Physiological Impacts of Climate Change Using Remote Sensing

David S Wethey, Sarah A Woodin, Thomas J Hilbish, Venkat Lakshmi
University of South Carolina
Brian Helmuth, Northeastern University

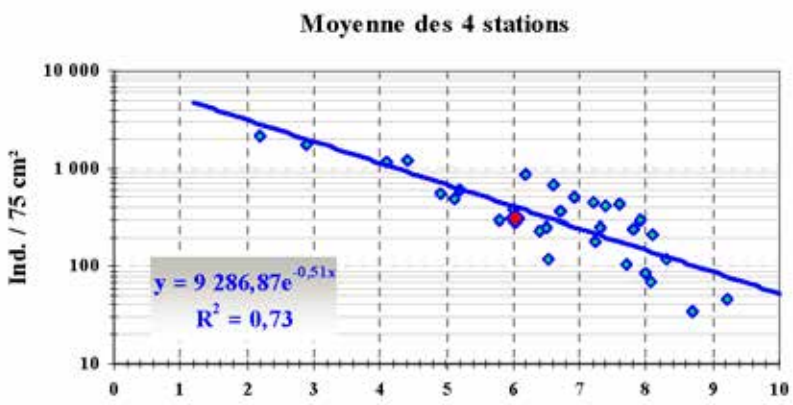
wethey@biol.sc.edu

Biogeographic Modeling

- Ecosystem engineering species that control the rest of the assemblage
  - competitive dominants
  - sediment stabilizers
  - sediment destabilizers
- Age structured metapopulation
- Reproduction controlled by Sea Surface Temperature
- Gridded ICOADS temperatures
  - 1850-present
- Dispersal
  - 10% N, 10% S
  - 10 km max
- Seed entire coast with species in 1850 and allow population distribution to evolve over time

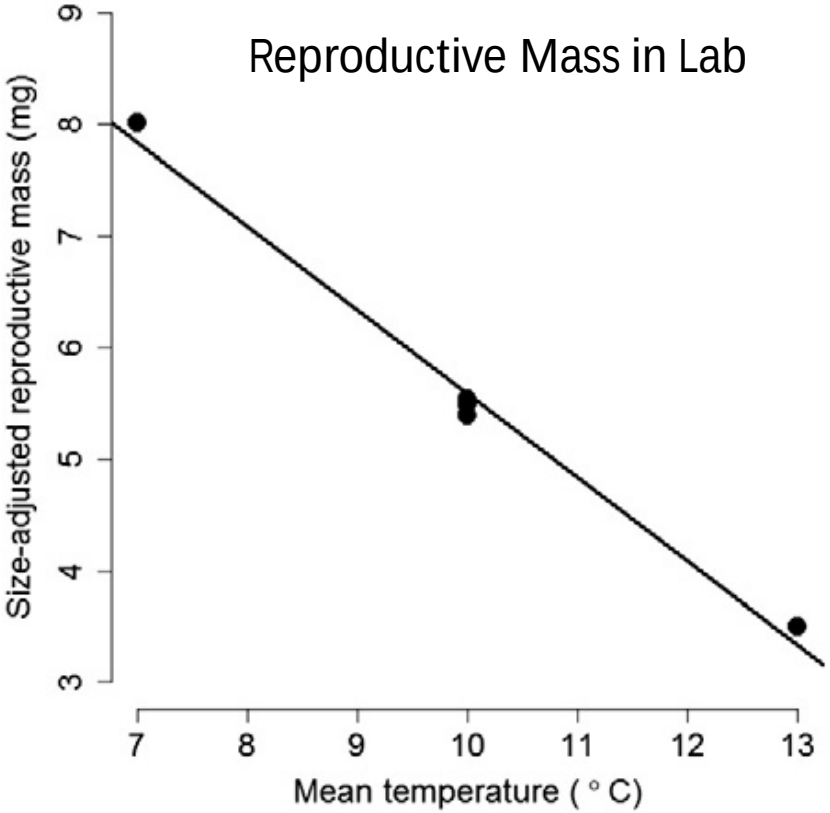
Reproduction vs SST barnacle - *Semibalanus*

Recruitment in Field 1983-2013



temperature

Reproductive Mass in Lab

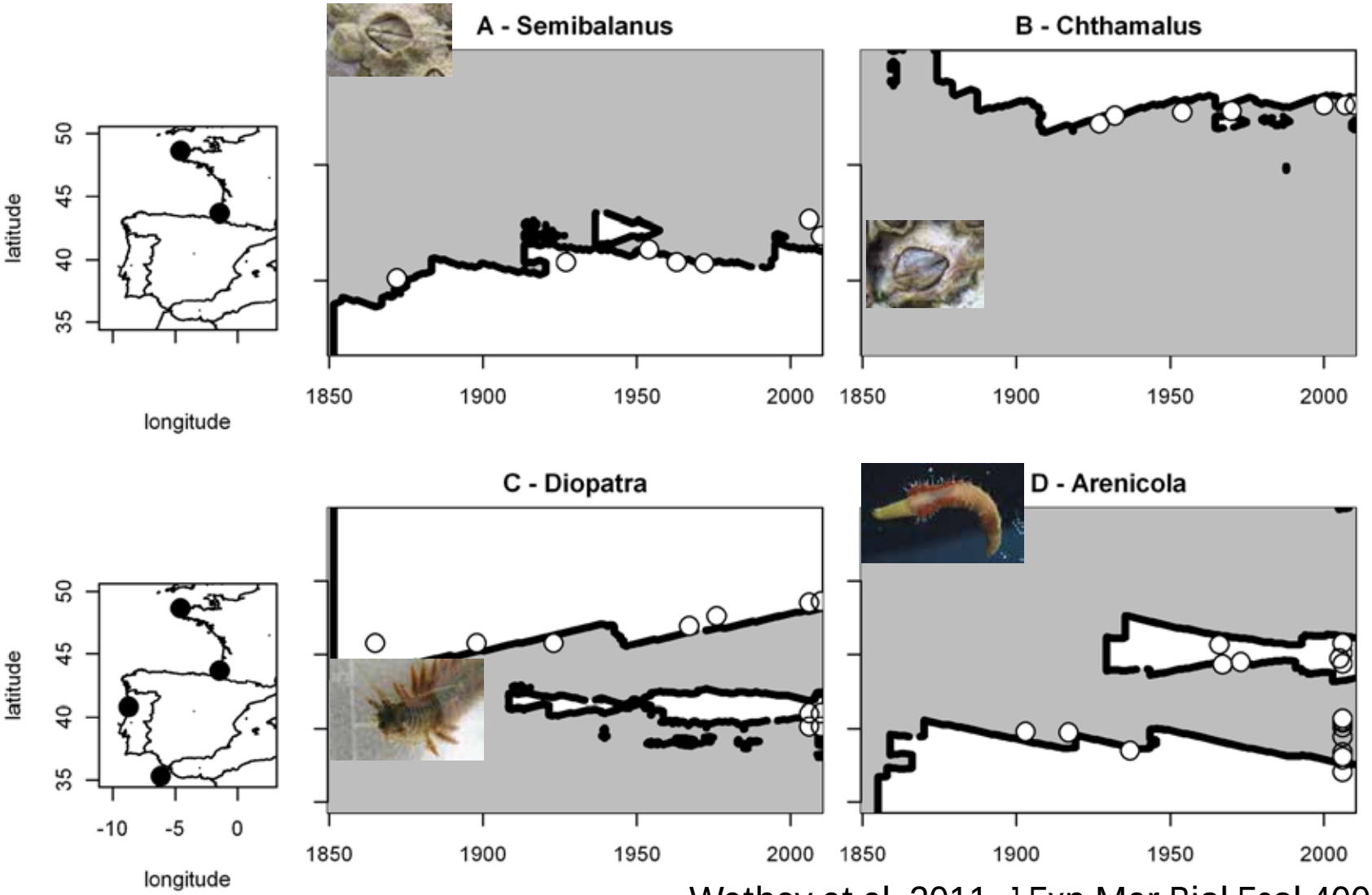


Dreves et al. 2013. IFREMER

Rognstad & Hilbish 2014 J Exp Mar Biol Ecol

Hindcasts of Geographic Limits (lines) and
Historical Records of Limits (dots)

Holes develop in distributions when conditions change



Wethey et al. 2011. J Exp Mar Biol Ecol 400:132-144

Species Distribution Modeling

- Correlative niche models
- Mechanistic niche models
- These models assume that mechanisms and patterns found in one geographic region or epoch can be used to predict distribution in another.
- This is the concept of niche conservatism, model stationarity or model transferability.

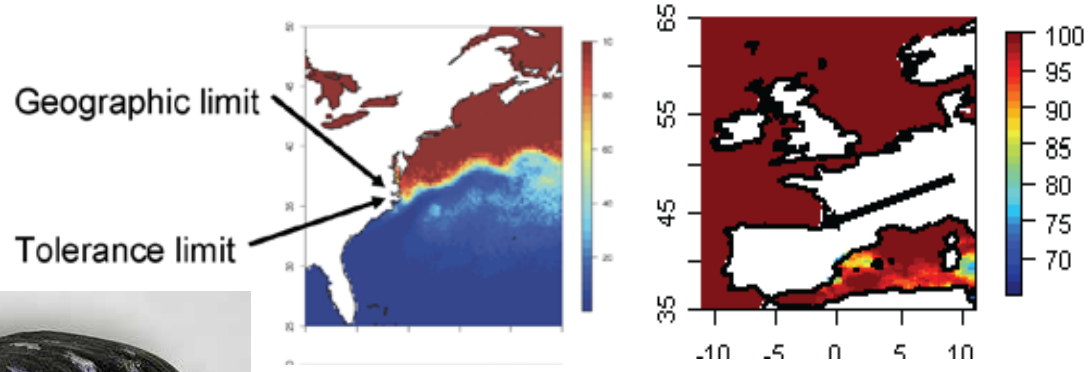
Can physiology inform species distribution models?

- Examine difference between lethal vs performance limits
    - Thermal death vs scope for growth / energy budget
- Commercially important shellfish
    - Extensive physiology, production, biogeography data

- Extremely important to find reasons for failure of assumption of niche conservatism in species distribution models that work in one geographic region but fail to make correct predictions elsewhere.

Species Distribution Model Based On Thermal Tolerance

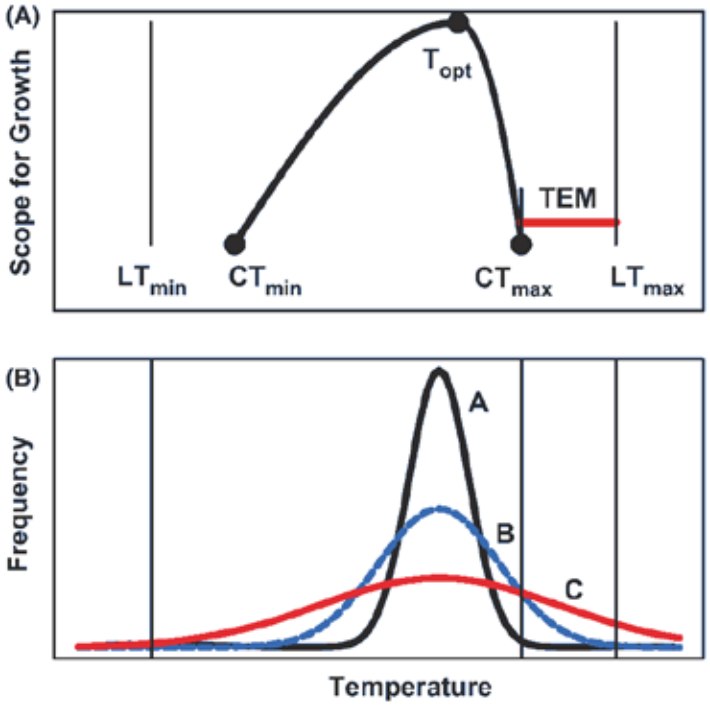
Marine mussel *Mytilus edulis* Distribution Model Validated for US East Coast

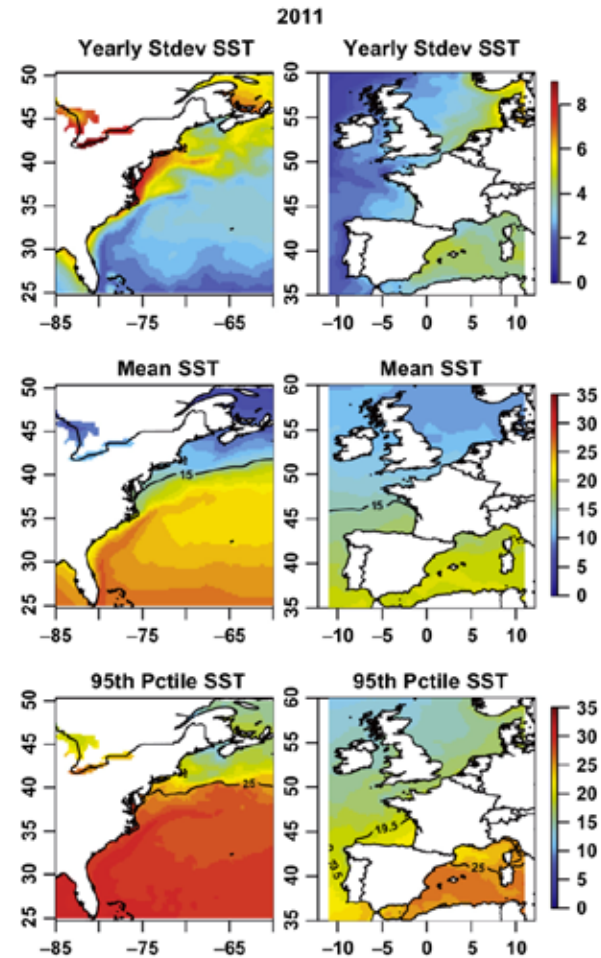


Fails utterly in Europe

Woodin et al. 2013 Ecology & Evolution 3:3334-3346

Models are likely to fail if ecological performance limits are different from physiological tolerance limits, and environmental variance differs between regions



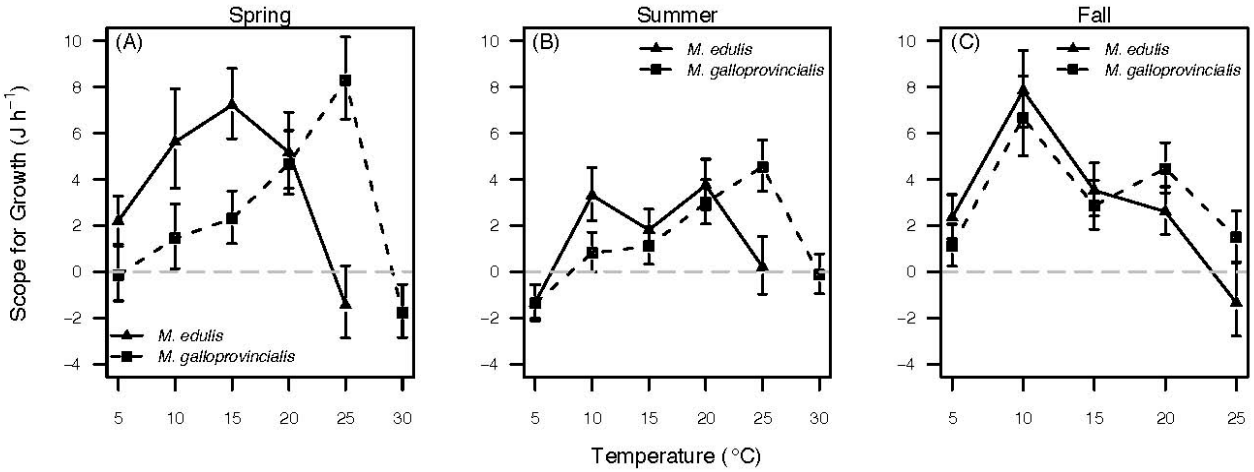


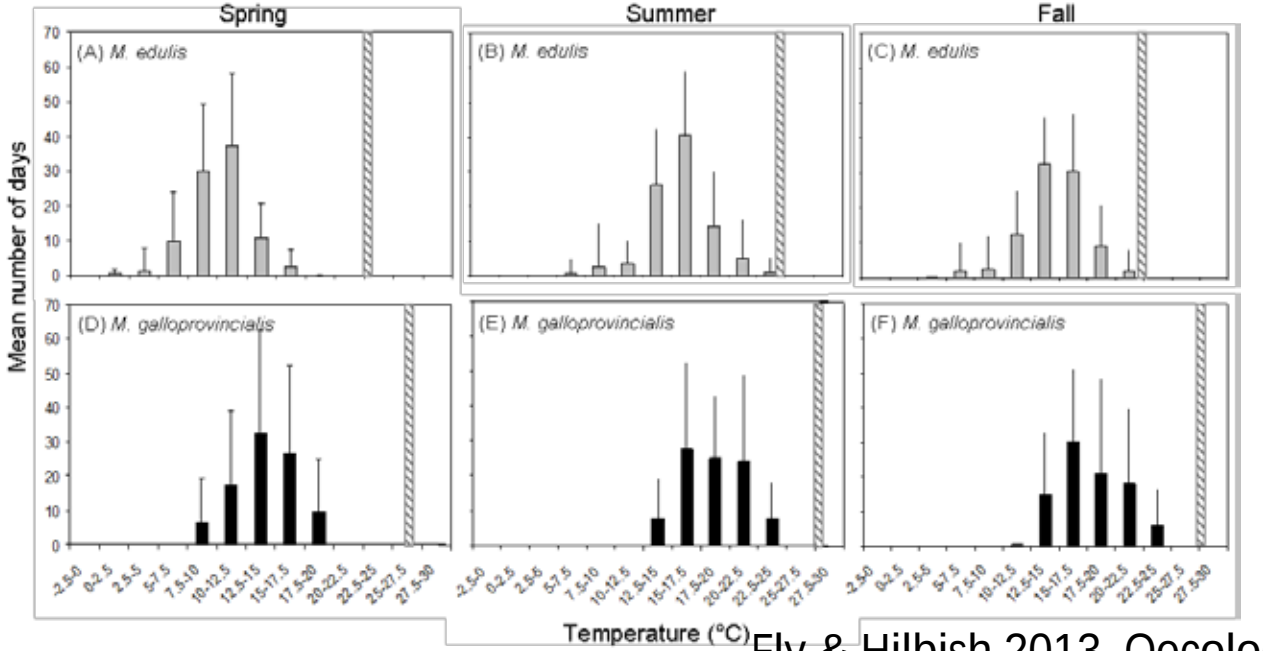
TEM = transient event margin
CT_{max}= physiological performance limit
LT_{max} = lethal temperature

Seasonality matters, like Radeloff DHI which includes a coefficient of variation

Woodin et al. 2013 Ecology & Evolution 3:3334-3346

Scope for growth and biogeography of commercial mussels in Europe

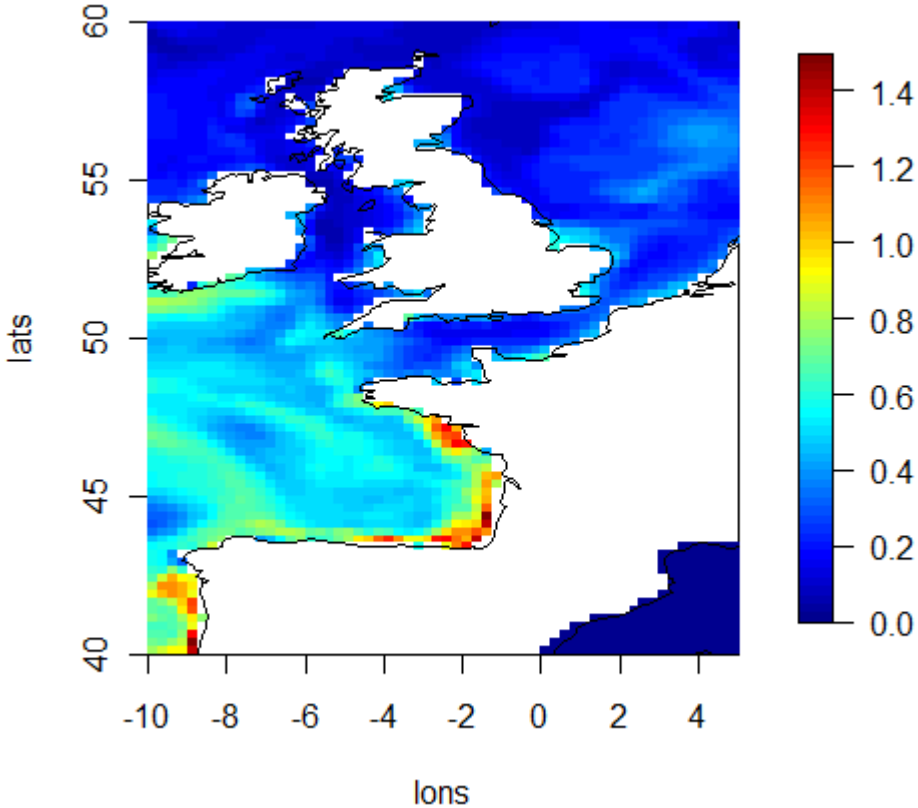




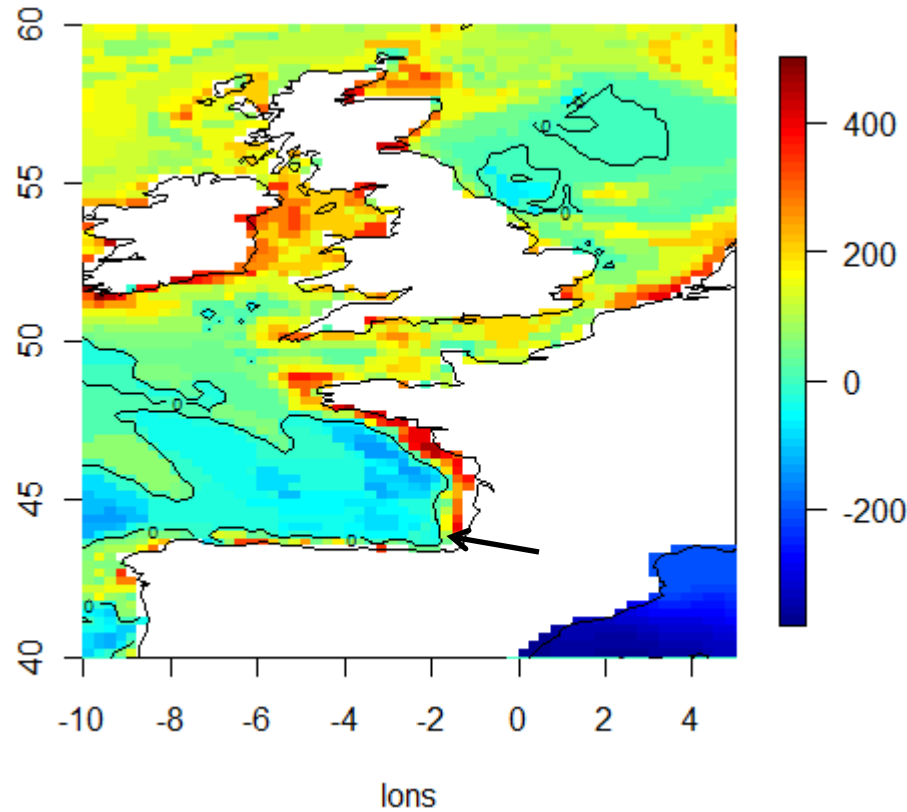
Fly & Hilbish 2013. Oecologia 172:35-46

Scope for Growth Models incorporating daily SST and Satellite Chlorophyll yield the approximate southern limit of *Mytilus edulis* in Europe

Chlorophyll µg/L



End of Year body mass via SFG



Analogous to Waring-Coops 3PGS physiological growth models

Fly, Hilbish, Wethey, Rognstad 2015. Am Malacol Bull 33:1-14

Mussel Thermal Limit Projections in Europe

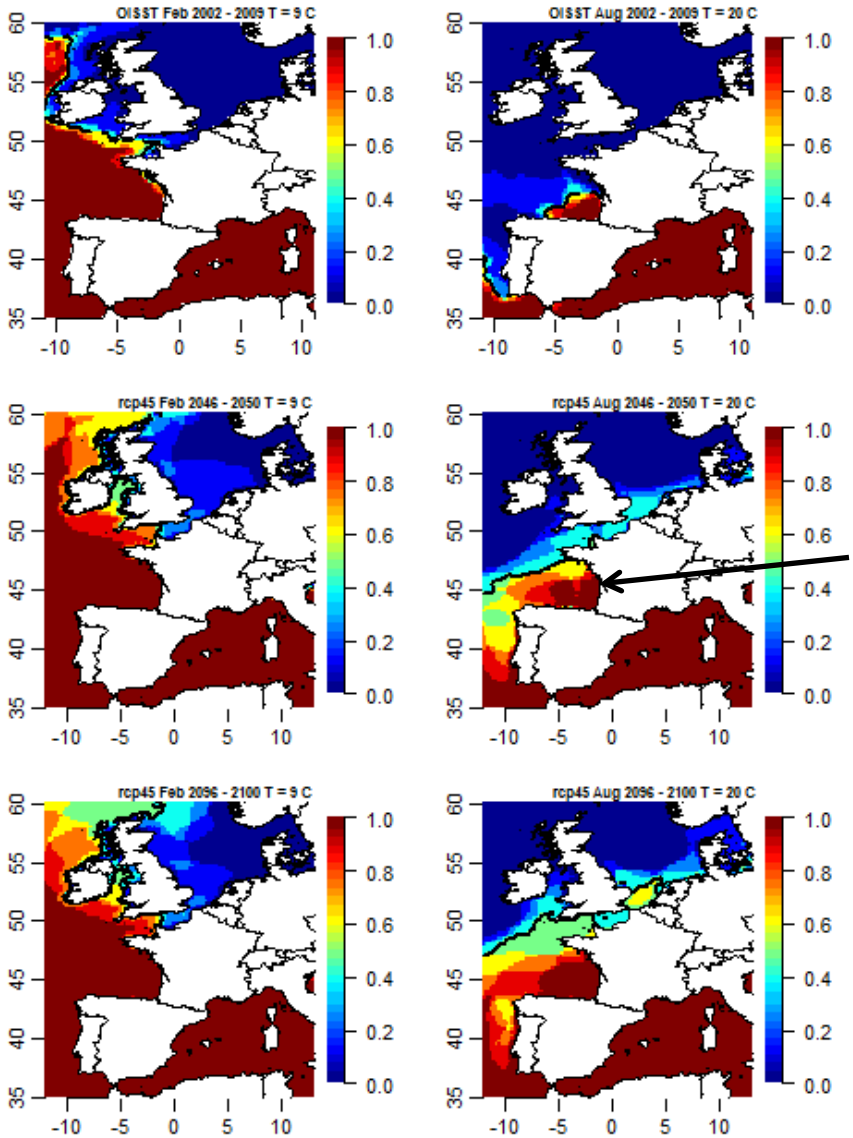
M galloprovincialis

M edulis

Present climate
Fraction of years hotter than threshold

RCP 4.5 2046-2050
Fraction of models predicting years hotter than threshold

RCP 4.5 2096-2100



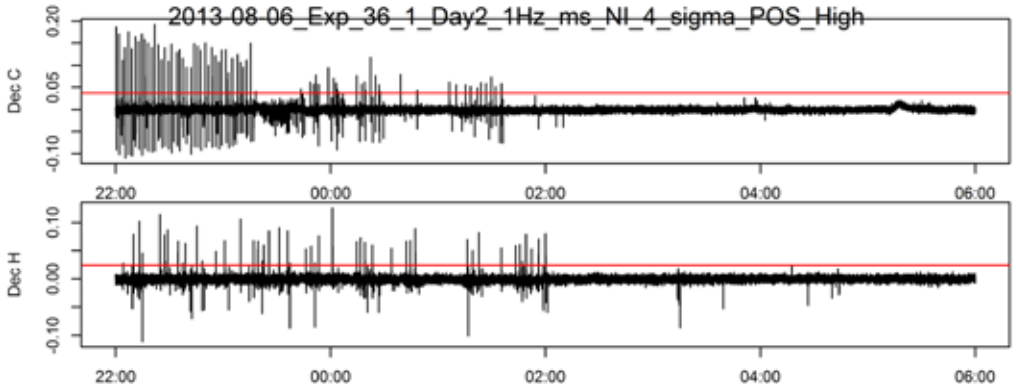
Thresholds derived from scope for growth results

Primary source of mussel seed for Europe will no longer exist

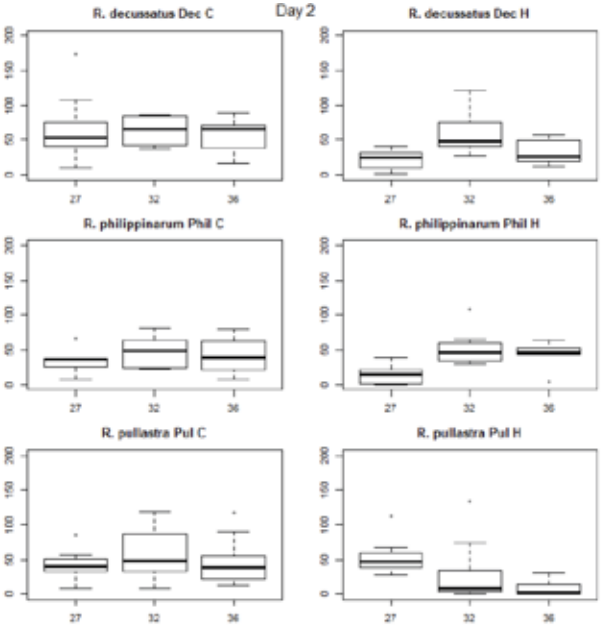
Fly, Hilbish, Wethey, Rognstad 2015. Am Malacol Bull 33:1-14

Effect of Temperature on activity of commercial clams in Spain

Porewater pressure dynamics due to burrowing



Pressure Pulses per Hour



R decussatus
Long siphons
€ €

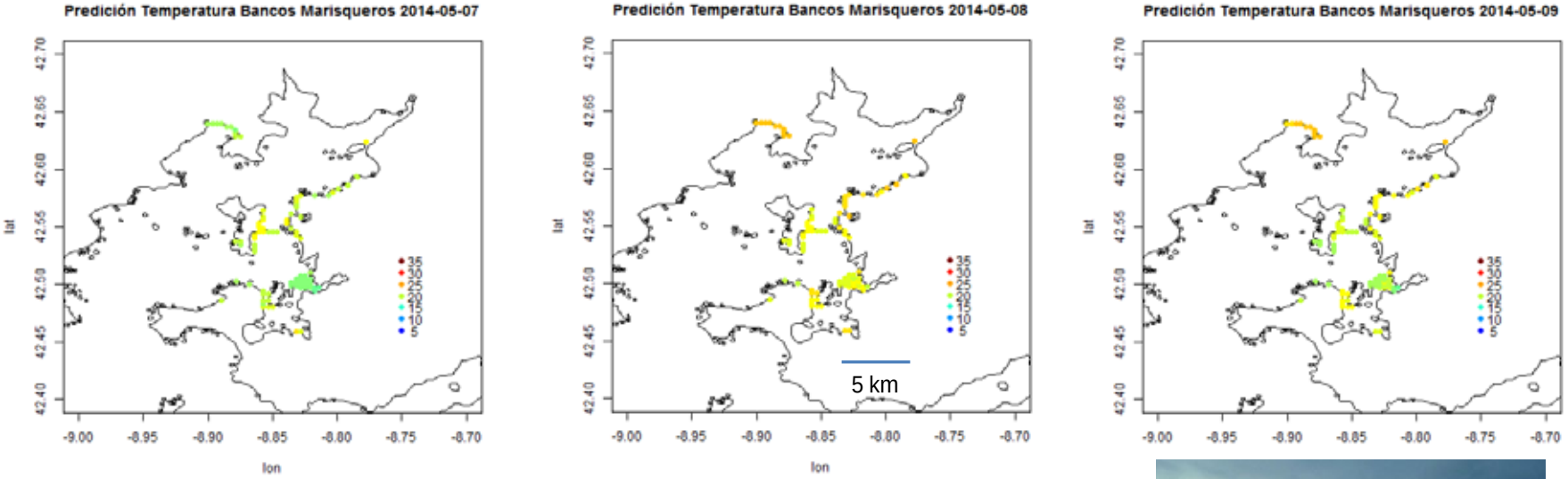
R philippinarum
Shortest siphons
€

V pullastra
Medium siphons
€ € €

Decussatus increased activity	32°C
Philippinarum increased activity to	36°C
Pullastra reduced activity 32°C died	36°C

Collaboration with fisheries cooperatives in Galicia (NW Spain)

Short-term forecasting of **temperatures** in commercial intertidal clam beds
Ría de Arousa – most important grow-out region in Spain



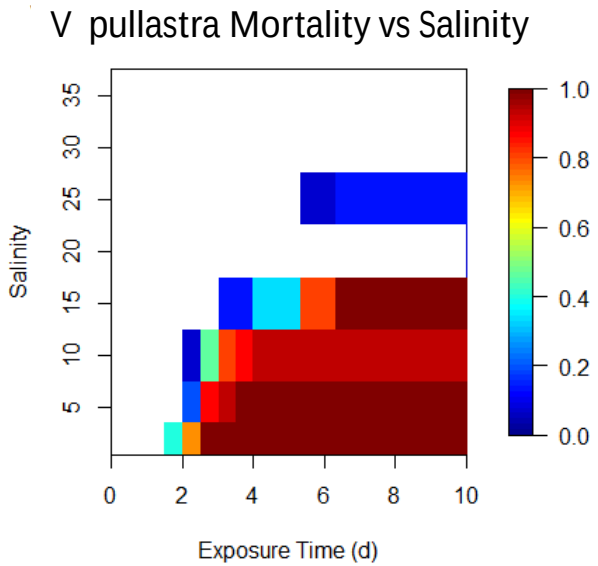
Mortality model from lab experiments
Short term intertidal temperature forecasts
1km WRF meteorological model (Meteo-Galicia)
250 m MOHID ocean model (Meteo-Galicia)
NOAH intertidal sediment land surface model

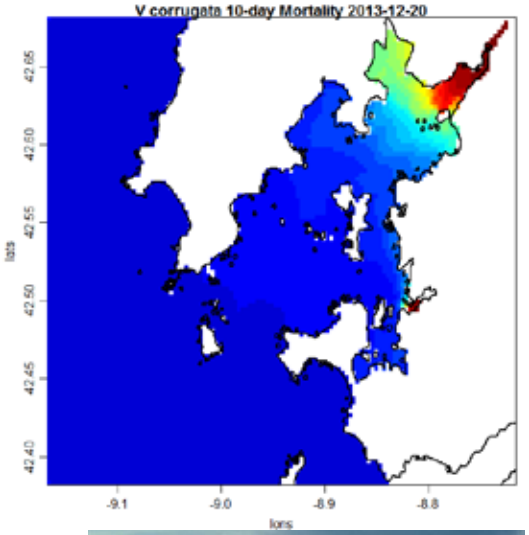
3-day forecasts of risky conditions
Advance warning of die-offs

Working on extending forcecasts to 7 days

Collaboration with fisheries cooperatives in Galicia (NW Spain)

Short-term forecasting of **salinity** in commercial intertidal clam beds
Ría de Arousa – most important grow-out region in Spain



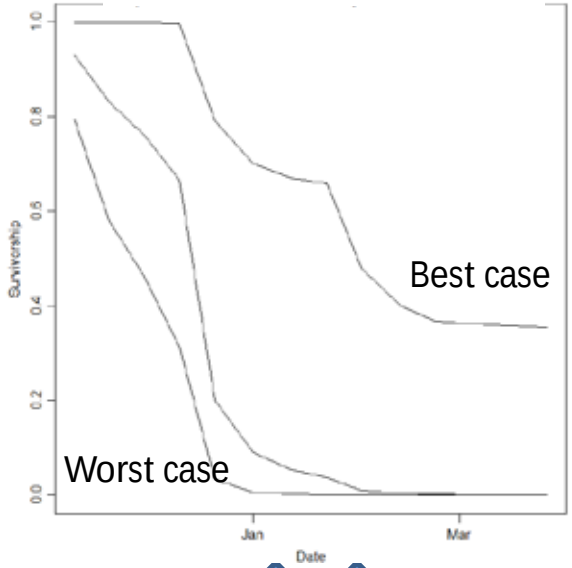


Mortality model from lab experiments
250 m MOHID ocean model (Meteo-Galicia)
SWAT rainfall-runoff model (Meteo-Galicia)
Short term intertidal salinity forecasts

3-day forecasts of mortality risk
Advance warning of die-offs

Working to extend forecasts to 7 days

V pullastra Mortality



Catastrophic harvest losses in winter 2013-2014
Due to heavy rains causing salinity reduction
in upper Ría de Arousa

Our model predicted high mortality in the upper estuary at time of reports of mass mortality

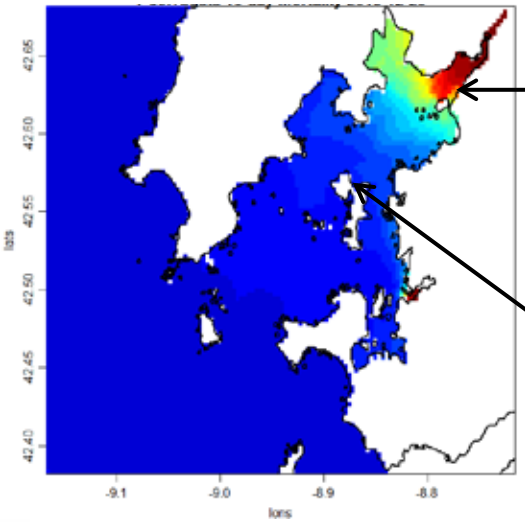
Diario de Arousa.com

Los arenales se llenan de almejas muertas que confirman pérdidas millonarias en Carril

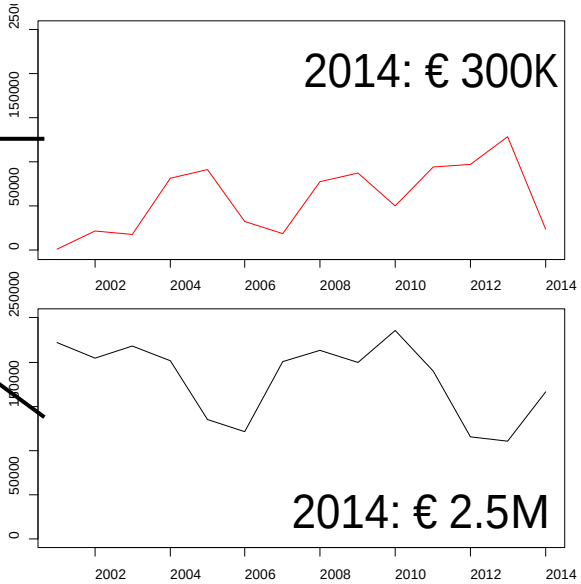
S. L. villagarcía | 03 de Febrero de 2014

Conchas y almejas muertas por la baja salinidad del agua llenan ya las playas (J. Salgado)

V pullastra Mortality



V pullastra Harvest



Collaboration with fisheries cooperatives in Galicia (NW Spain)

Gender bias in effects of climate change on fisheries

- Women harvest exclusively the intertidal
- Men harvest exclusively the subtidal
- As the climate warms, and the most valuable clams are forced lower on the shore, the women will lose their livelihood and the men will gain a resource.
- We are starting a collaborative project with ecologists, physiologists, forecasters (our group), and socioeconomic modelers, and several fisheries cooperatives, to build short term forecasts based on MeteoGalicia models, and long term scenario models of economic consequences based on CMIP5.
- Funded by Spanish Ministry of Economy and Competitiveness

GOBIERNO DE ESPAÑA

MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

Summary

- Ecosystem engineers and commercially important species moving poleward
  - Consequences for mariculture, nutrient fluxes, community composition, gender bias in economics of fisheries
- Important to consider physiological performance in species distribution models
- Metapopulation approach is very powerful
- Model stationarity/transferability related to physiological performance and environmental variability
- Distribution models need to include extreme events
- All models are hypotheses
  - Don’t trust any individual model – use ensembles