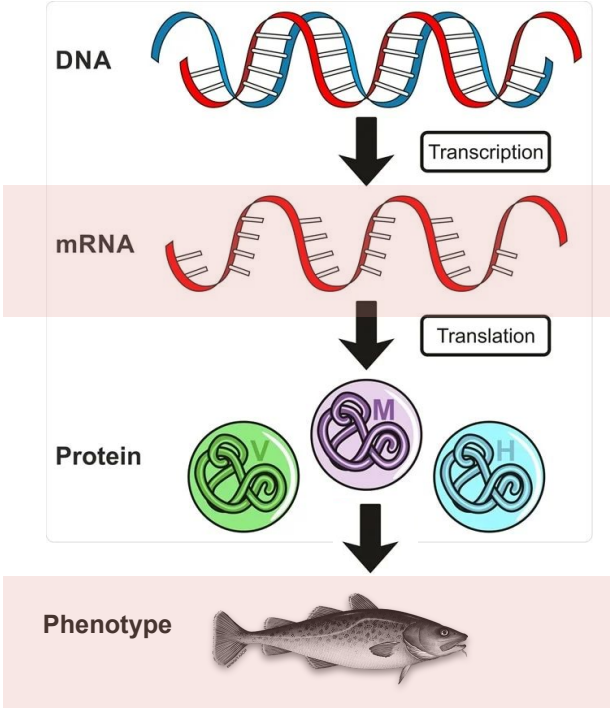

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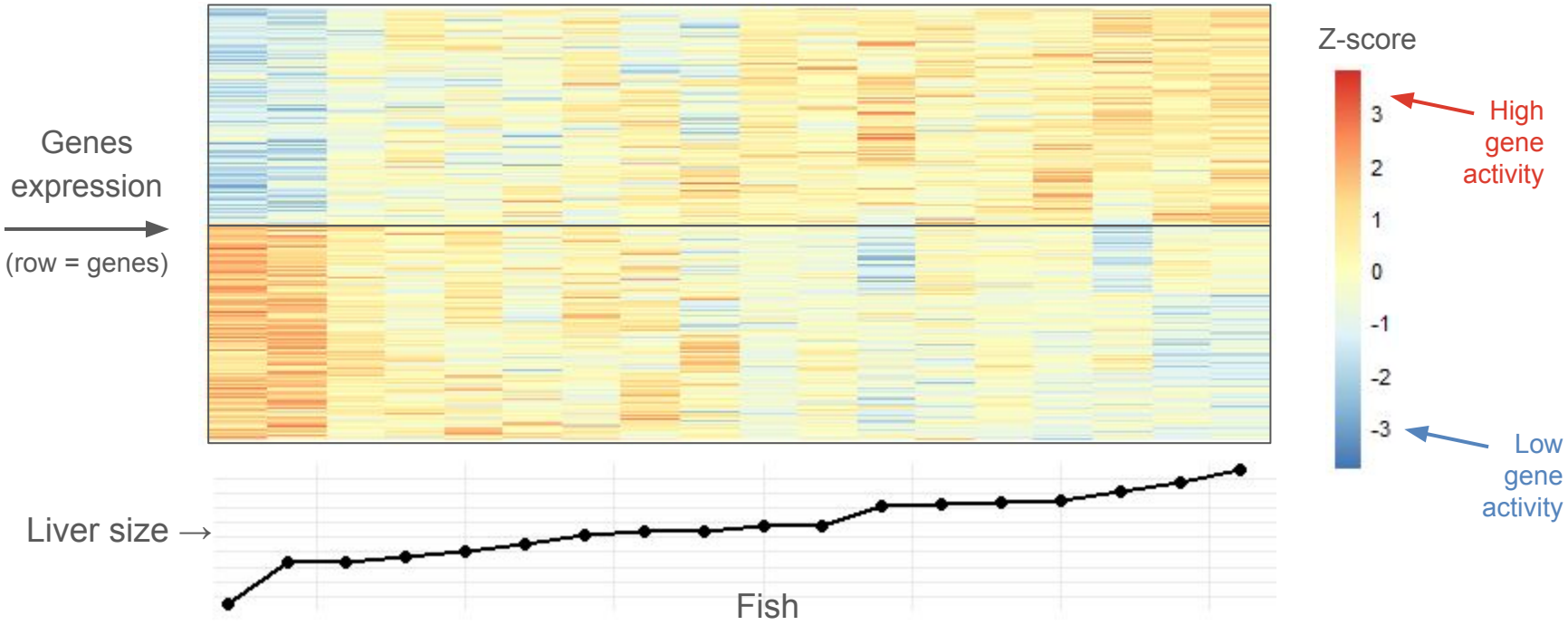
~ 1,600 genes with <u>expression</u> associated with liver size in warming



*Marker in a gene coding for a **receptor for serotonin** (5-HT4) which regulates appetite*

Liver size performance indicators in warming, both GENETICS and EXPRESSION

	Chromosome	# of markers	Gene ID	Protein Name	Function
Cell adhesion	4	3	LOC132456135	Netrin receptor UNC5D	Cell adhesion, apoptosis in response to DNA damage
Calcium transport	12	2	tmco1	Calcium load-activated calcium channel	Calcium transport, endoplasmic reticulum calcium homeostasis
	10	1	LOC132466560	TBC1 domain family member 9B	Membrane trafficking, calcium transport
Immune system	2	1	LOC132453053	Stonustoxin subunit beta	May be related immune system function. From stonefish, toxic/fatal to mammals.
	5	1	LOC132457513	Stonustoxin subunit beta	May be related immune system function. From stonefish, toxic/fatal to mammals.
	23	1	LOC132452628	NLR family CARD domain-containing protein 3	Negative regulator of the innate immune response
	23	1	LOC132452644	HERV-H LTR-associating protein 2	Enhances T-cell proliferation and cytokine production
	17	2	LOC132445594	Unknown	Unknown

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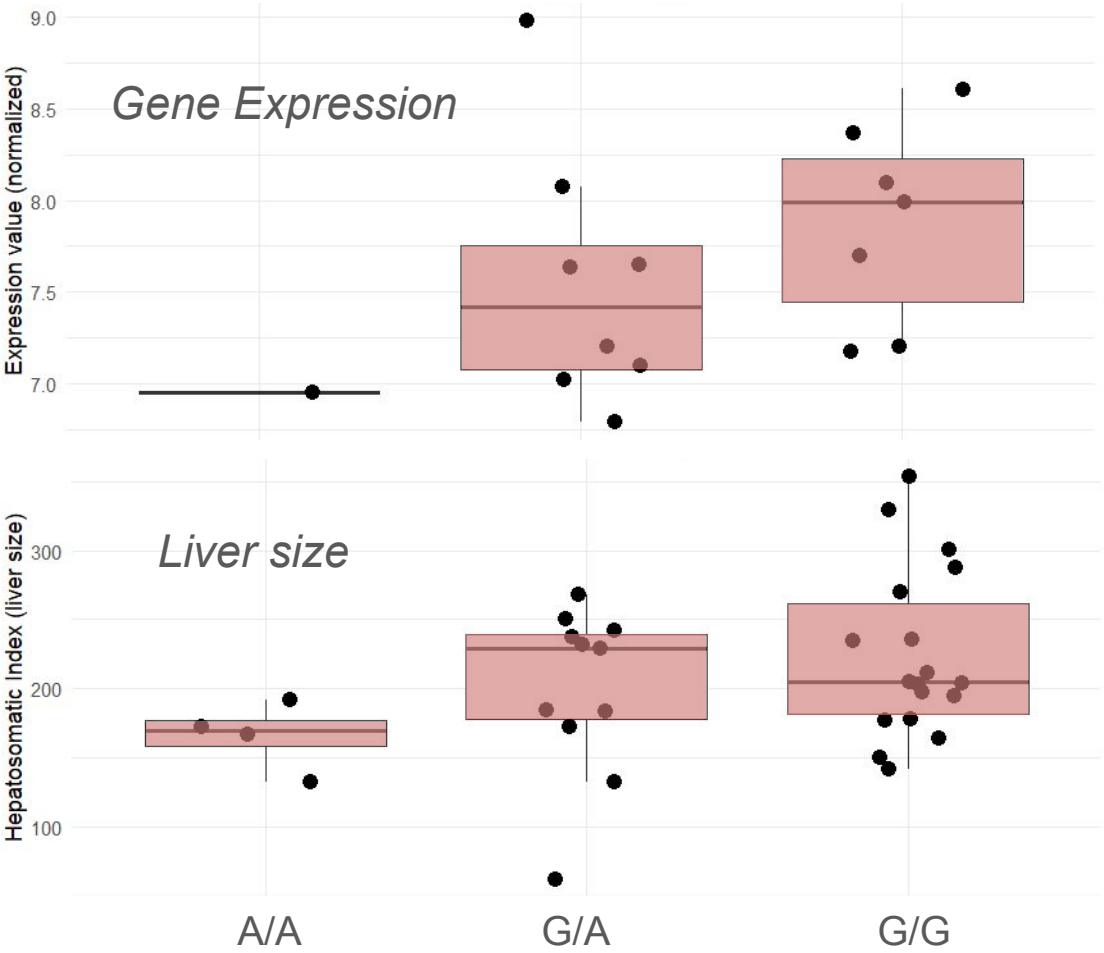
	23	1	LOC132452628	NLR family CARD domain-containing protein 3	Negative regulator of the innate immune response
	23	1	LOC132452644	HERV-H LTR-associating protein 2	Enhances T-cell proliferation and cytokine production
	17	2	LOC132445594	Unknown	Unknown



NLR family CARD domain-containing protein 3

Negatively regulates immune system

“Genome-to-Phenome” dataset for juvenile Pacific cod

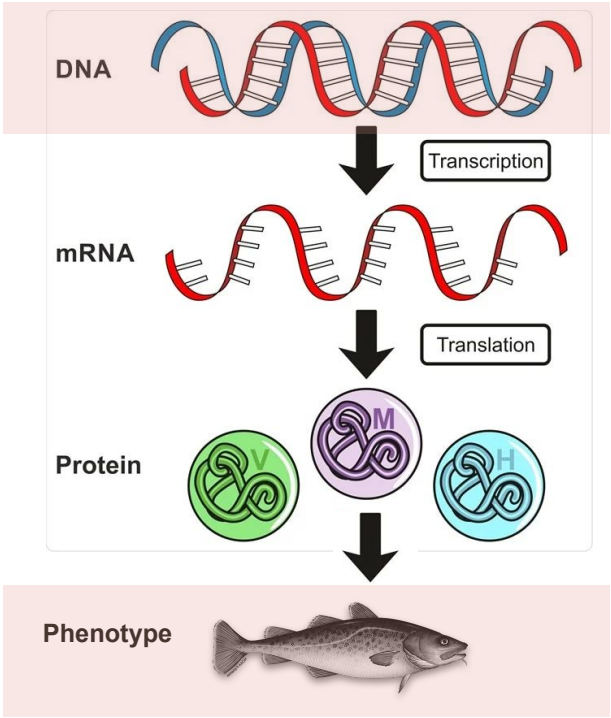
- ✓ Genetics – **they are one population**

  western Gulf of Alaska / Eastern Bering Sea

- ✓ Phenotypes – **Fewer lipid reserves in warming, slightly slower growth**

- ✓ Gene expression – **Lipid usage, immune activity, & damage control may deplete energy reserves**

- ✓ Markers of juvenile performance in warming
  - ✓ **~100 genetic markers**
  - ✓ **~1,600 gene expression indicators**



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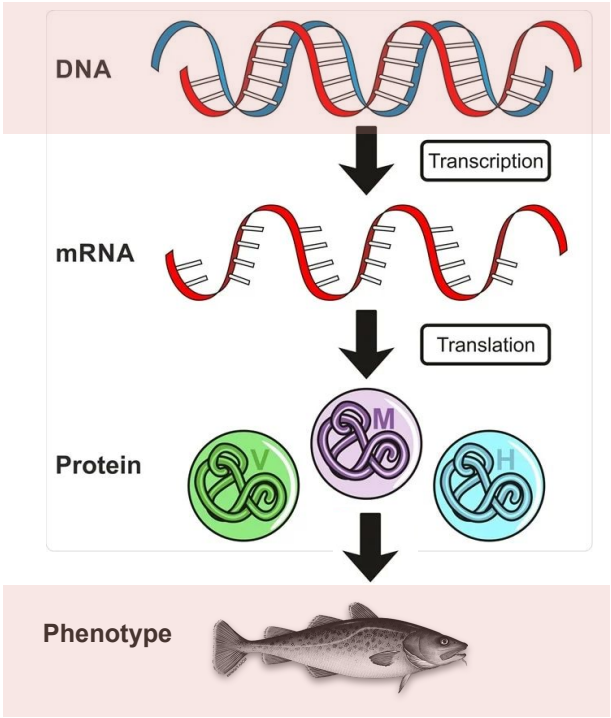
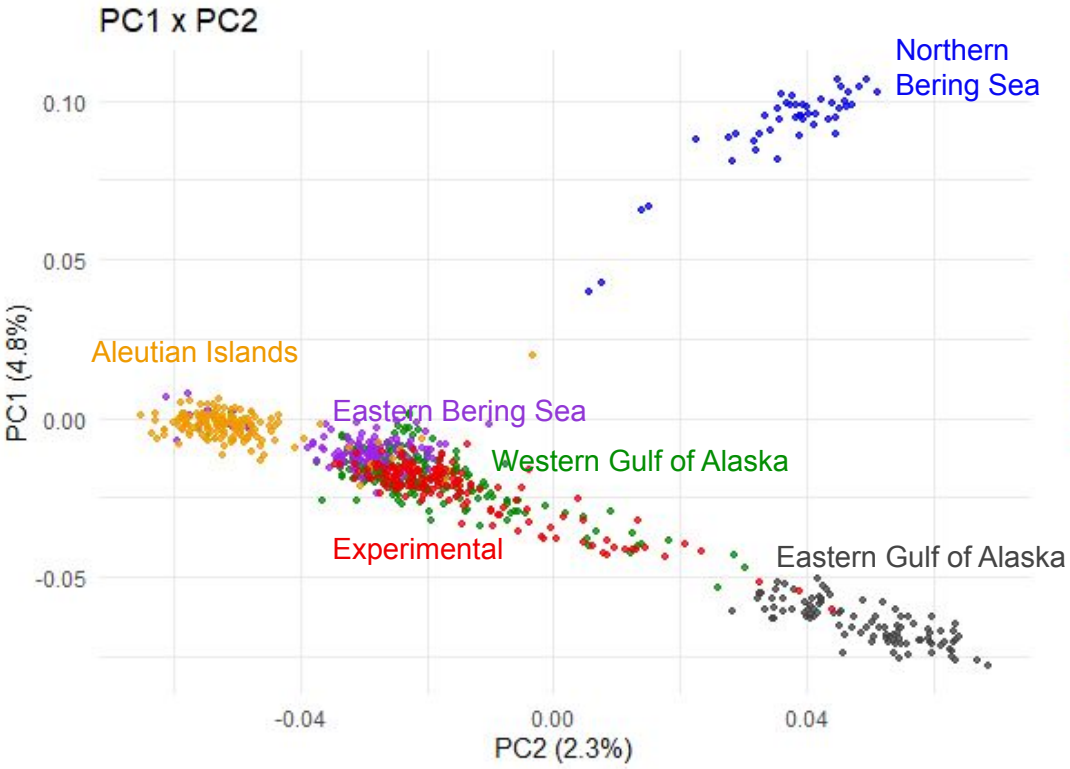
- ✓ Markers of juvenile performance in warming
  - ✓ **~100 genetic markers**
  - ✓ **~1,600 gene expression indicators**

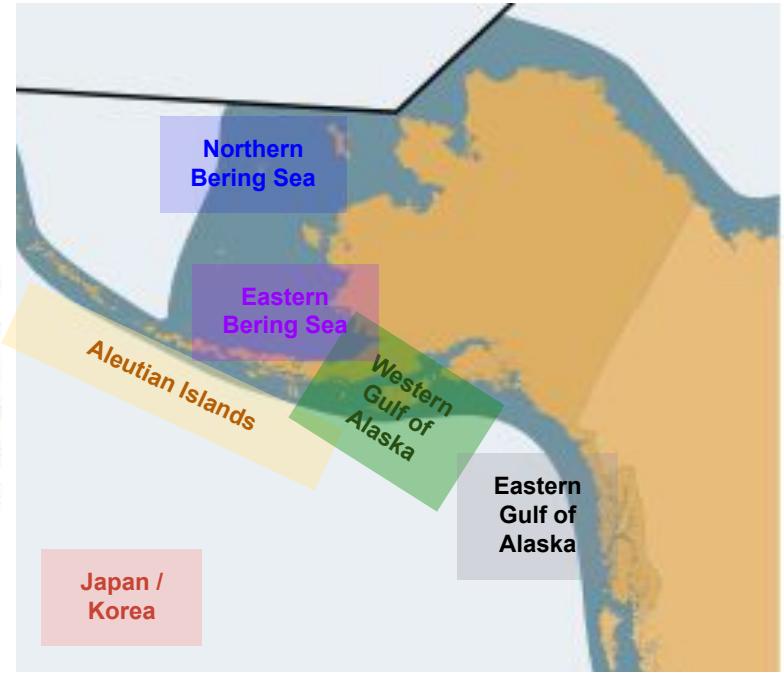
- Can we predict “performance” or “resilience” of other cod groups using our markers?



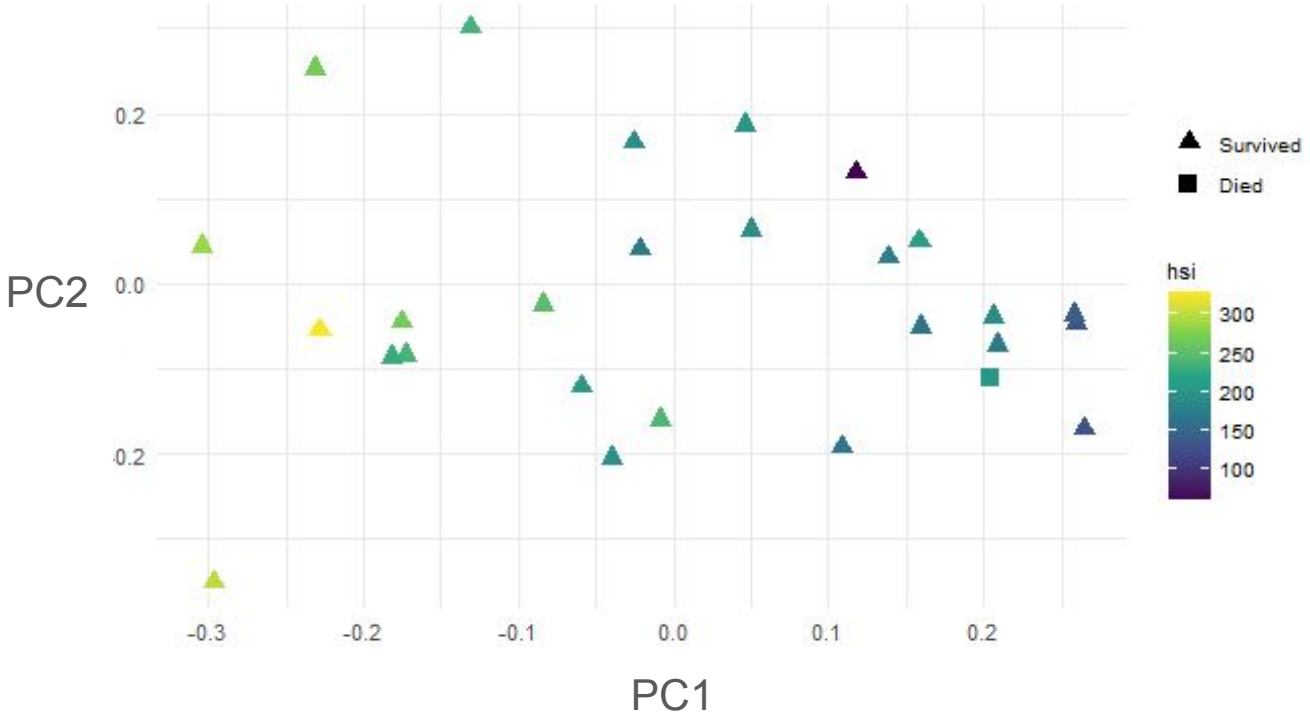
Adapted from: udaix/Shutterstock.com

Which populations would we predict to have largest livers in warm conditions?



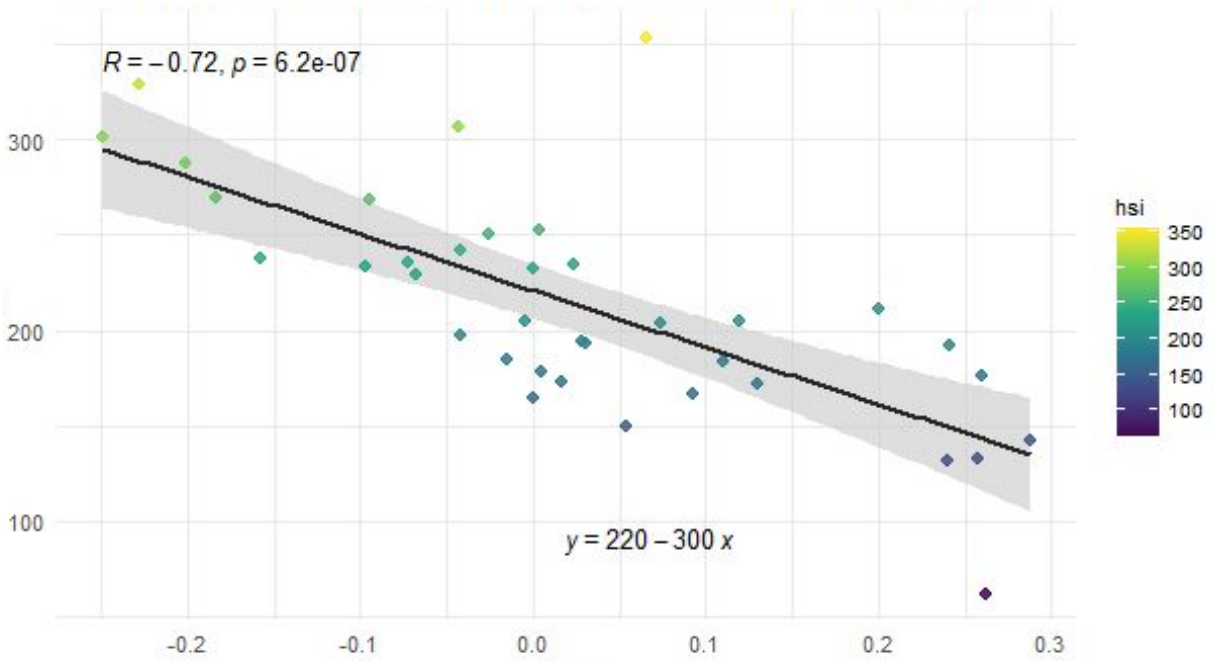


Analyses so far - use genotypes at **32 markers to predict liver size** with PC scores



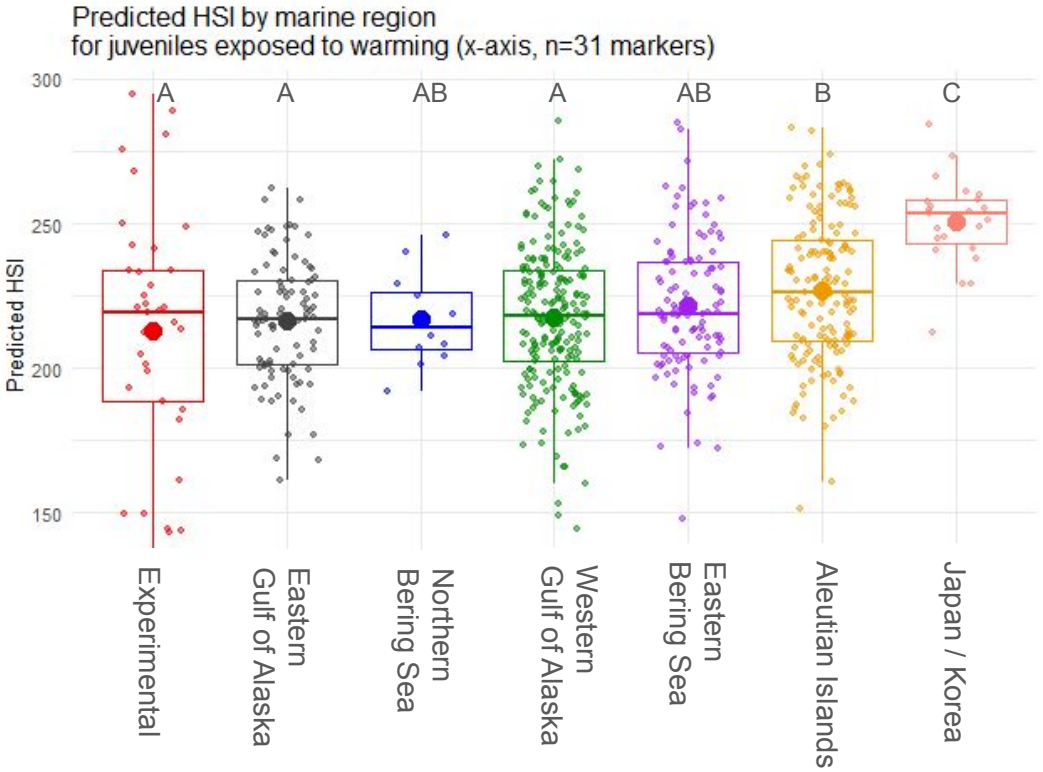
Analyses so far - use genotypes at **32 markers to predict liver size** with PC scores

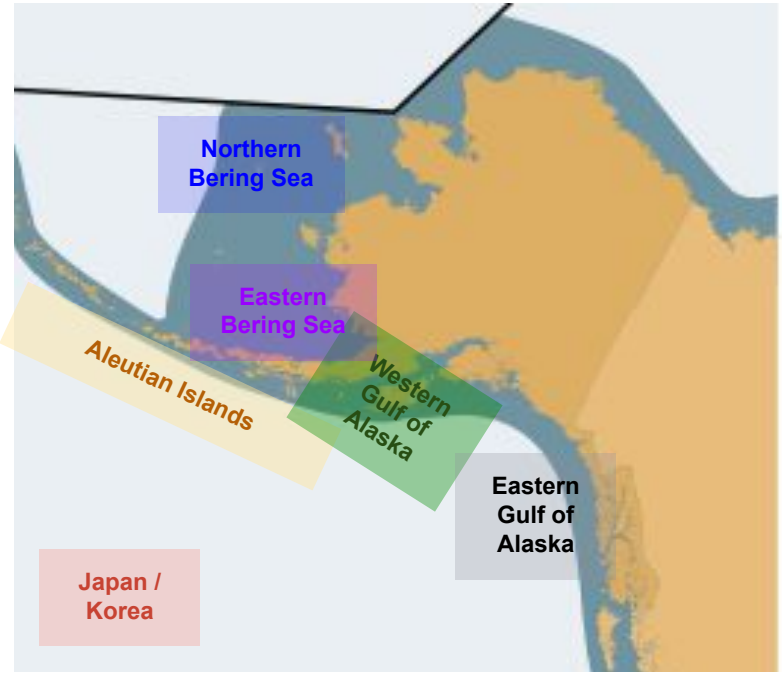
Liver size,
fish exposed to
warming



PC scores (summed)
55% total variation

Which populations would we predict to have largest livers in warm conditions?





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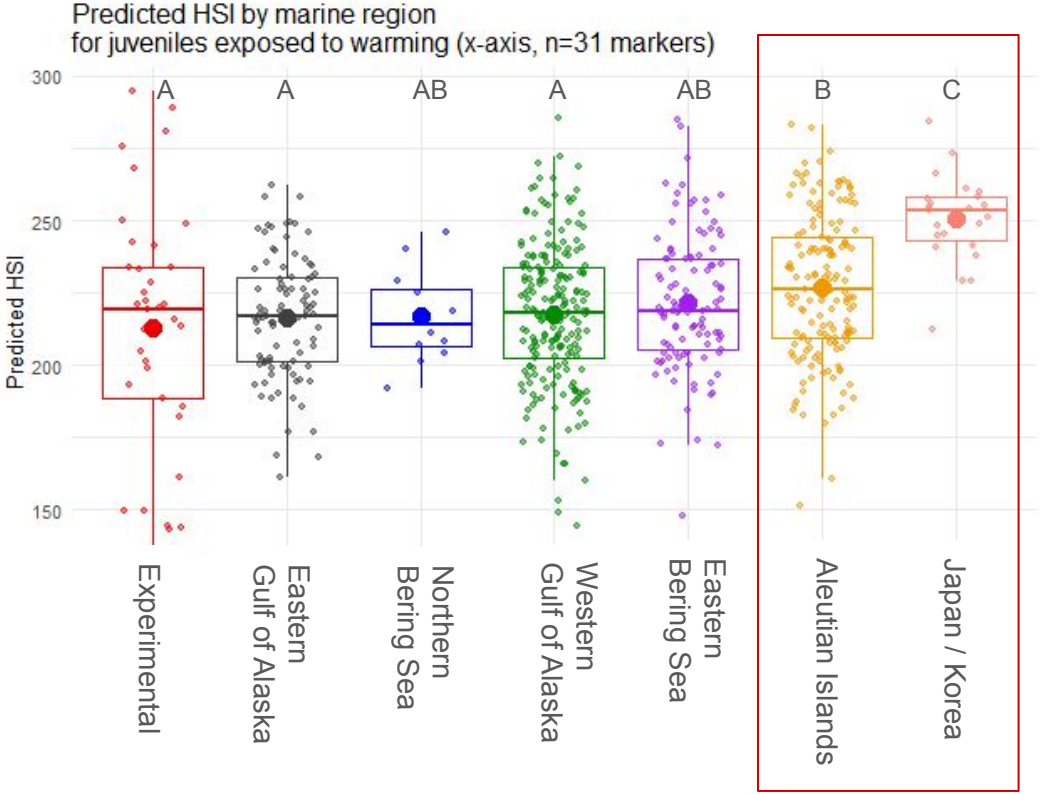

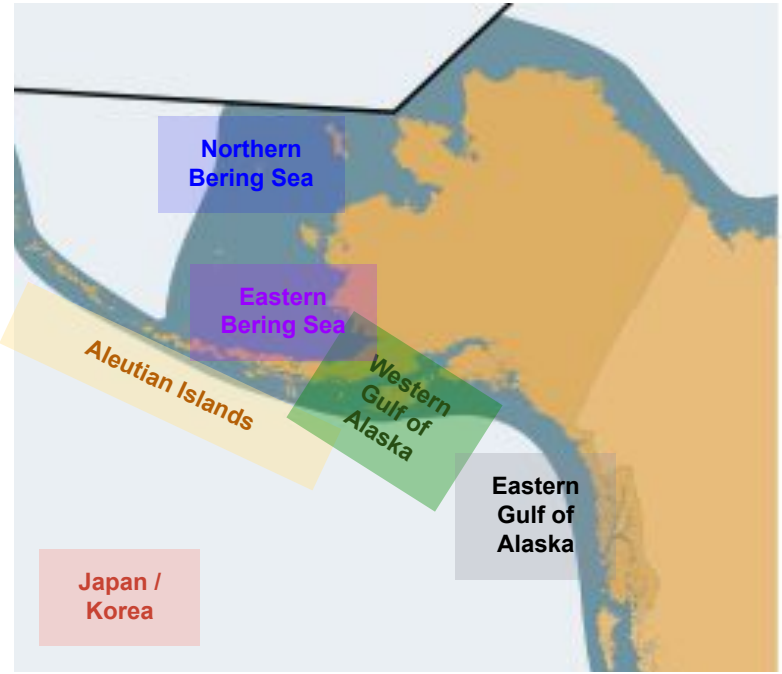

Broad Conclusions (preliminary)

- **Low juvenile recruitment in GoA during heatwaves** is likely related to low overwintering survival due to **fewer lipid reserves.**

- Stock assessments may need to **adjust mortality/recruitment rates** in heat wave years
  - Larval study (Slesinger et al. 2024; Spencer et al. *in revision) - <u>much</u> higher mortality*

- **Genetic variability related to adaptive traits** may enable selection for individuals **more capable of allocating lipid reserves**

- Other Pacific cod groups could be screened for **putative markers of performance**
  - Through time – before/during/after heat waves (future project!) - is selection happening?
  - Distinct Pacific cod groups – are some groups more resilient than others?

- Building Resources for Pacific cod – lists of genes that are temperature sensitive in larvae, juveniles, indicators of performance, etc.

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Questions?