Climate Change and Aquaculture: Pacific Workshop

Warming Waters

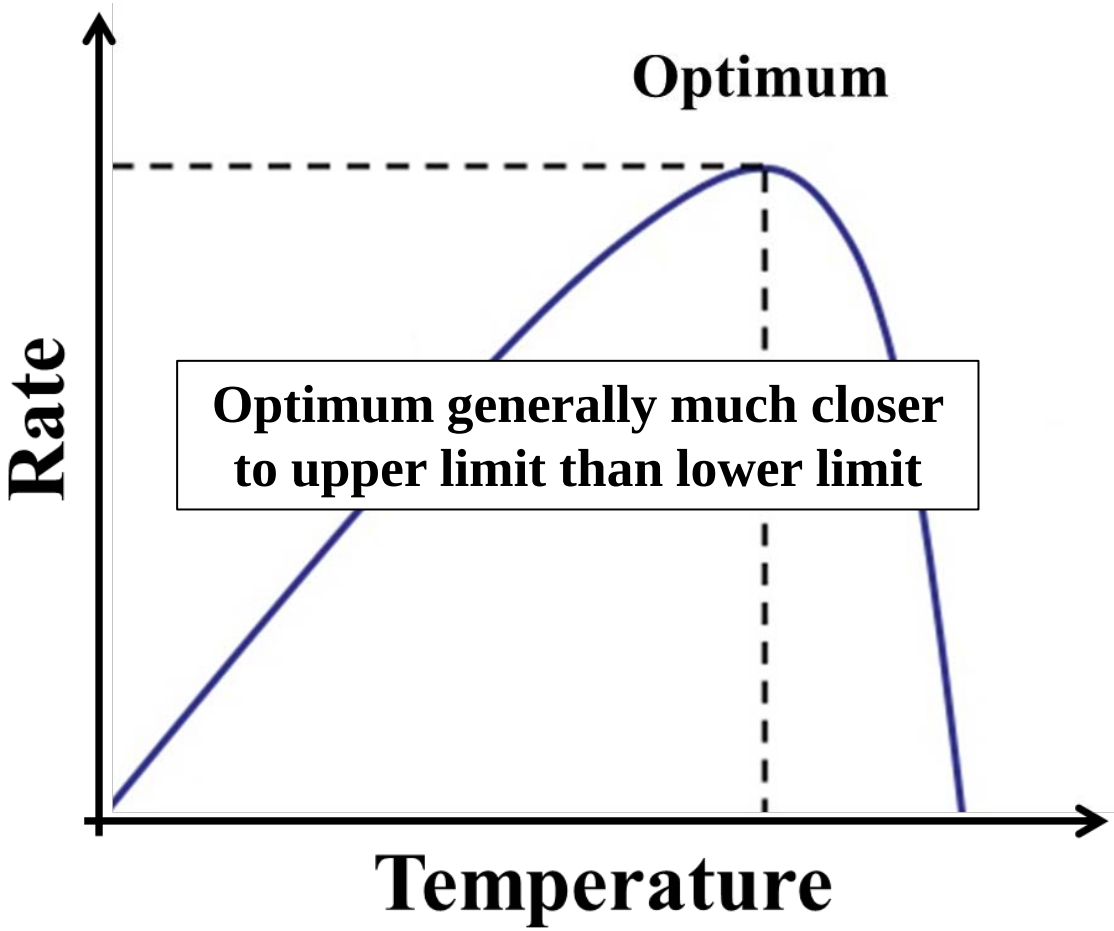
Tillmann Benfey

Outline

- **Effects of increased temperature on …**
  - **Biochemistry and physiology**
  - **Feeds and foods**
  - **Pathogens, parasites and pests**
- **Mitigation**
  - **Site selection & engineering**
  - **Nutrition**
  - **Disease management**
  - **Breeding**

Biochemistry and Physiology

↑ Temperature = ↑ Rate of Reaction



<u>Wide-ranging effects</u>

- **Enzyme reactions**
- **Metabolism**
- **Oxygen demand**
- **Cell division**
- **Development**
- **Growth**
- **Reproduction**
- **Feed consumption**
- **Etc.**

Biochemistry and Physiology

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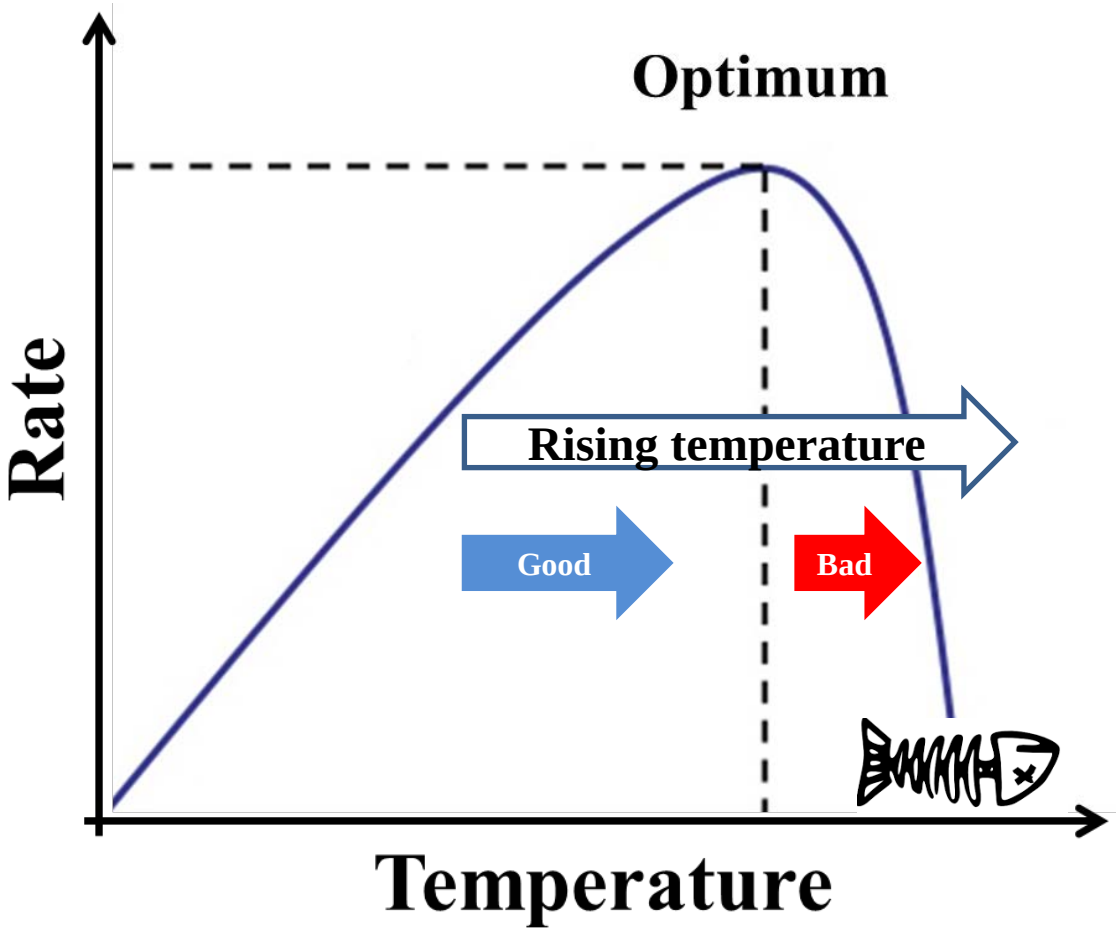

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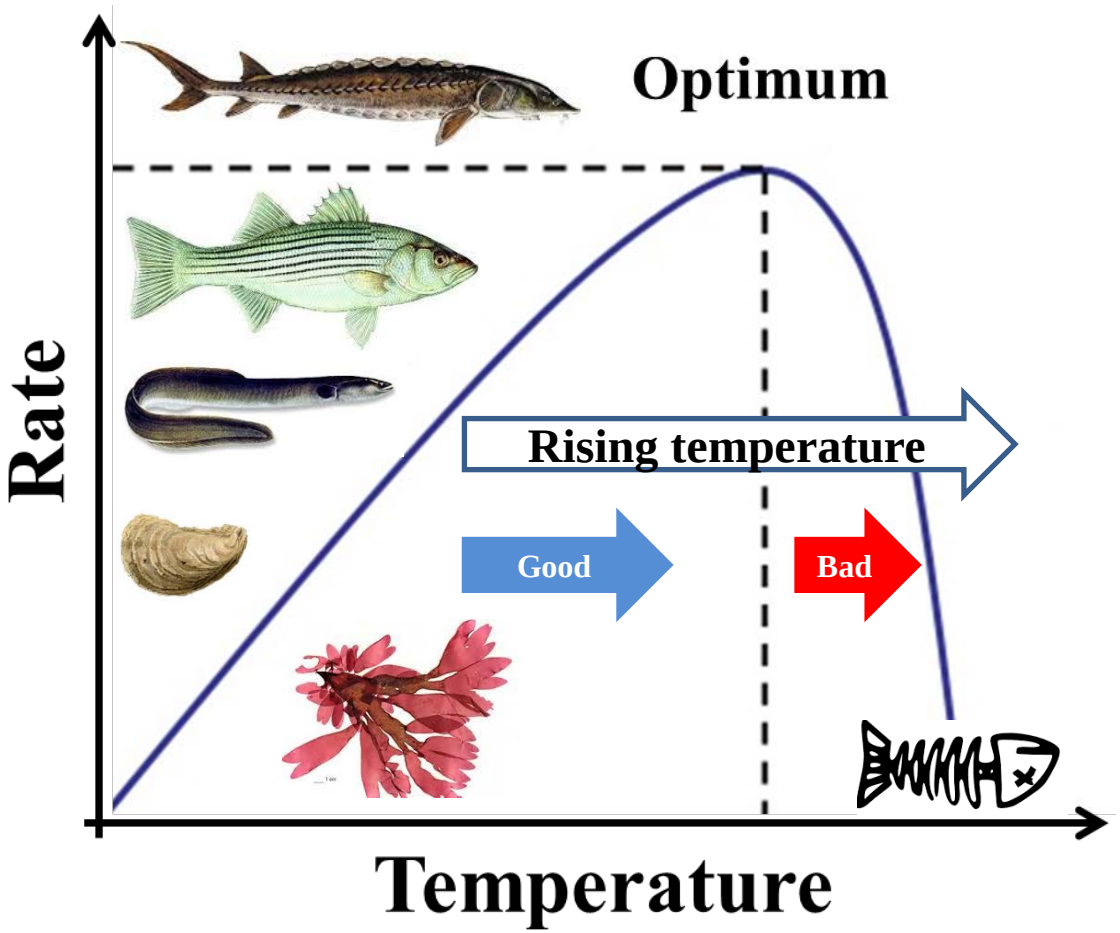

<u>Examples</u>: sturgeon, striped bass, eels, oysters, dulse

Biochemistry and Physiology

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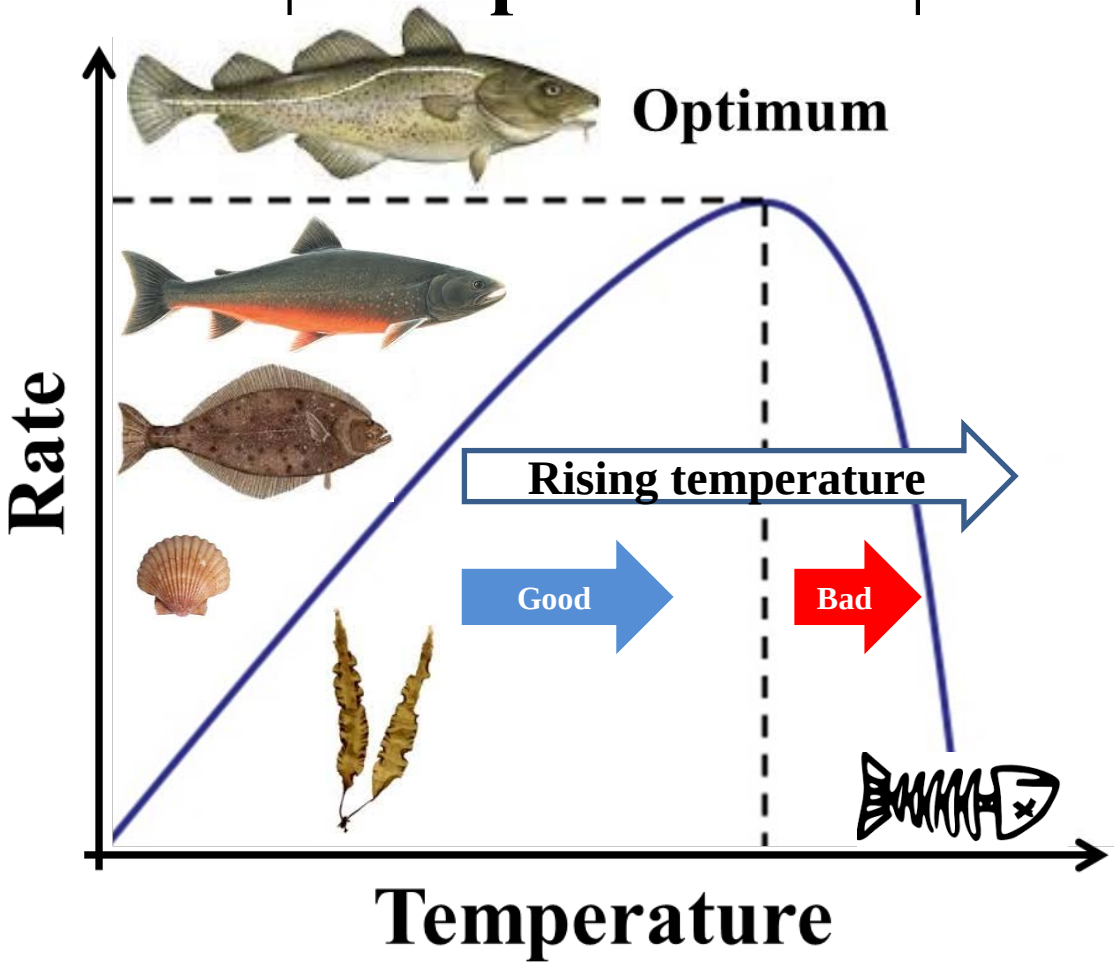
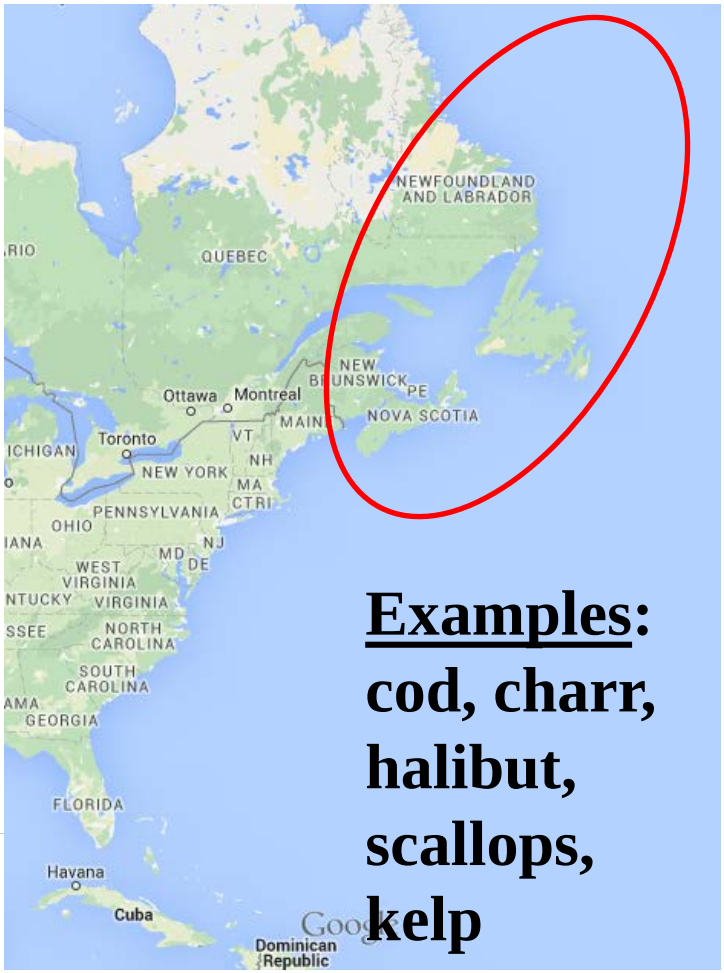
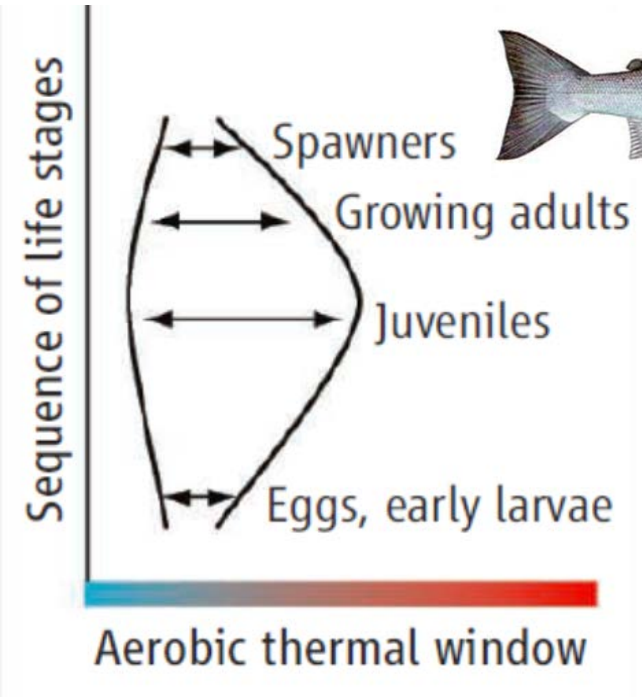




<u>Examples</u>: cod, charr, halibut, scallops, kelp

Optimum is a Moving Target

Developmental Stage and Biological Process



Pörtner & Farrell, 2008. Physiology and climate change. Science 322: 690-692.

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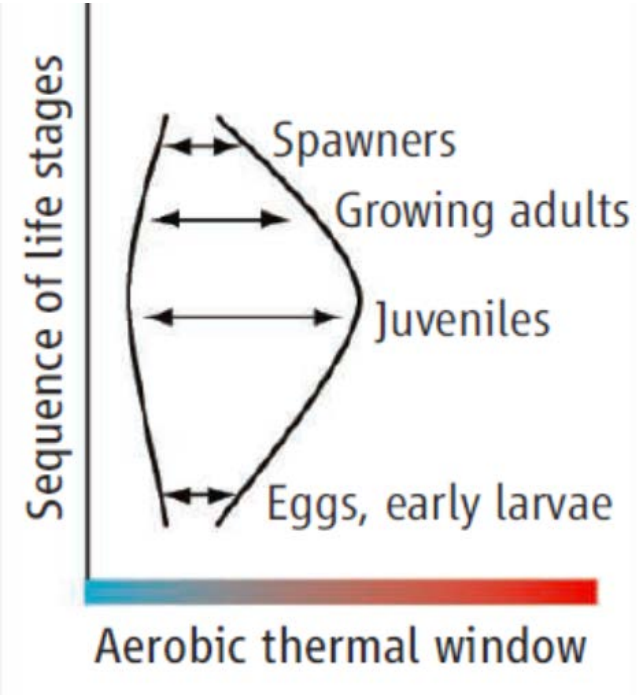
Developmental Stage and Biological Process



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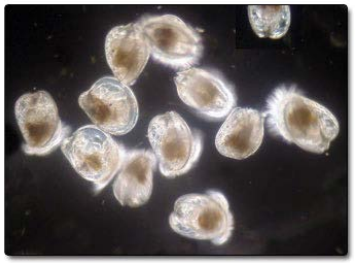
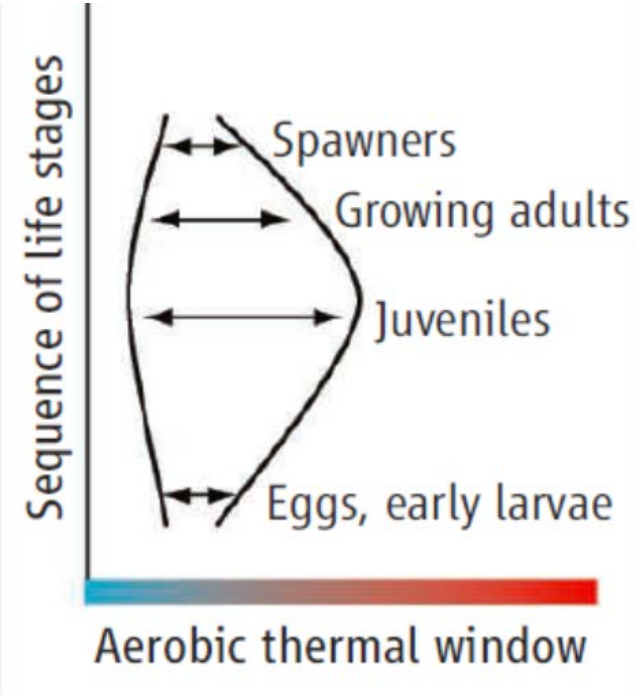
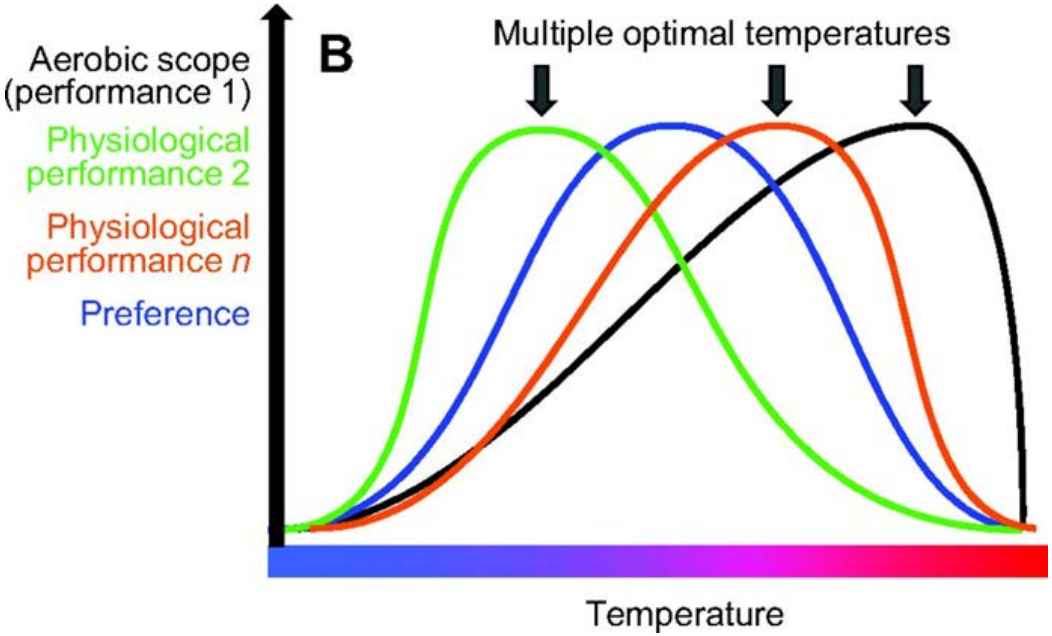


Optimum is a Moving Target

Developmental Stage and Biological Process



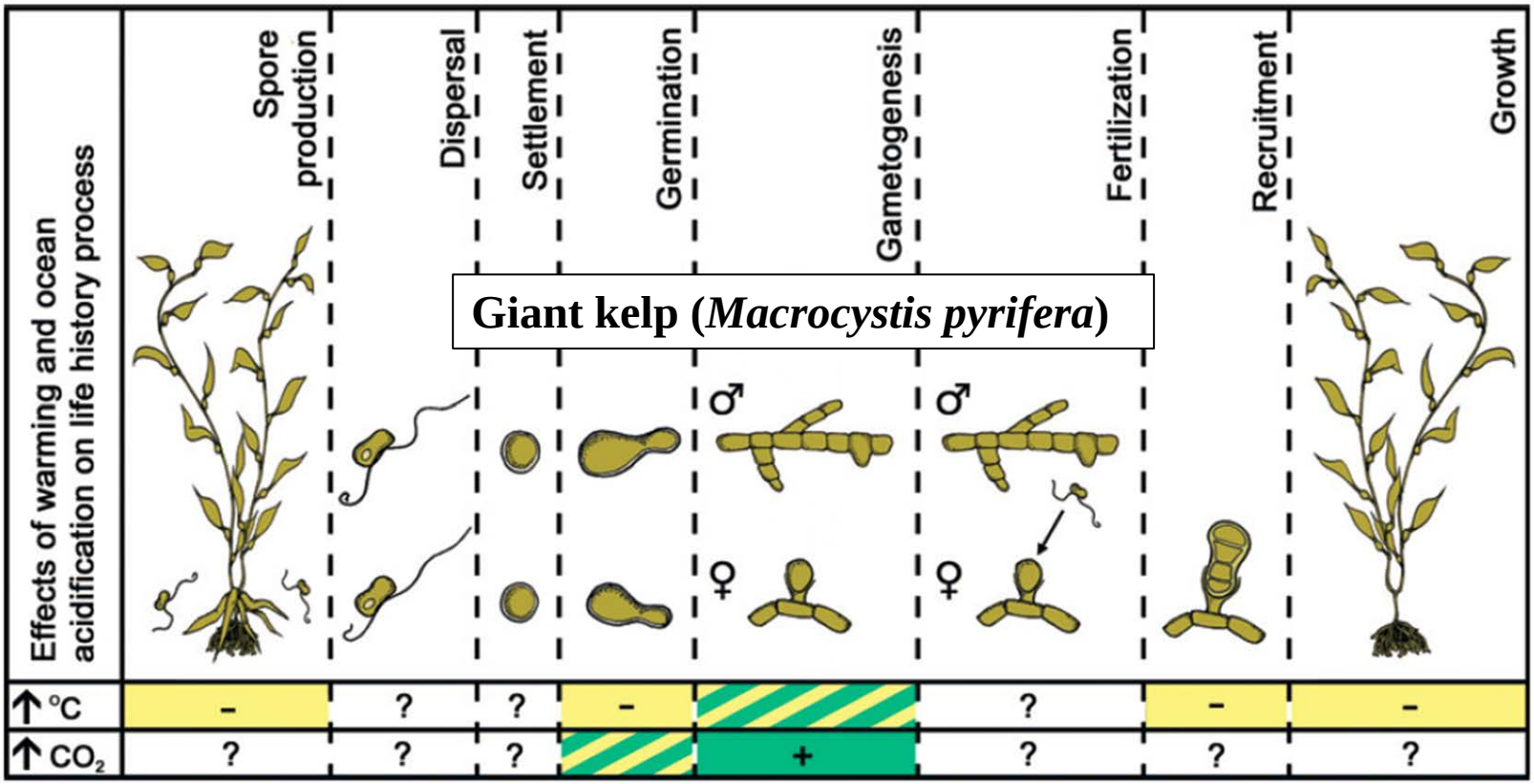


Pörtner & Farrell, 2008. Physiology and climate change. Science 322: 690-692.

Clark et al., 2013. Aerobic scope measurements of fishes in an era of climate change: respirometry, relevance and recommendations. J. Exp. Biol. 216: 2771-2782.

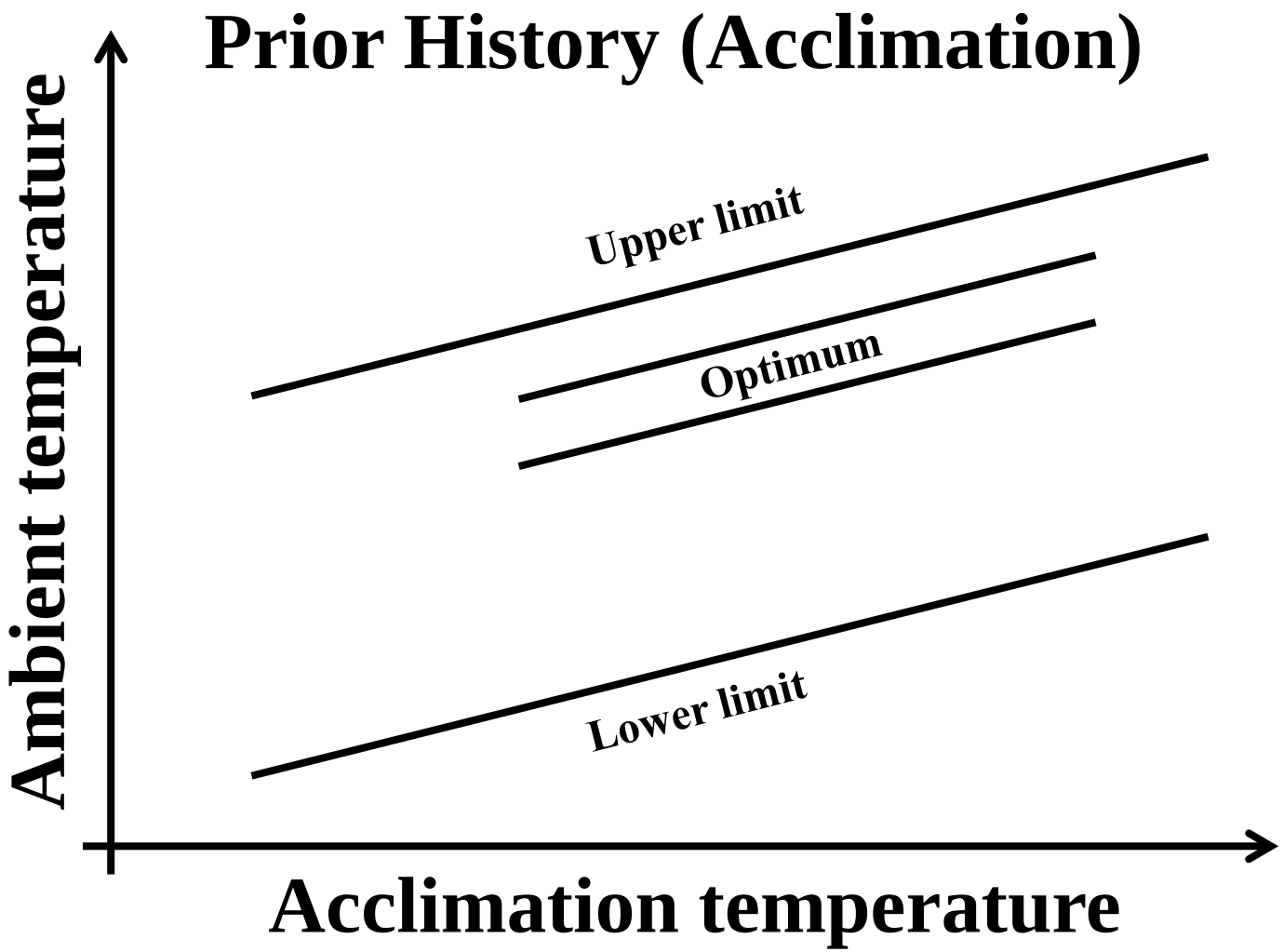
Optimum is a Moving Target

Developmental Stage and Biological Process



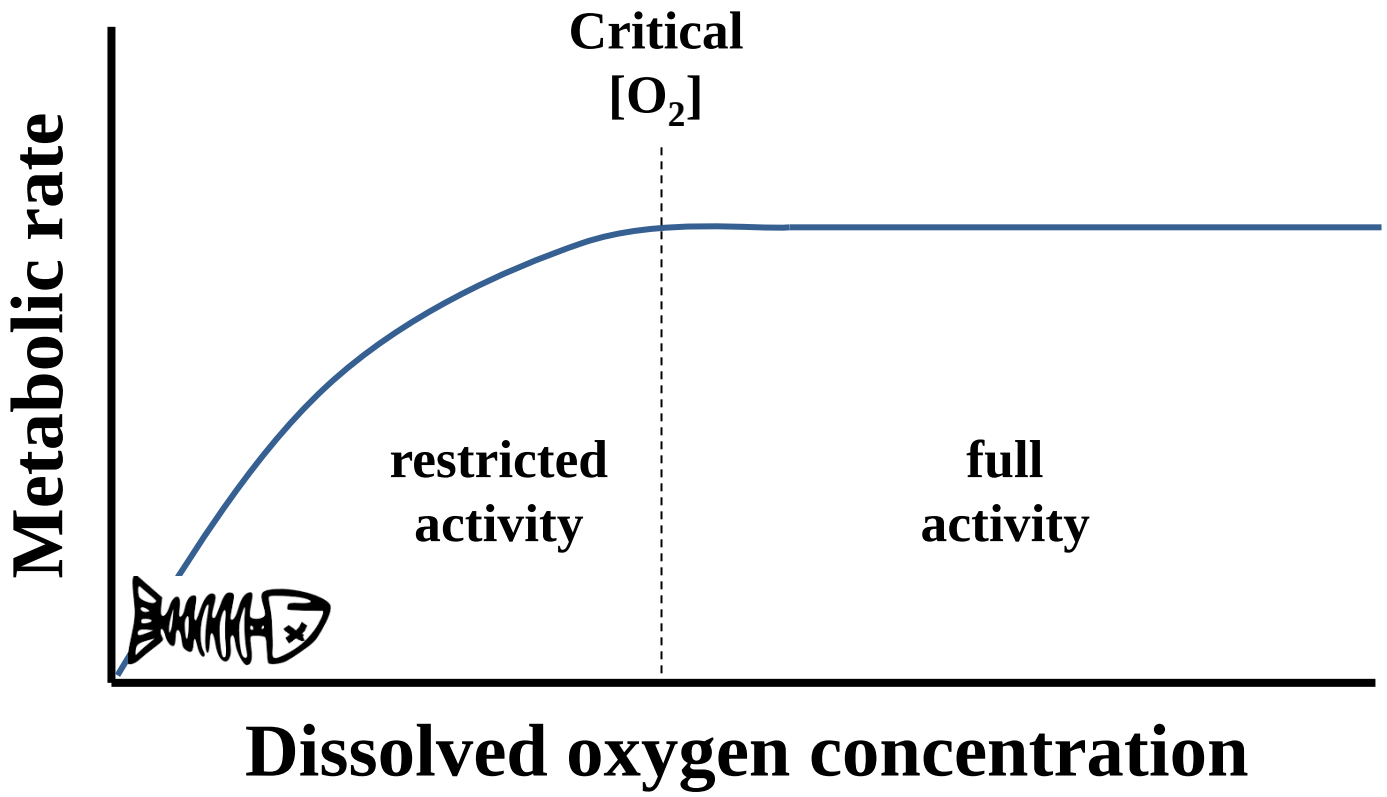
Harley et al., 2012. Effects of climate change on global seaweed communities. J. Phycol. 48: 1064-1078.

Optimum is a Moving Target



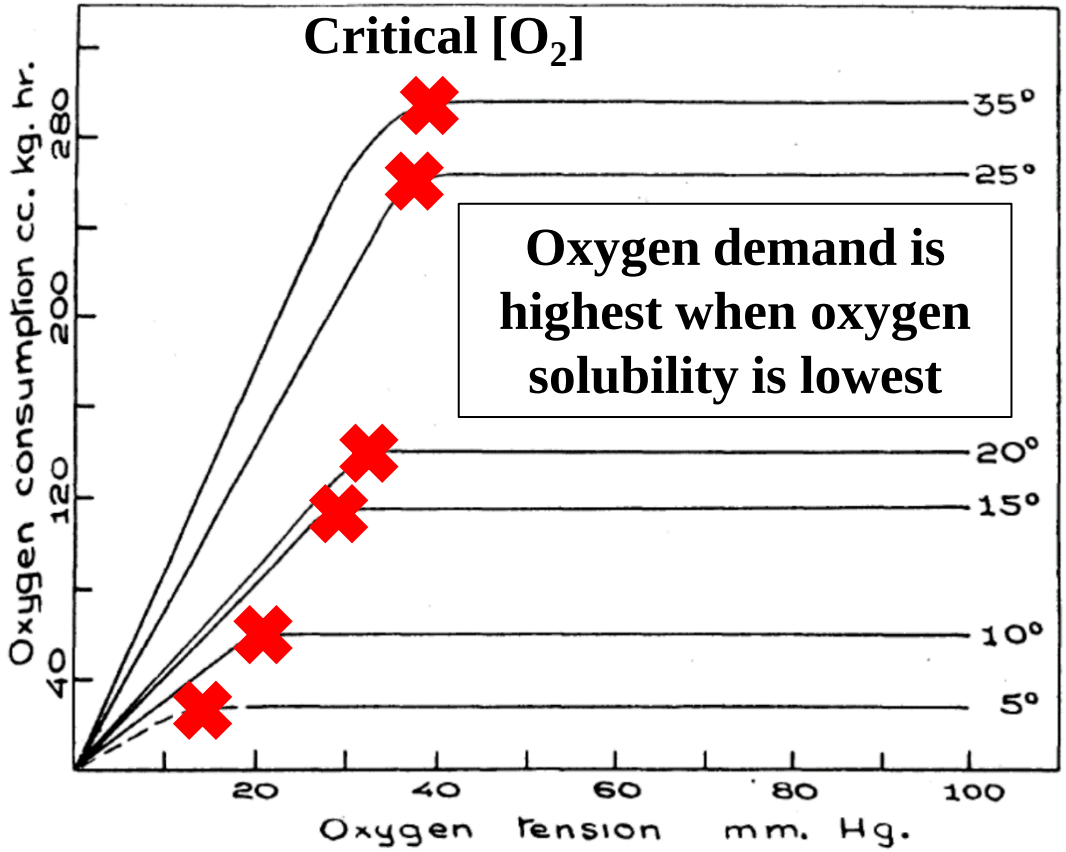
Biochemistry and Physiology

↑ Temperature = ↓ Gas Solubility (including O_2)



Optimum is a Moving Target

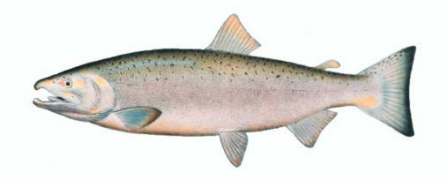
Prior History (Acclimation)

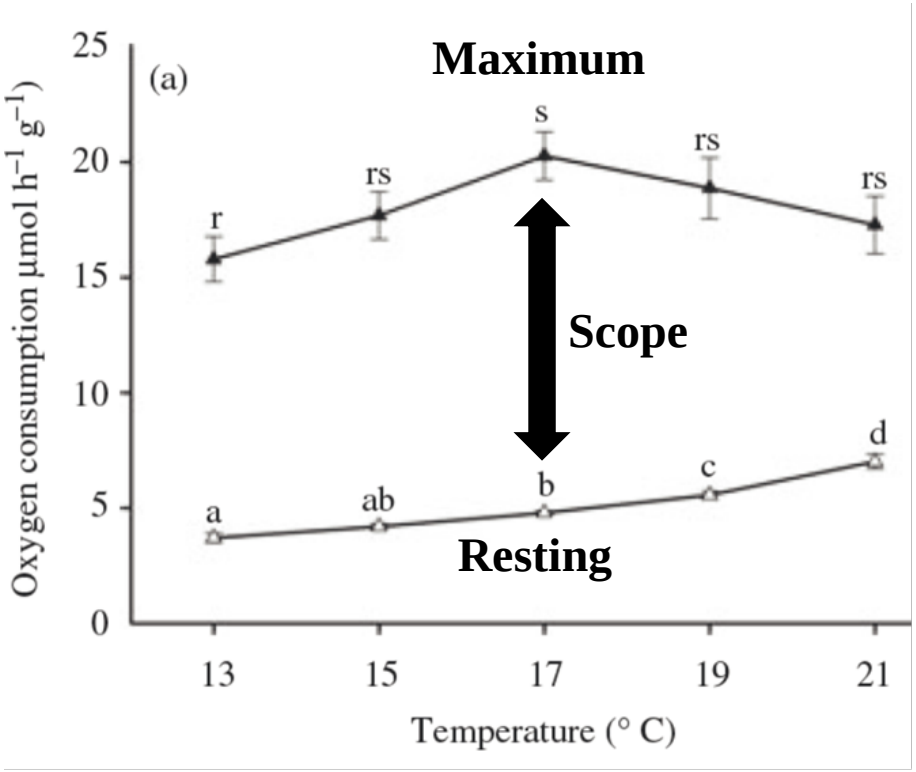


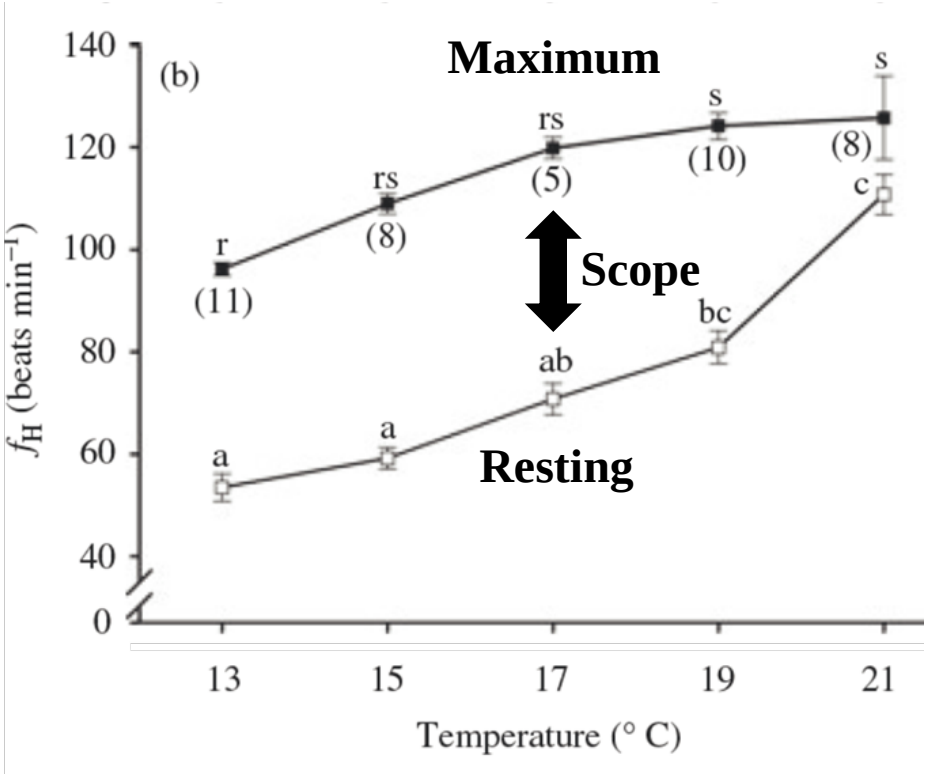
Fry & Hart, 1948. The relation of temperature to oxygen consumption in the goldfish. Biol. Bull. 94: 66-77.

Determining Optimum Temperature

Aerobic / Cardiac Scope



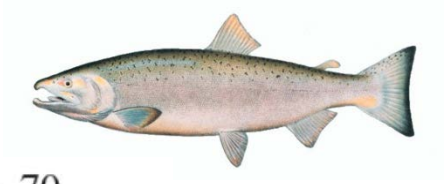


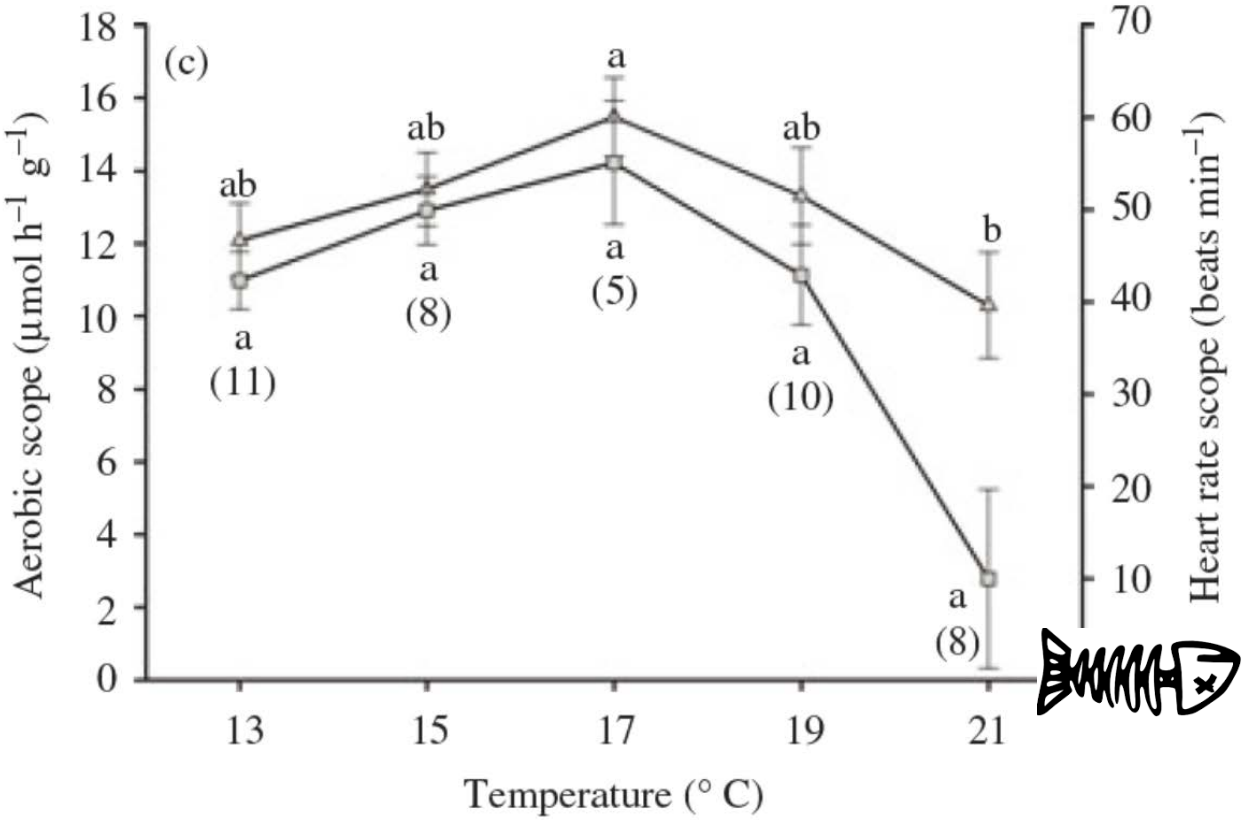


Casselman et al., 2012. Using maximum heart rate as a rapid screening tool to determine optimum temperature for aerobic scope in Pacific salmon *Oncorhynchus* spp. J. Fish Biol. 80: 358-377.

Determining Optimum Temperature

Aerobic / Cardiac Scope





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Determining Optimum Temperature

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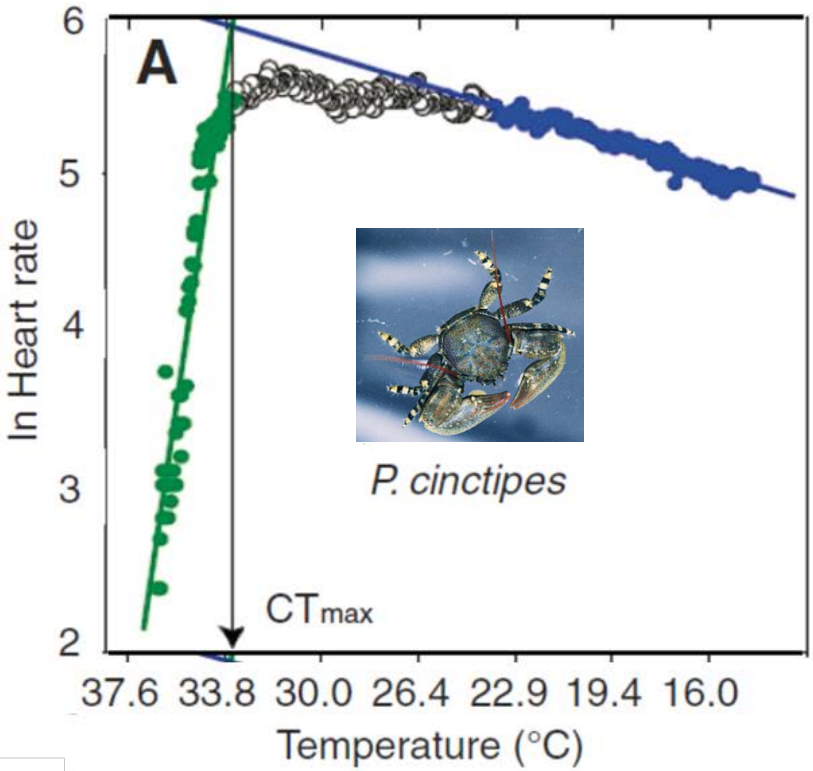
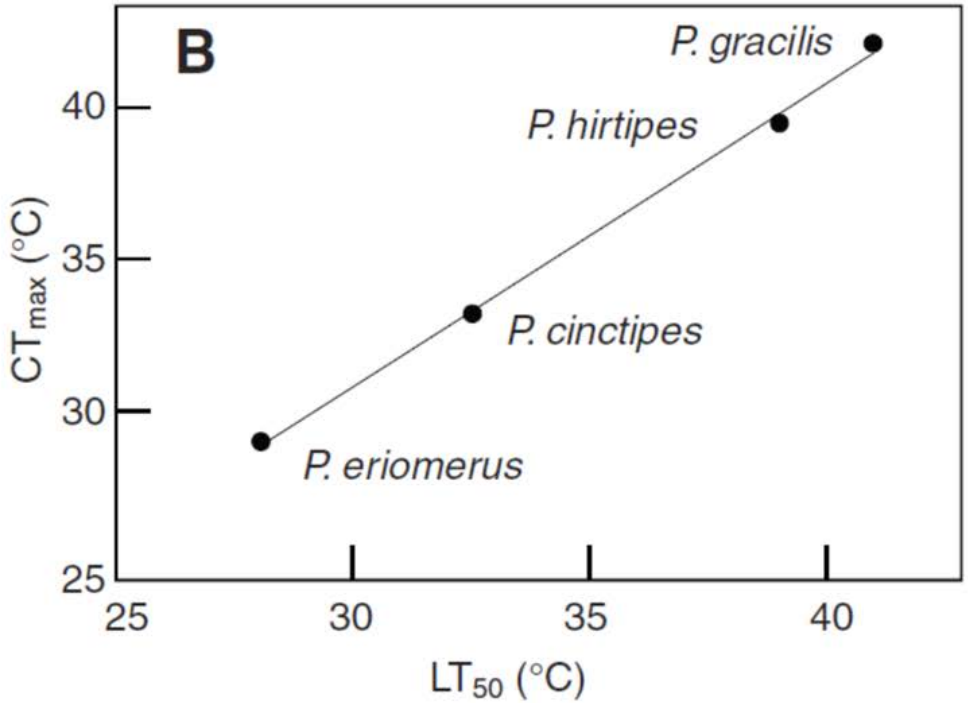




Somero, 2010. The physiology of climate change: how potentials for acclimatization and genetic adaptation will determine 'winners' and 'losers'. J. Exp. Biol. 213: 912-920.

Ask the Questions …

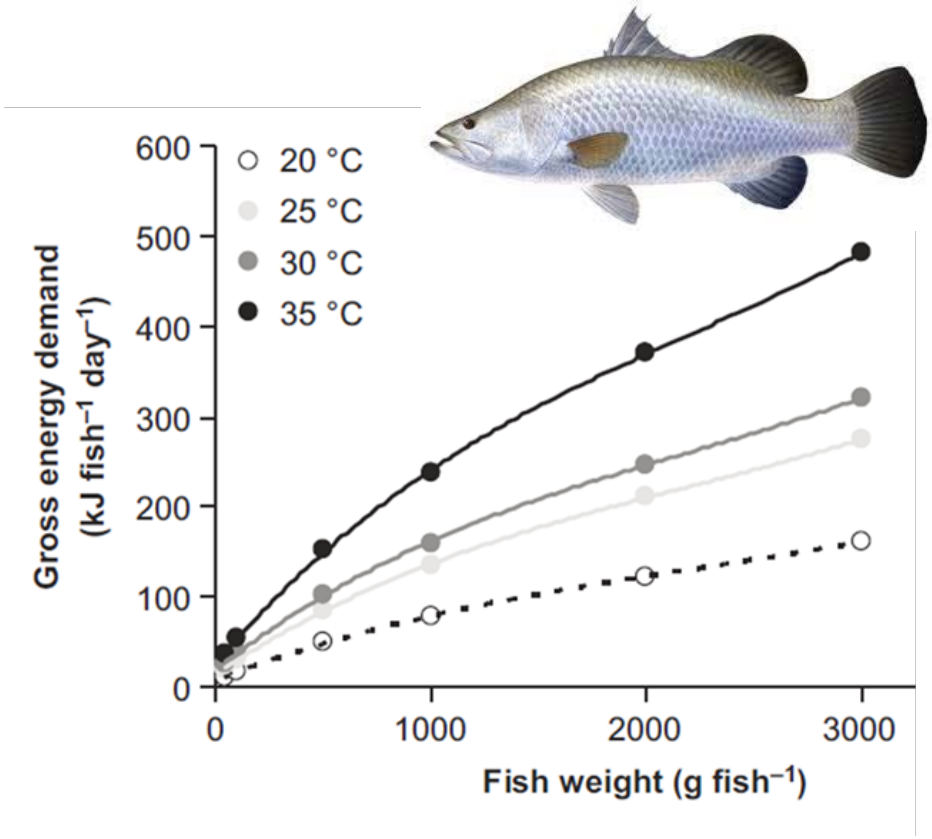
- **How close to the optimum for *Species X* do the highest temperatures currently get, or do they already exceed it?**
- **How much physiological buffer (aerobic scope) does *Species X* have at the current highest temperatures?**
- **What do the predictions say for maximum temperature increase (and duration) during high temperature events?**

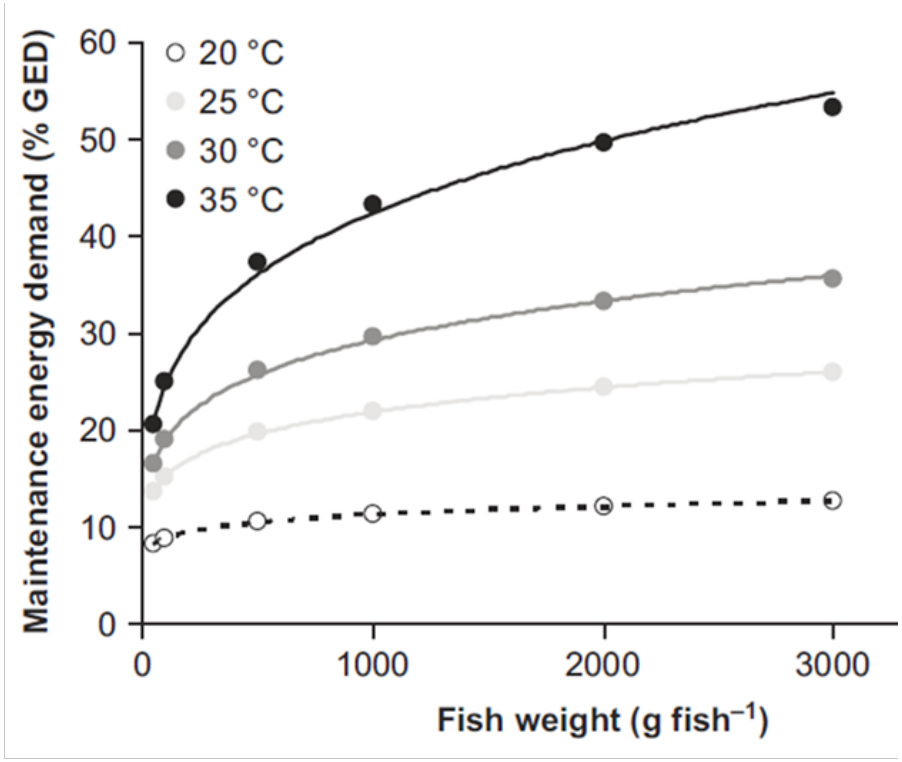
Feeds & Foods

- **Changes in feed intake and utilization**
  - **Energy allocation**
  - **Fatty acid profiles**
  - **Appetite**

- **Changes in phyto-plankton species distribution and abundance**

Feeds & Foods



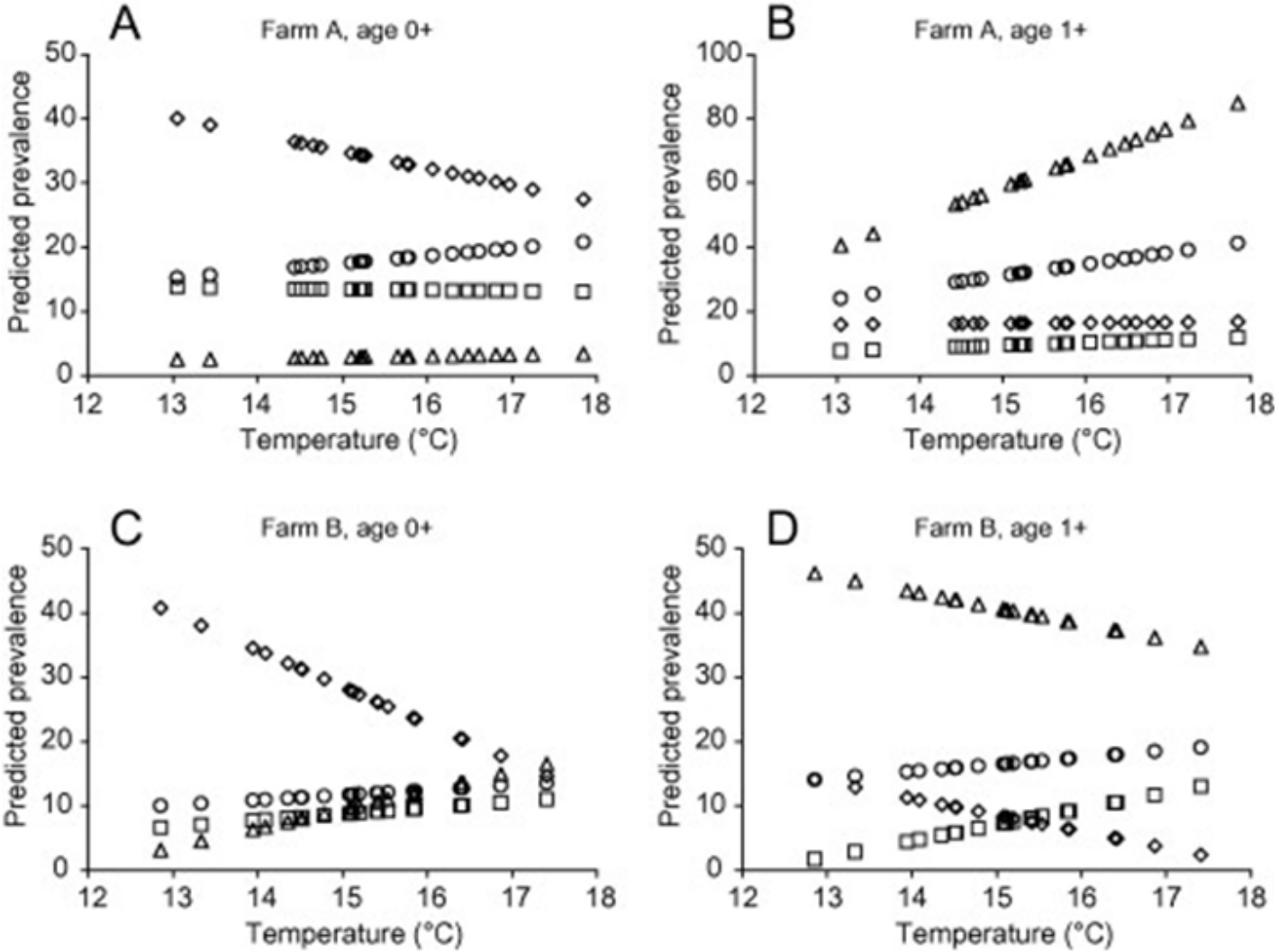


Glencross and Bermudes, 2012. Adapting bioenergetic factorial modelling to understand the implications of heat stress on barramundi (*Lates calcarifer*) growth, feed utilisation and optimal protein and energy requirements - potential strategies for dealing with climate change? Aquacult. Nutr. 18: 411-422.

Ask the Questions …

- **How does temperature affect the nutritional and energy requirements for *Species X*?**
- **How does temperature affect the feed requirements (or food availability) for *Species X*?**
- **Can business support the increased cost (fed species)? Can environment support the increased requirement (extractive species)?**

Pathogens, Parasites and Pests

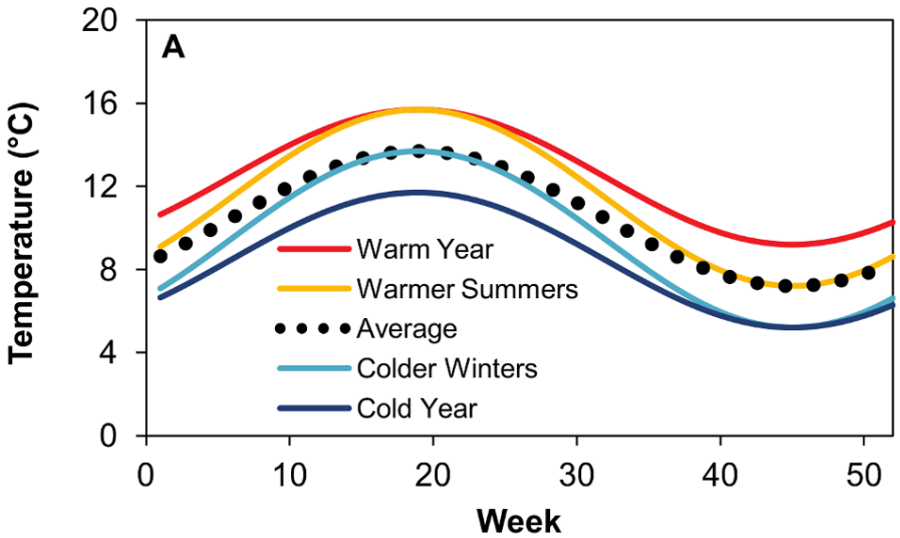


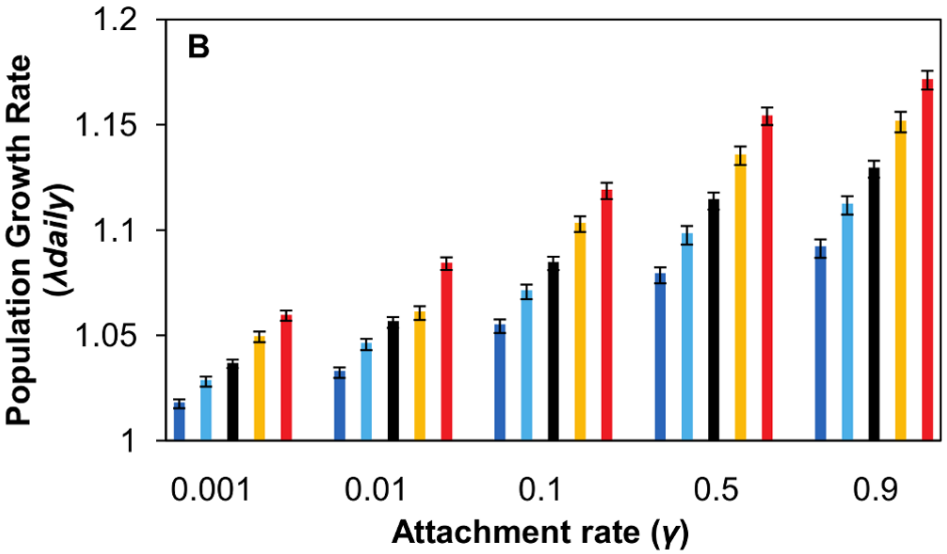
Atlantic salmon (Finland)

◊ ***Ichthyobodo necator***
□ ***Chilodonella spp.***
Δ ***Ichthyophthirius multifiliis***
○ ***Flavobacterium columnare***

Karvonen et al., 2010. Increasing water temperature and disease risks in aquatic systems: Climate change increases the risk of some, but not all, diseases. Int. J. Parasitol. 40: 1483-1488.

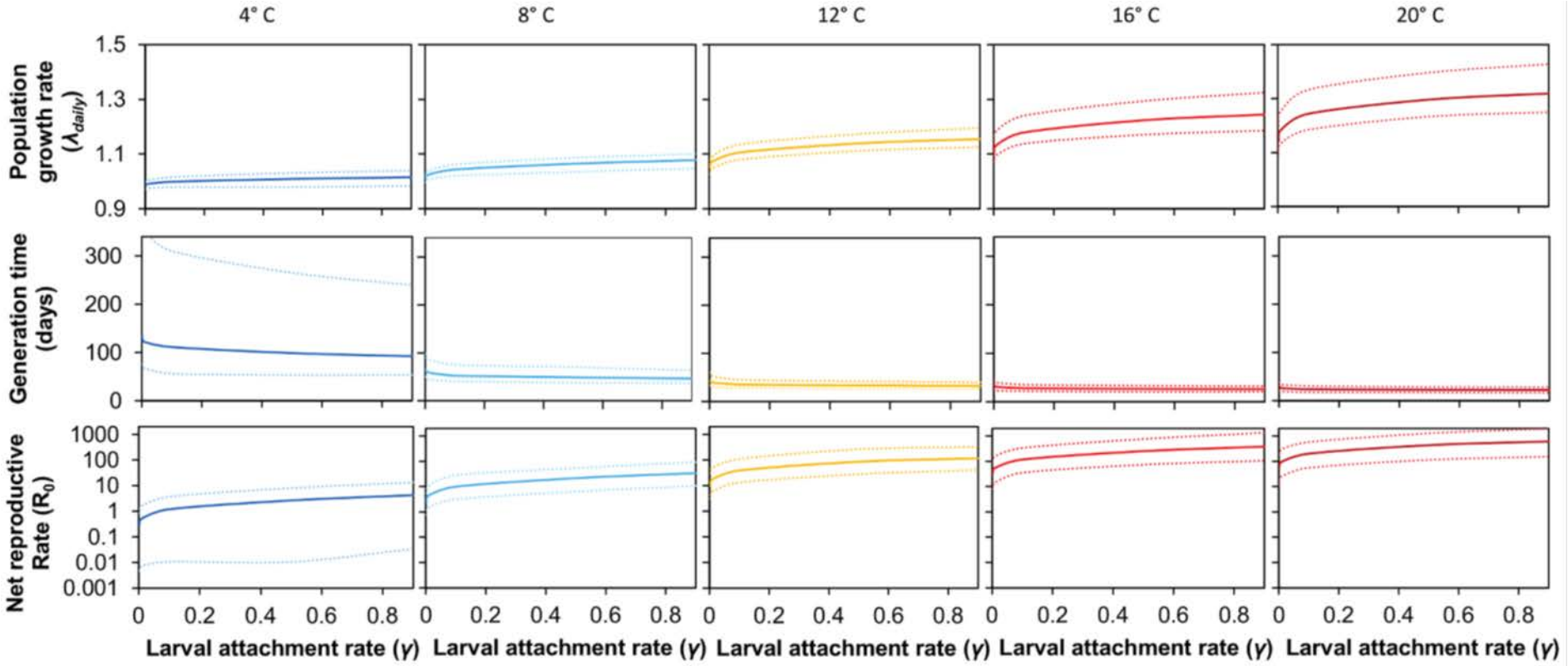
Pathogens, Parasites and Pests





Groner et al., 2014. Modelling the impact of temperature-induced life history plasticity and mate limitation on the epidemic potential of a marine ectoparasite. PLoS ONE 9(2): e88465.

Pathogens, Parasites and Pests



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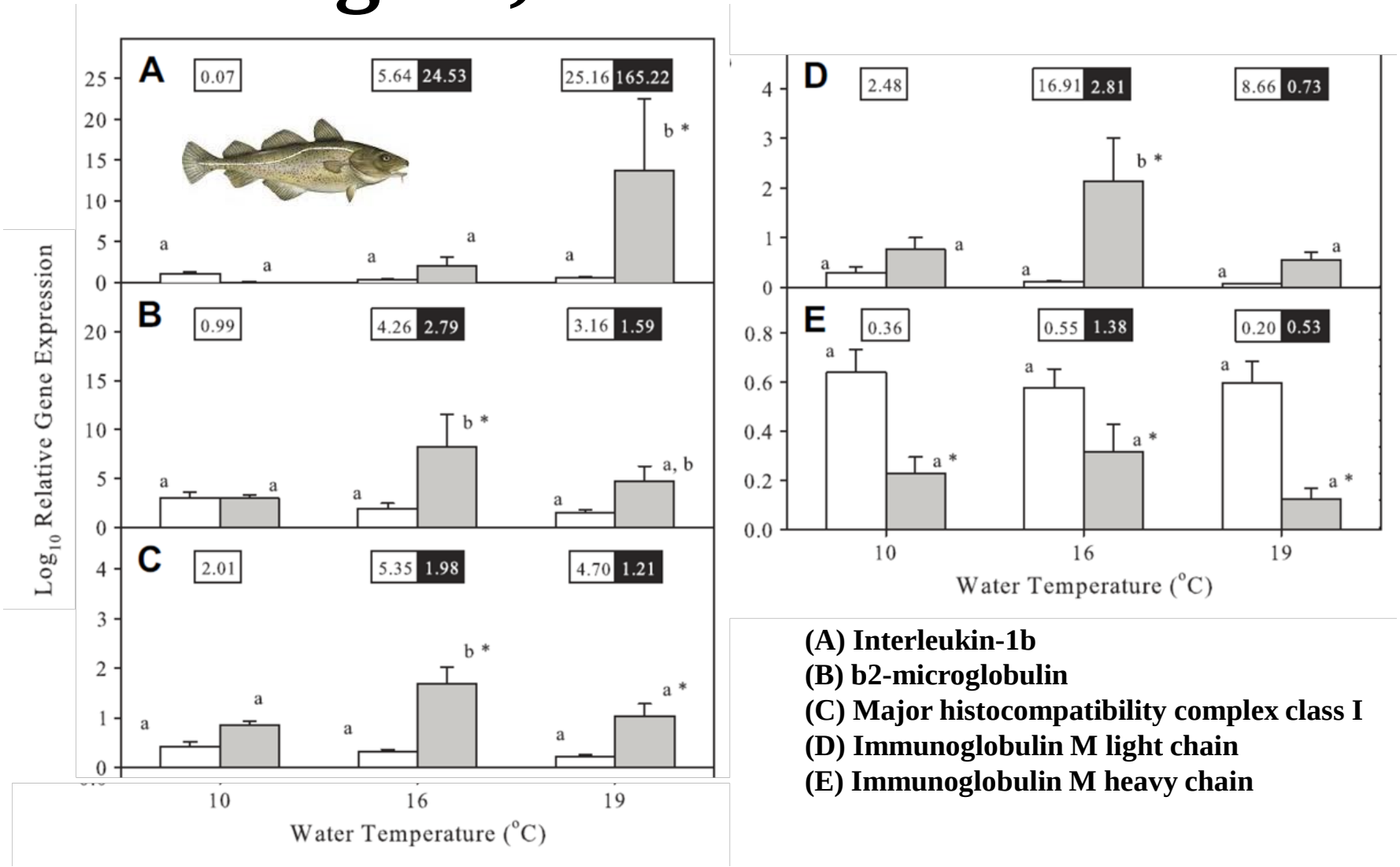
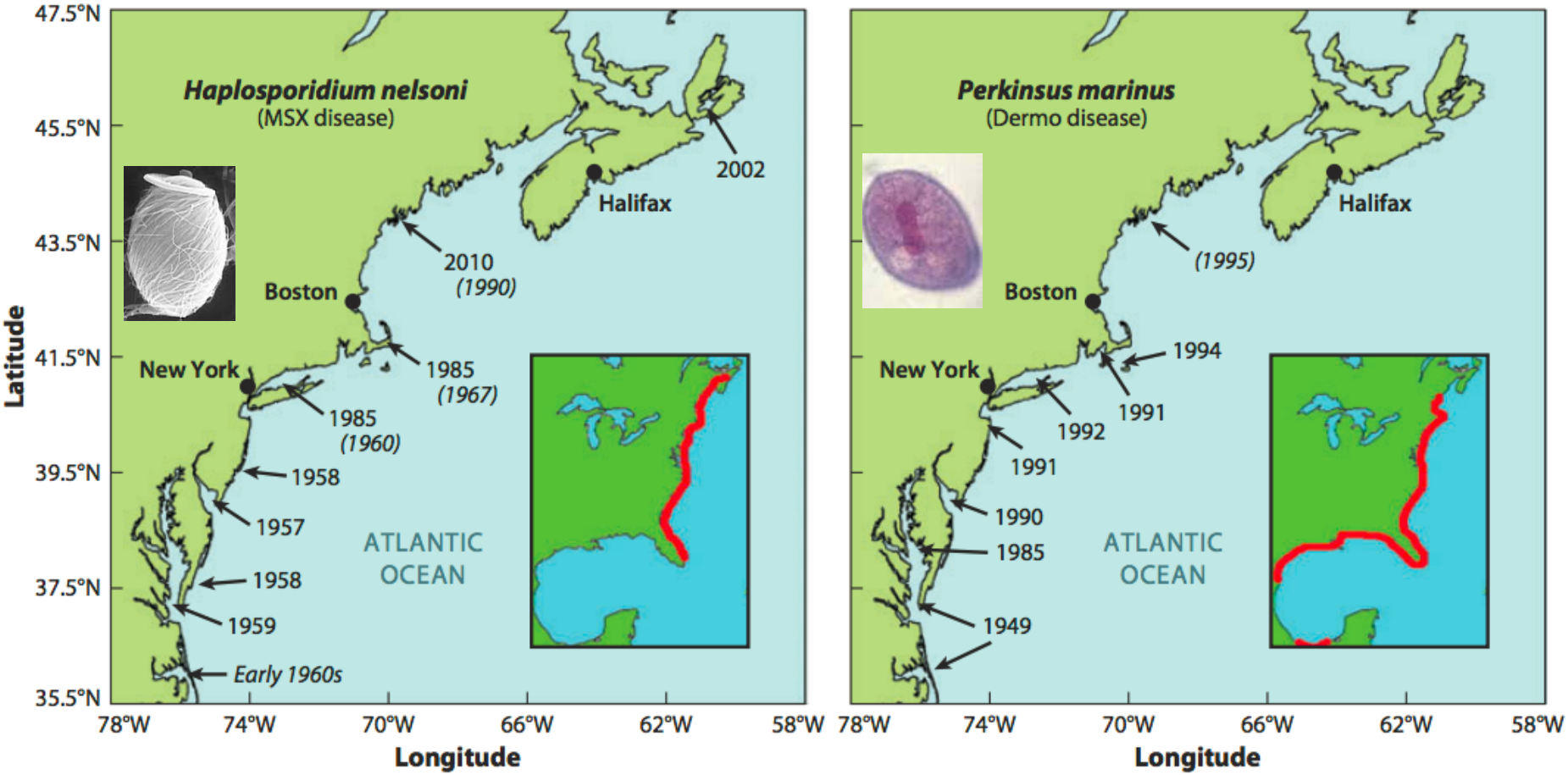


(A) Interleukin-1b
(B) b2-microglobulin
(C) Major histocompatibility complex class I
(D) Immunoglobulin M light chain
(E) Immunoglobulin M heavy chain

Pérez-Casanova et al., 2008. The immune and stress responses of Atlantic cod to long-term increases in water temperature. Fish Shellfish Immunol. 24: 600-609.

Pathogens, Parasites and Pests

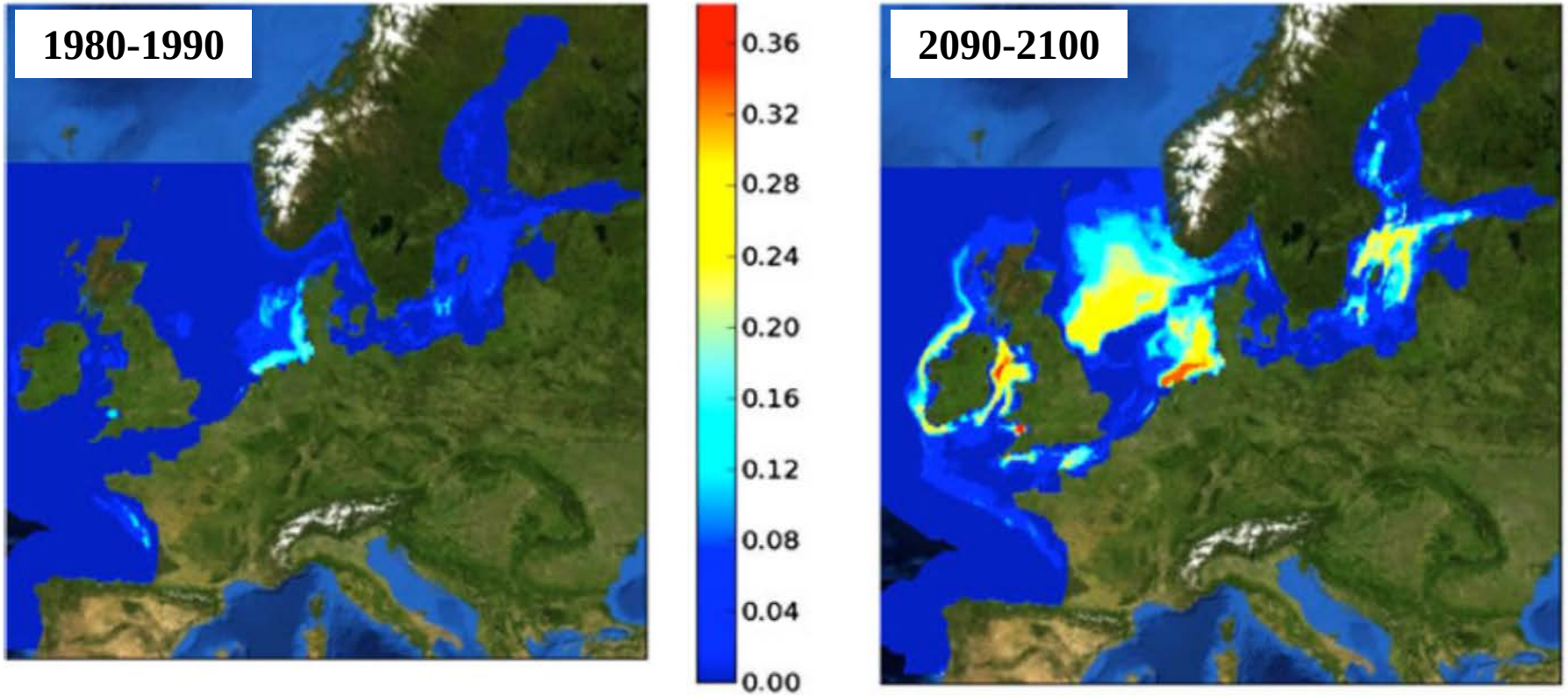


http://onsnetwork.org/eimd/2014/07/29/case-studies-murder-she-wrote-in-the-ocean/

Pathogens, Parasites and Pests

Pathogens, Parasites and Pests

Harmful Algal Blooms, e.g., *Prorocentrum* spp.



Glibert et al., 2014. Vulnerability of coastal ecosystems to changes in harmful algal bloom distribution in response to climate change: projections based on model analysis. Global Change Biology 20: 3845-3858.

Ask the Questions …

- **How does temperature affect the distribution/replication/virulence of pathogens, parasites and pests?**
- **How does temperature affect the innate ability of *Species X* to respond?**
- **How does temperature affect the efficacy of current management tools?**

Outline

- Effects
  - Biochemistry and physiology
  - Feeds and foods
  - Pathogens, parasites and pests
- Mitigation
  - Site selection & engineering
  - Diets
  - Breeding programs

Site Selection and Engineering

- **Monitoring and modelling limnological and oceanographic conditions to identify suitable sites**
- **Artificial upwelling in deeper-water sites**
  - **Potentially creates other problems**
- **Onshore systems for better temperature control**
  - **Perhaps only for part of the production cycle, e.g., maintaining broodstock**

Nutrition

- **Fed species:**
  - **Formulation of feeds to meet requirements at elevated temperatures (energy levels, fatty acid profiles, feed stimulants, etc.)**
- **Extractive species:**
  - **Site selection**
  - **Site enrichment**

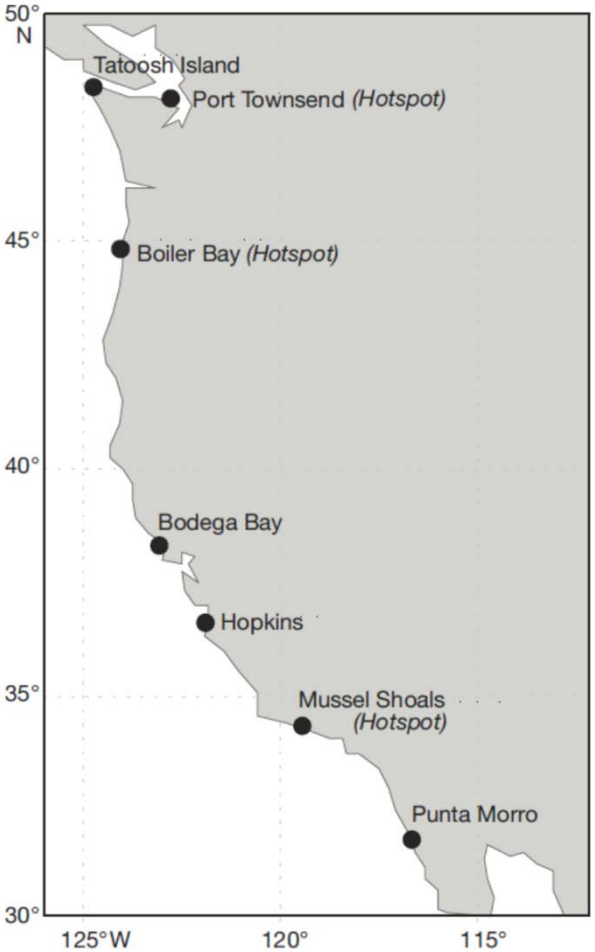
Disease Management

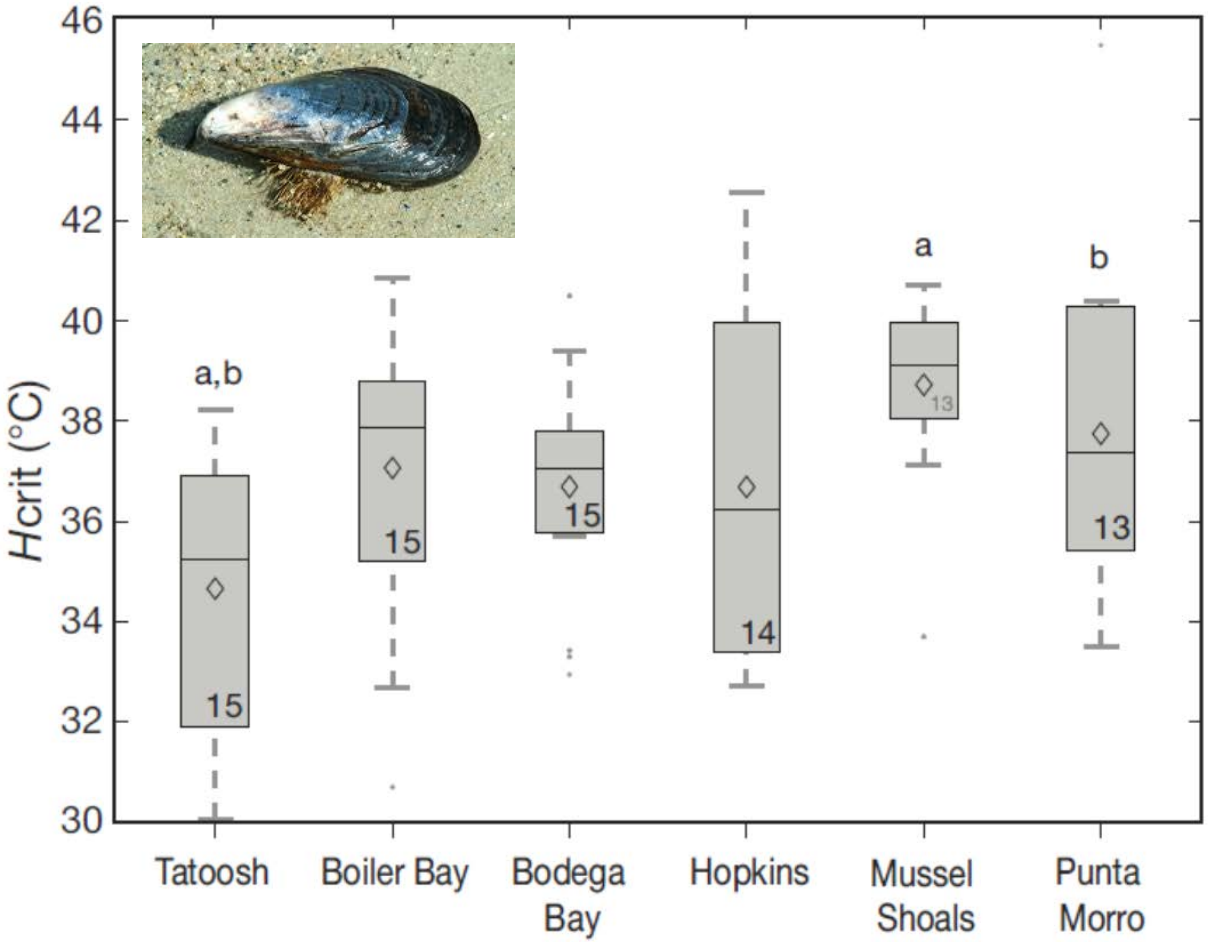
- **Monitor for changes in virulence and for immigration of new pathogens**
- **Determine efficacy of current chemo-therapeutants at higher temperatures, and develop new treatments**
- **Determine effects of temperature on immune function**

Breeding

- **Variation among stocks/strains**
- **Variation within stocks/strains (family effects)**
- **Molecular tools**
  - **Gene expression**
  - **Markers**

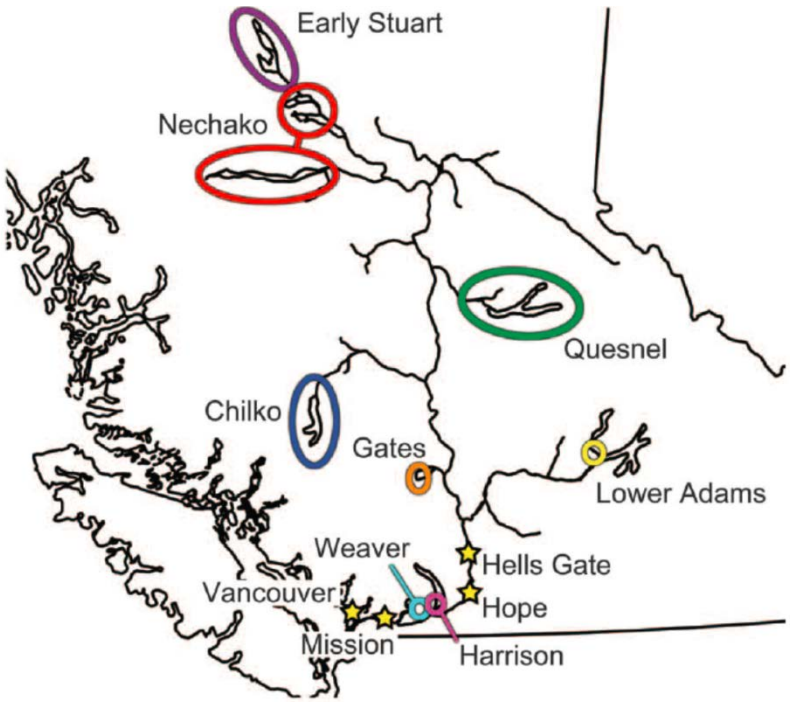
Stock Effects

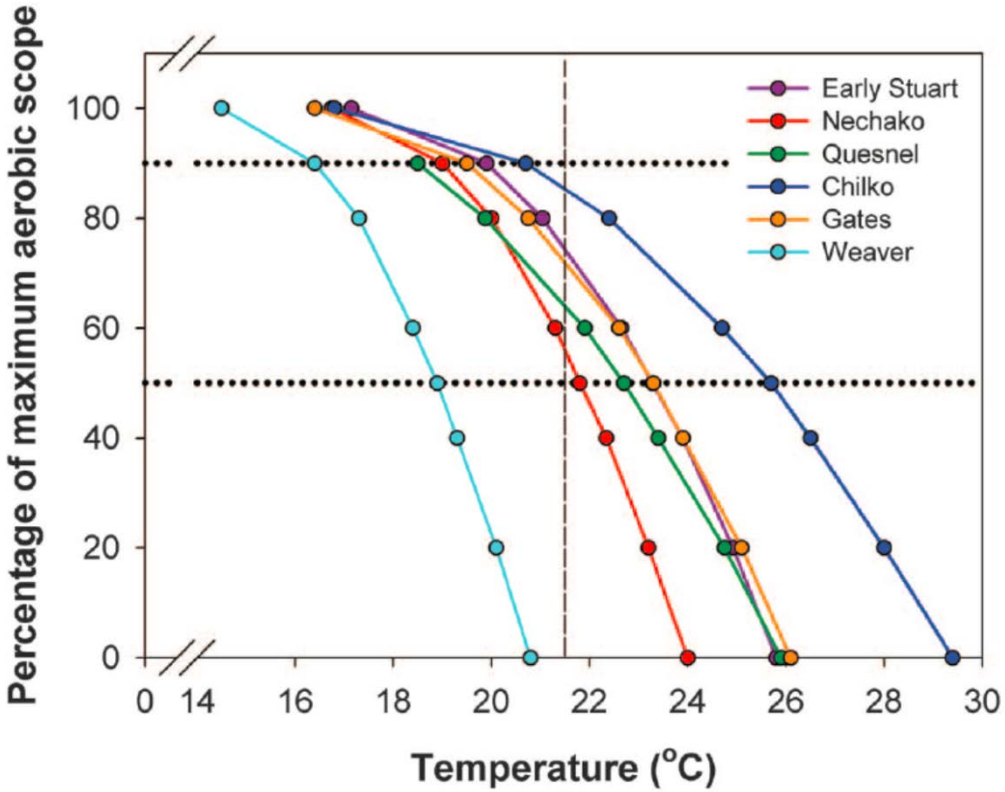




Logan et al., 2012. Latitudinal differences in *Mytilus californianus* thermal physiology. Mar. Ecol. Prog. Ser. 450: 93-105.

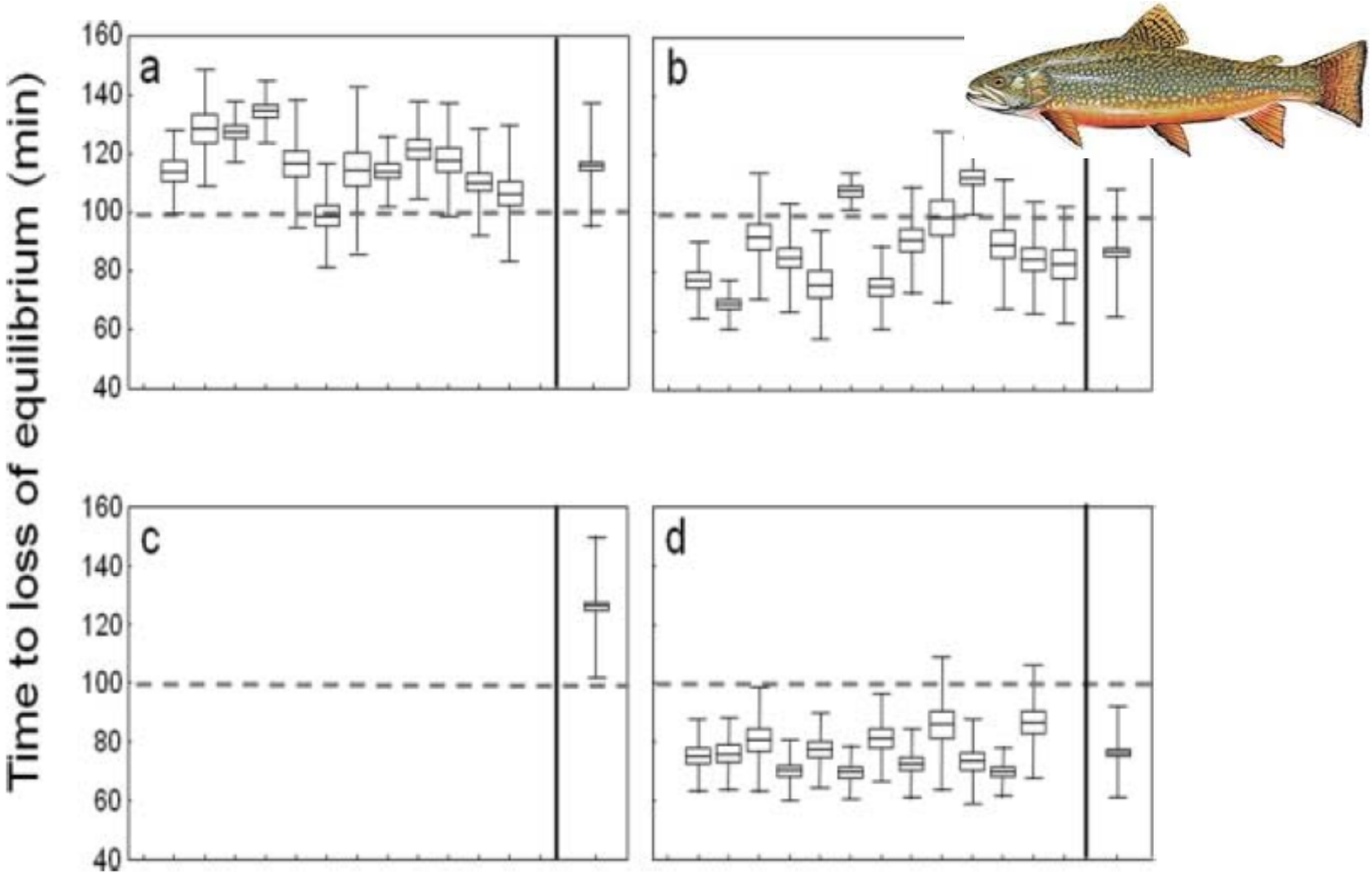
Stock Effects





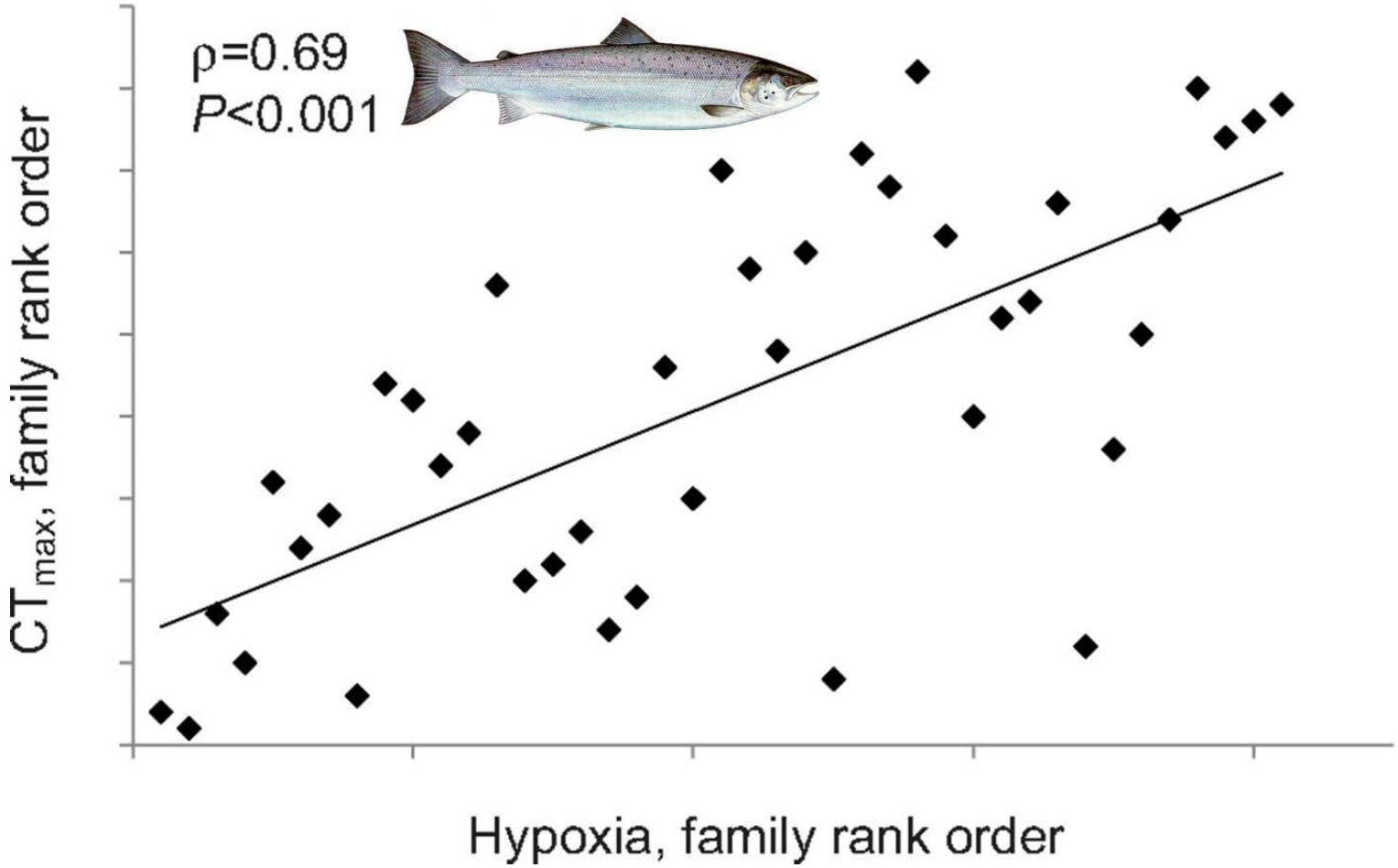
Eliason et al., 2011. Differences in thermal tolerance among sockeye salmon populations. Science 332: 109-112.

Strain and Family Effects



McDermid et al., 2012. Variation in acute thermal tolerance within and among hatchery strains of brook trout. Trans. Amer. Fish. Soc. 141: 1230-1235.

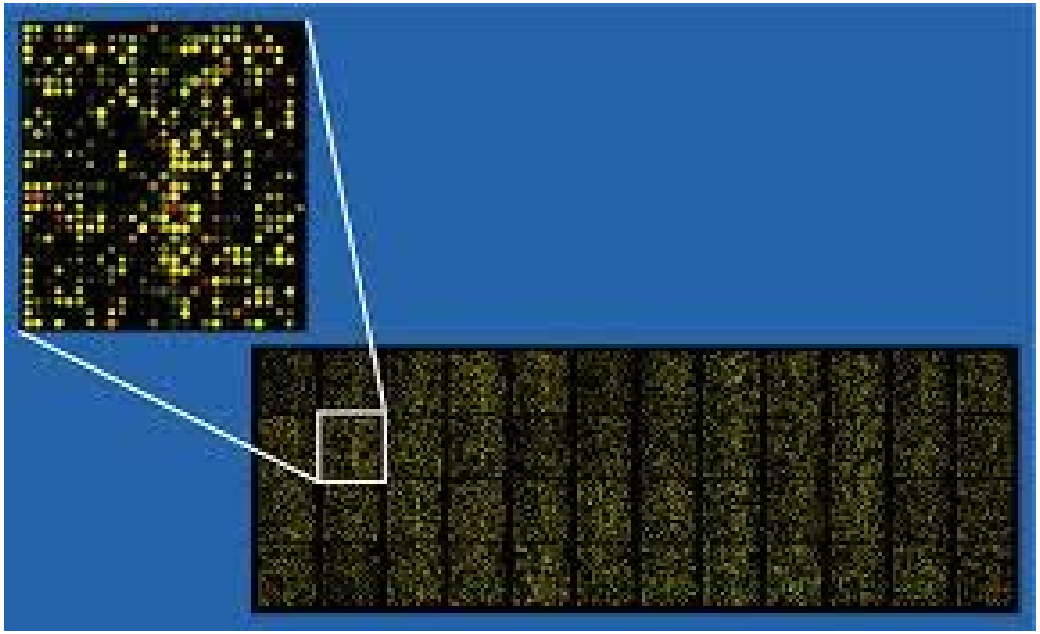
Family Effects



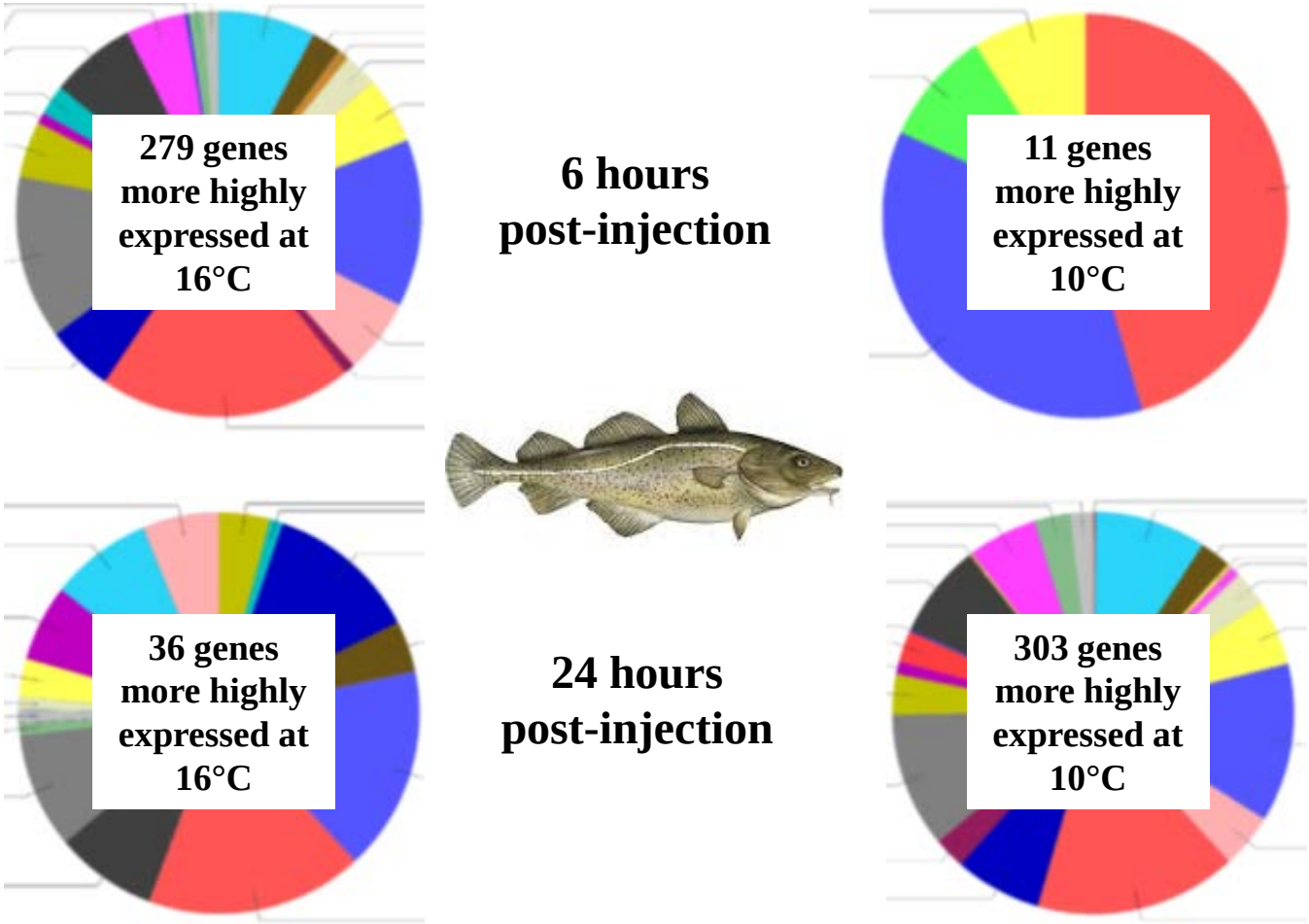
Anttila et al., 2013. Variation in temperature tolerance among families of Atlantic salmon (*Salmo salar*) is associated with hypoxia tolerance, ventricle size and myoglobin level. J. Exp. Biol. 216: 1183-1190.

Gene Expression

- **What genes (or gene functions) are up/down regulated by temperature change, and what are their roles?**



Gene Expression



Hori et al., 2012. A moderate increase in ambient temperature modulates the Atlantic cod (*Gadus morhua*) spleen transcriptome response to intraperitoneal viral mimic injection. BMC Genomics 13: 431.

Genetic Markers

- **What genetic markers can be used in breeding programs?**

Evolutionary Applications 7 (2014): 480-492

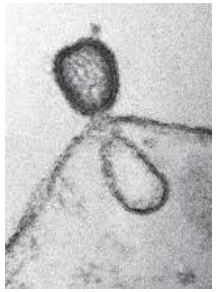
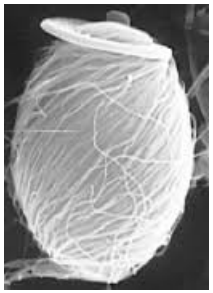
Open Access

Detection and mapping of QTL for temperature tolerance and body size in Chinook salmon (*Oncorhynchus tshawytscha*) using genotyping by sequencing

Meredith V. Everett* and James E. Seeb

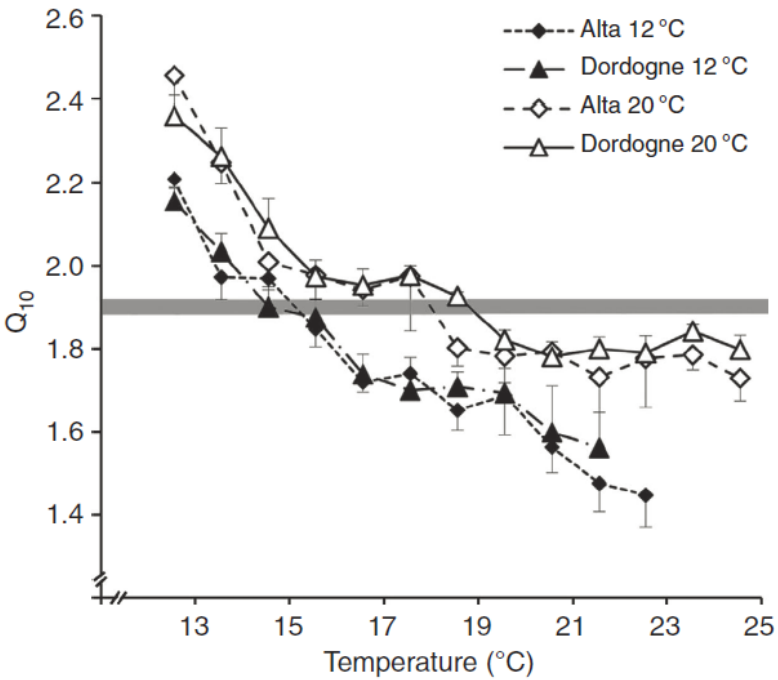
Conclusions

- **There will be winners and losers among culture species, to varying degrees**
- **There will also be winners and losers among pathogen, parasite and pest species, most of which have shorter generation times**


Conclusions

- **Must understand the biology of the culture species of interest and its interaction with its abiotic and biotic environment**



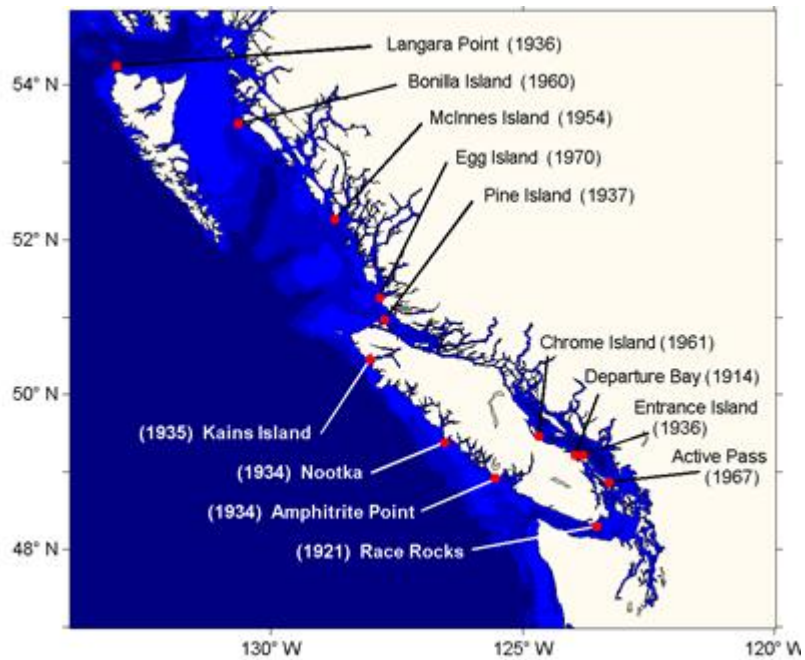
For the most part, the results reject our hypothesis for local adaptation and we show that Atlantic salmon are not tailored to their local biogeography. Independent of the origin, populations have a surprisingly high cardiac capacity to compensate to a warmer than optimal temperature. We suggest that such an attribute may aid Atlantic salmon populations to respond to future warming associated with climate change.

Anttila et al., 2014. Atlantic salmon show capability for cardiac acclimation to warm temperatures. Nature Communications 5: 4252.

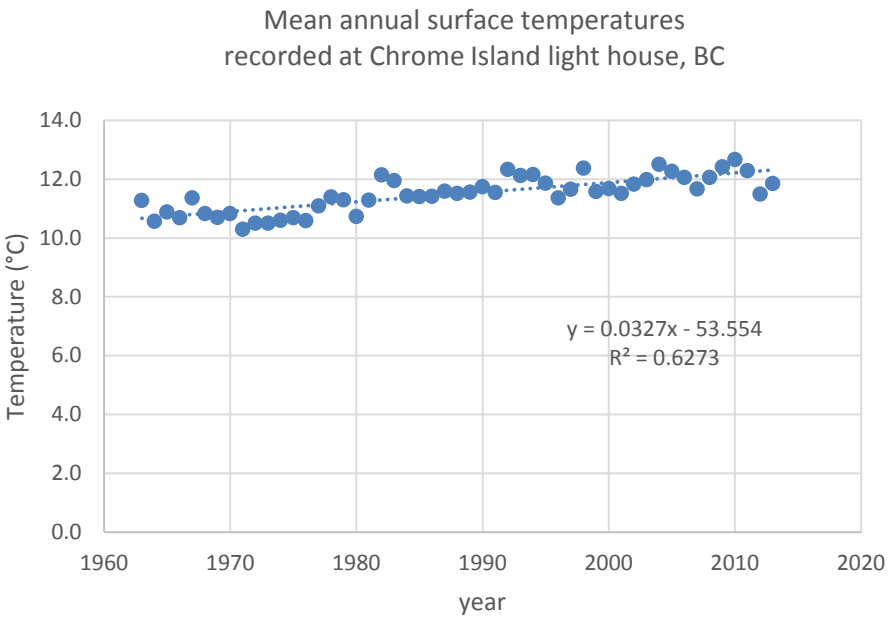
Conclusions

- **Must understand the biology of the culture species of interest and its interaction with its abiotic and biotic environment**
- **Mitigation may not be necessary (winners)**
- **Mitigation, if needed, includes**
  - **Site selection and engineering**
  - **Nutrition**
  - **Disease management**
  - **Breeding**

‘Local’ increase in mean annual surface temperatures



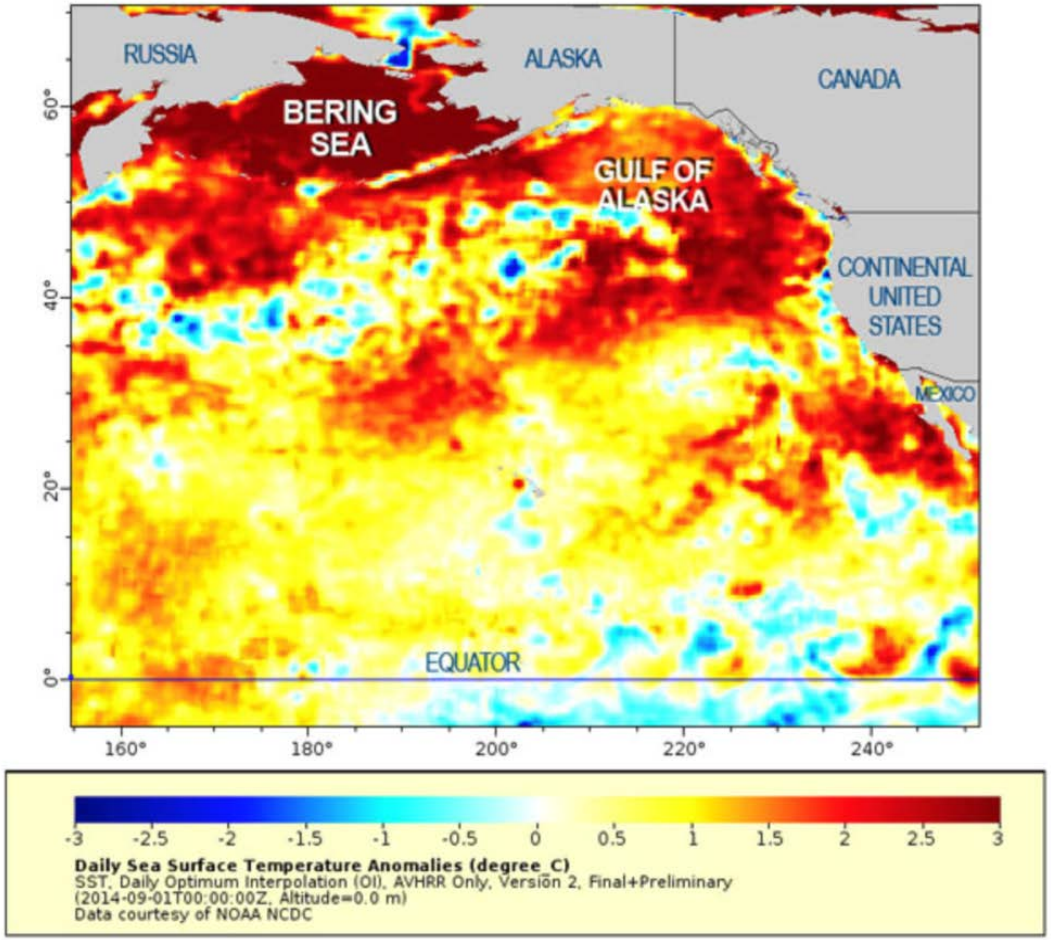
http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/lighthouses-phares/index-eng.html



- Various light houses throughout BC have been collecting water quality data for decades
- Let’s look at Chrome Island temperature data

- A 1.5 to 2.0 °C increase over 50 years

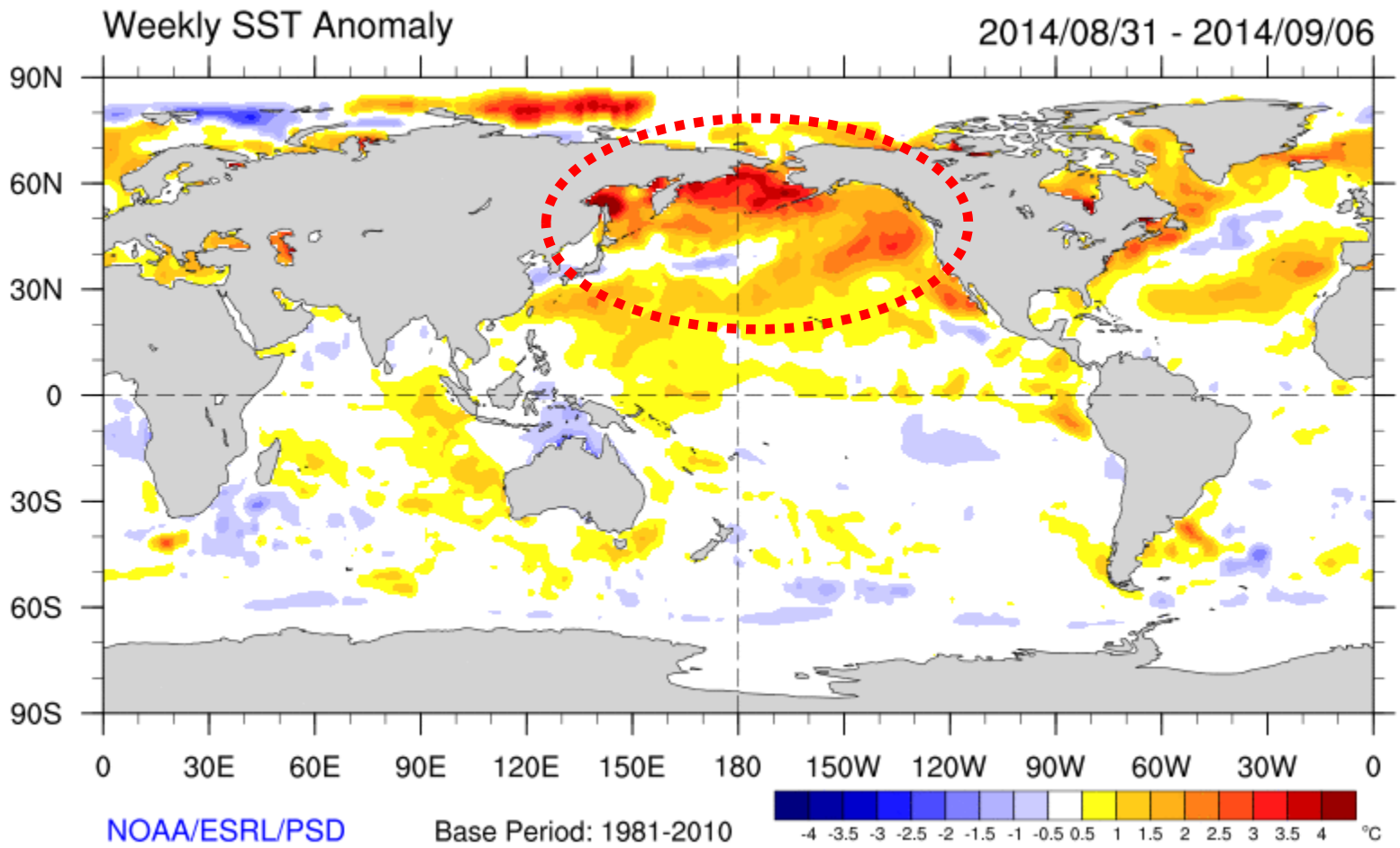
The North Pacific Ocean was unusually warm in 2014



- **Extreme warm conditions of that magnitude have not been seen before.**
- **It is difficult to predict that the impact of these conditions will be for salmon returning to British Columbia in 2015, but they are unlikely to be favourable to salmon.**

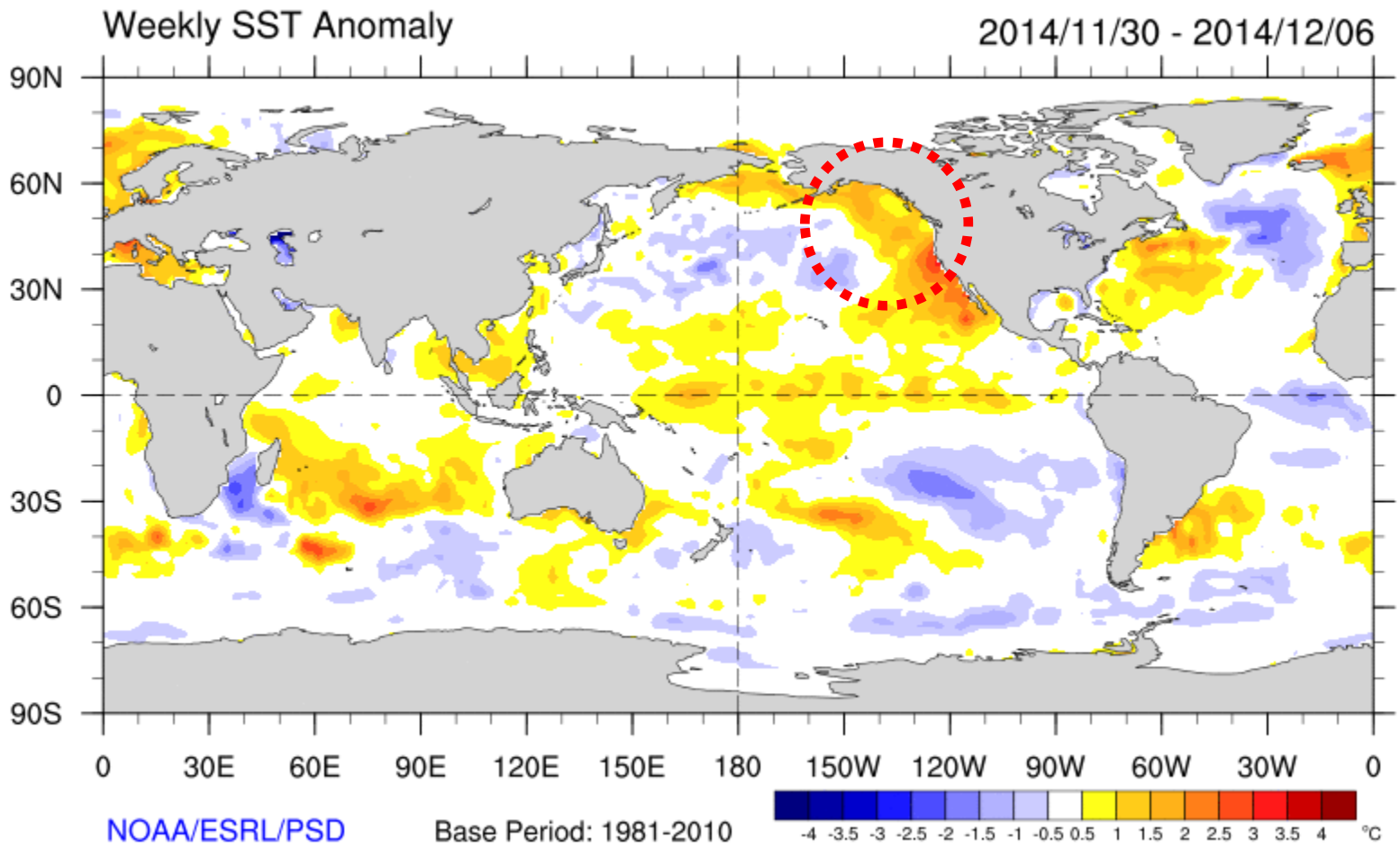
http://www.undercurrentnews.com/2014/09/12/noaa-says-warming-blob-to-impact-pacific-marine-life/

Unusual warm conditions occurred in 2014



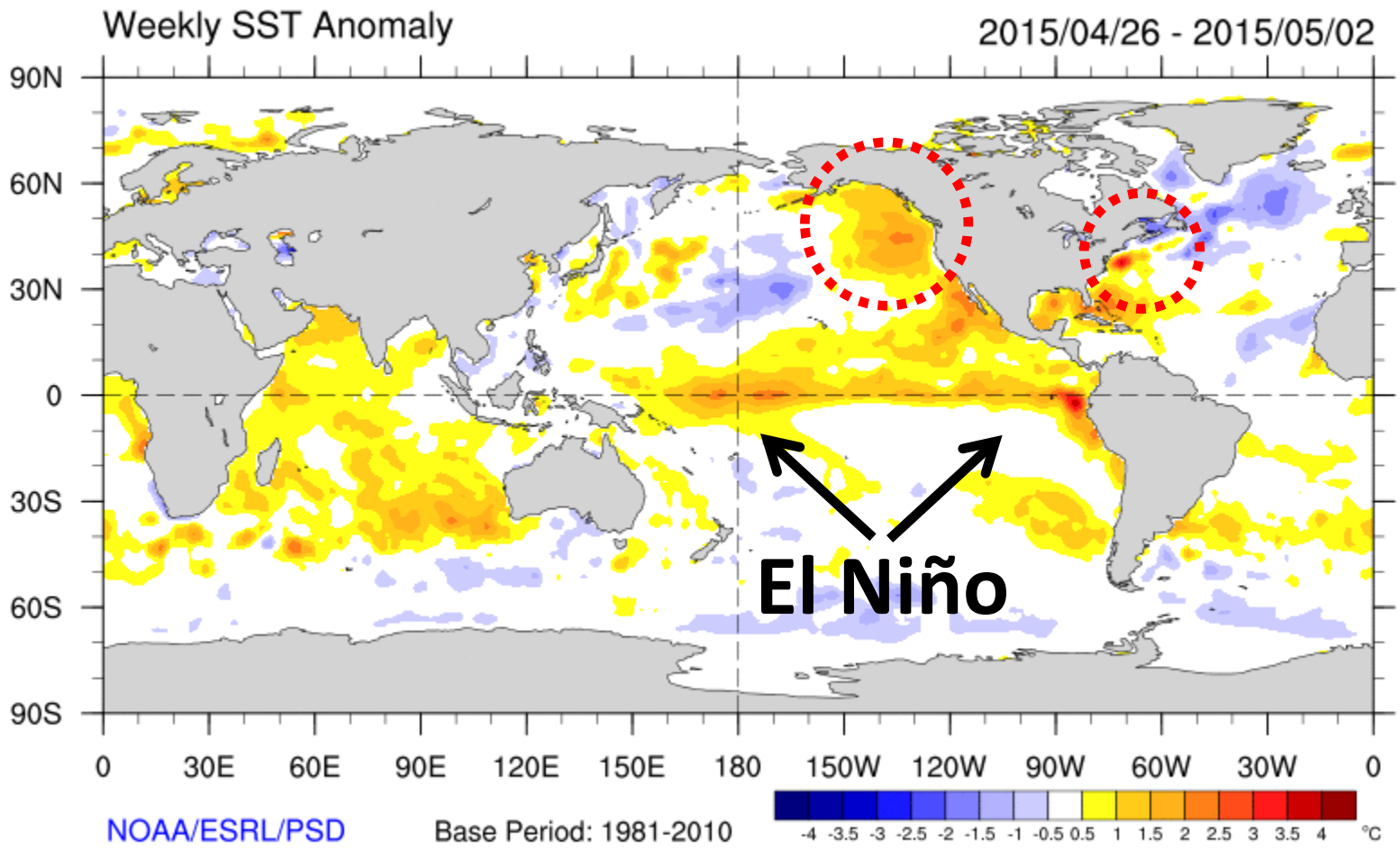
http://www.esrl.noaa.gov/psd/map/clim/sst.anom.anim.year.html

The warm waters moved inshore in the fall and stayed inshore through the winter



http://www.esrl.noaa.gov/psd/map/clim/sst.anom.anim.year.html

Warm conditions are persisting in 2015 with a possible El Niño



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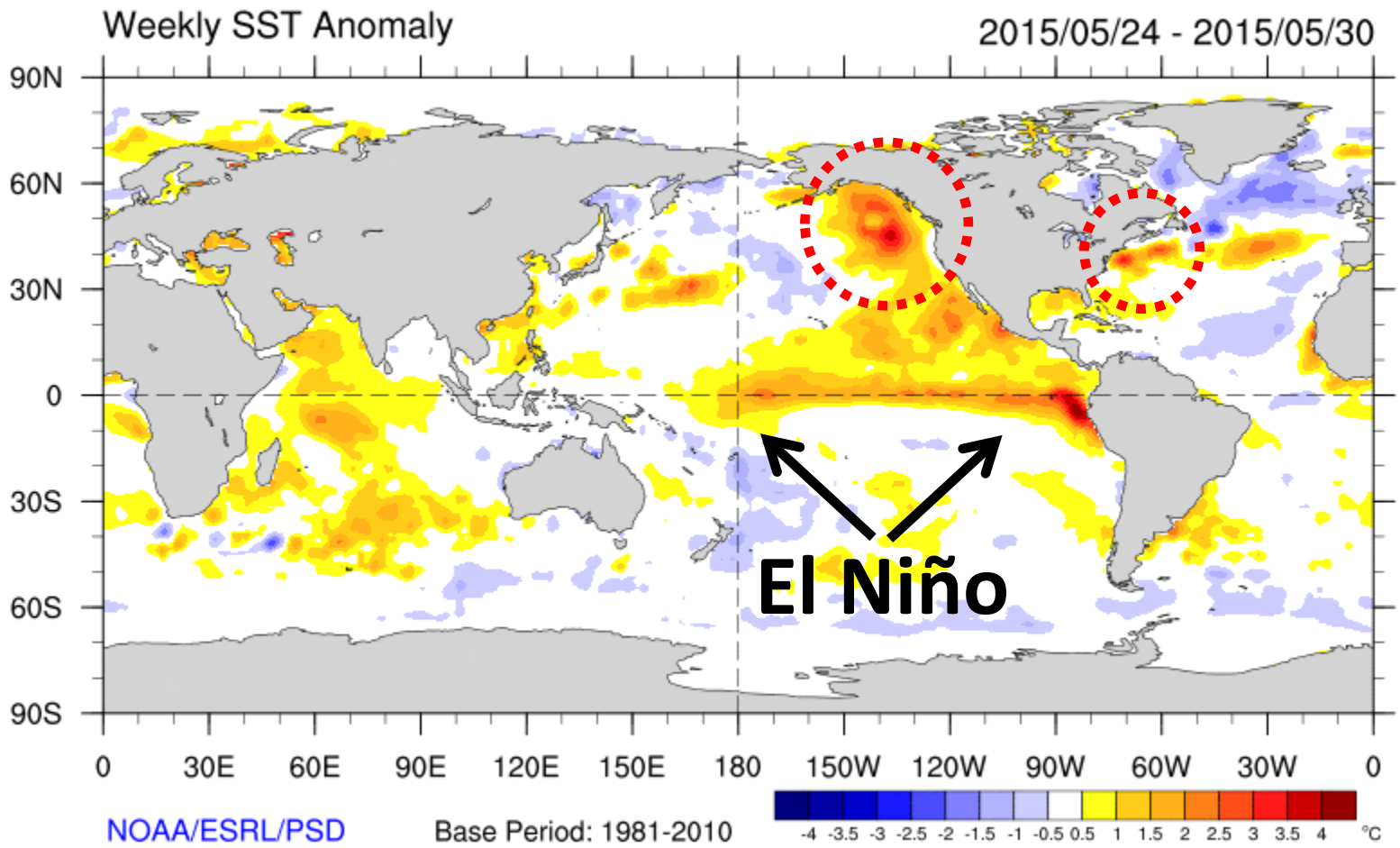

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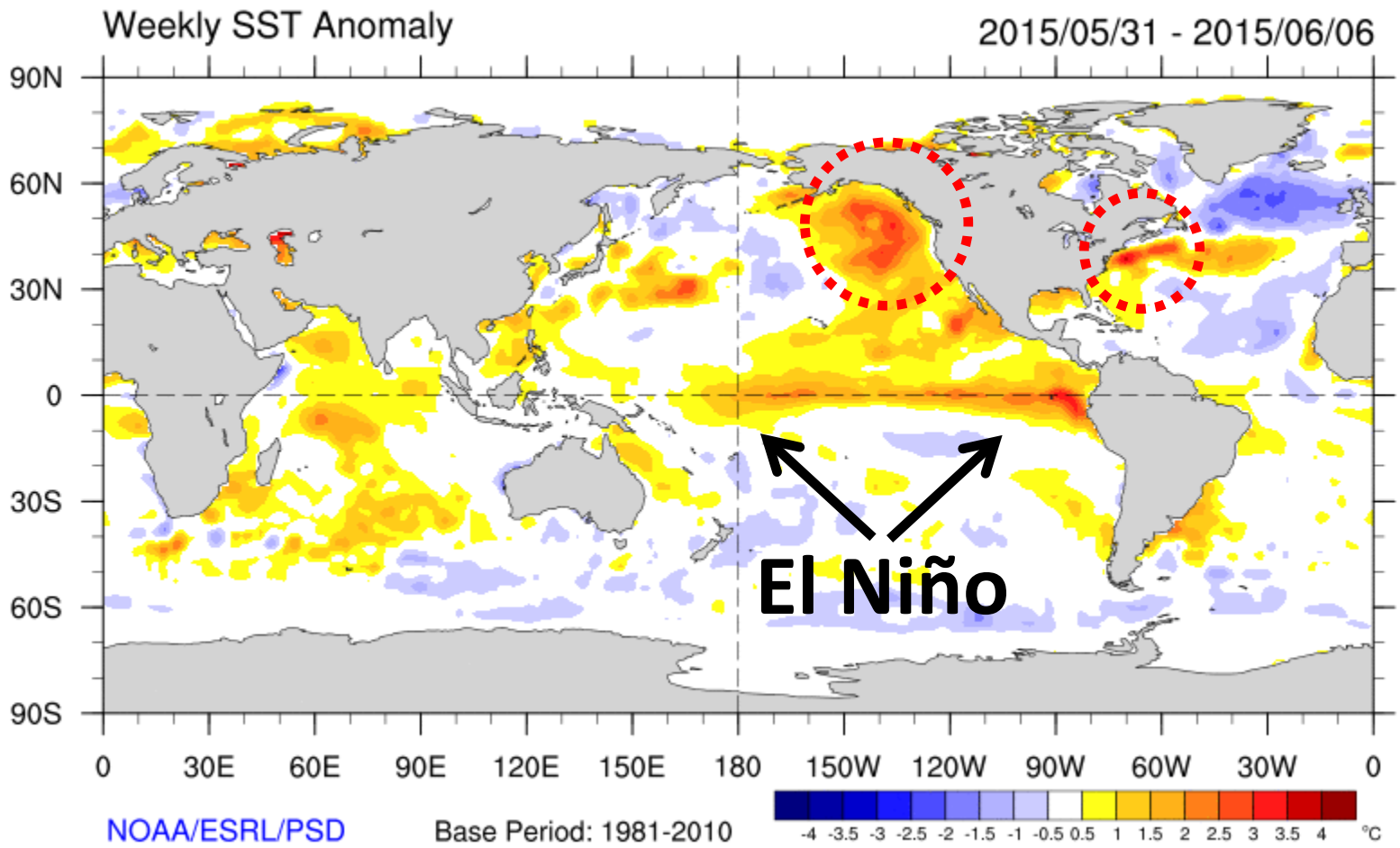

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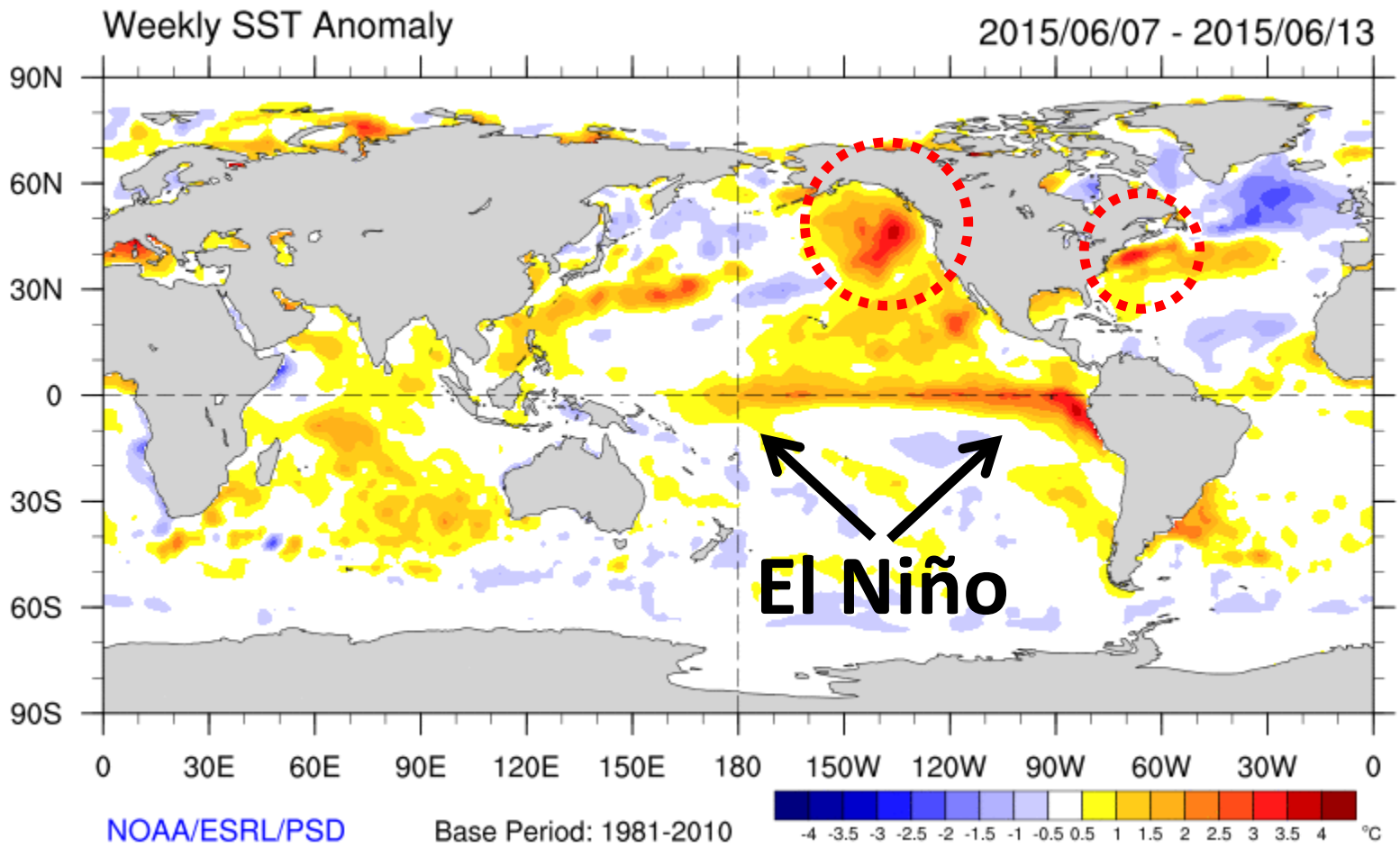

http://www.esrl.noaa.gov/psd/map/clim/sst.anom.anim.year.html

Also known as the ‘Blob’ in popular press

- This anomaly is related to a persistent high-pressure ridge that caused a calmer ocean during the past two winters, so less heat was lost to cold air above (Bond et al. 2014)

- The warmer temperatures we see now aren’t due to more heating, but less winter cooling (Bond et al. 2014)

- Uncertainty as to linkages with global warming at the moment (http://www.washington.edu/news/2015/04/09/warm-blob-in-pacific-ocean-linked-to-weird-weather-across-the-u-s/)

Questions / Comments