The role of temperature in determining how marine fish will be differentially affected by climate change

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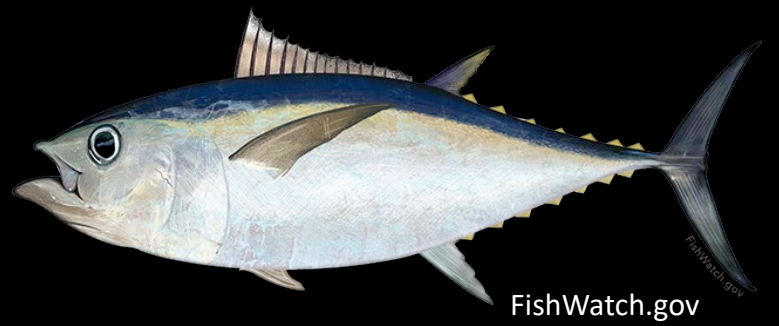
Jeff Polovina, Jen Raynor, Megan Donahue, Kyle Edwards, & Axel Timmermann

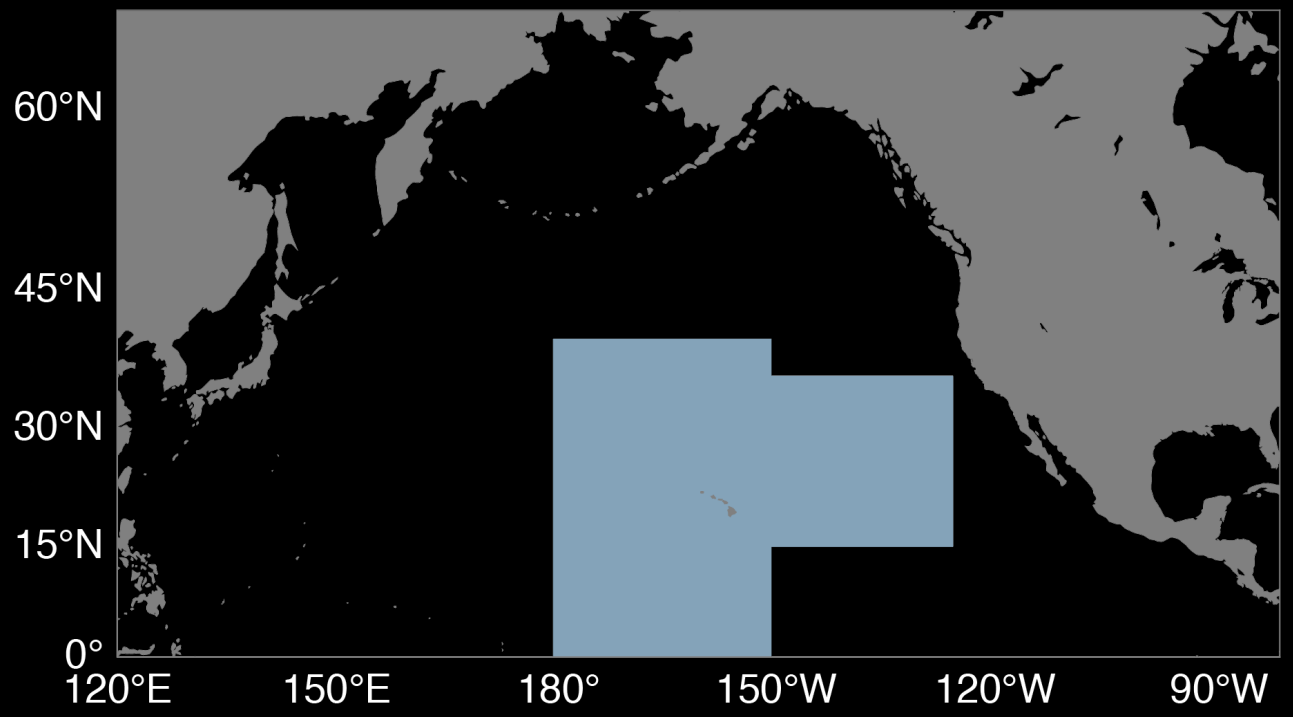
Hawaii-based longline fishery – 2016

- 141 vessels
- 50 million hooks
- > 15 million km^2



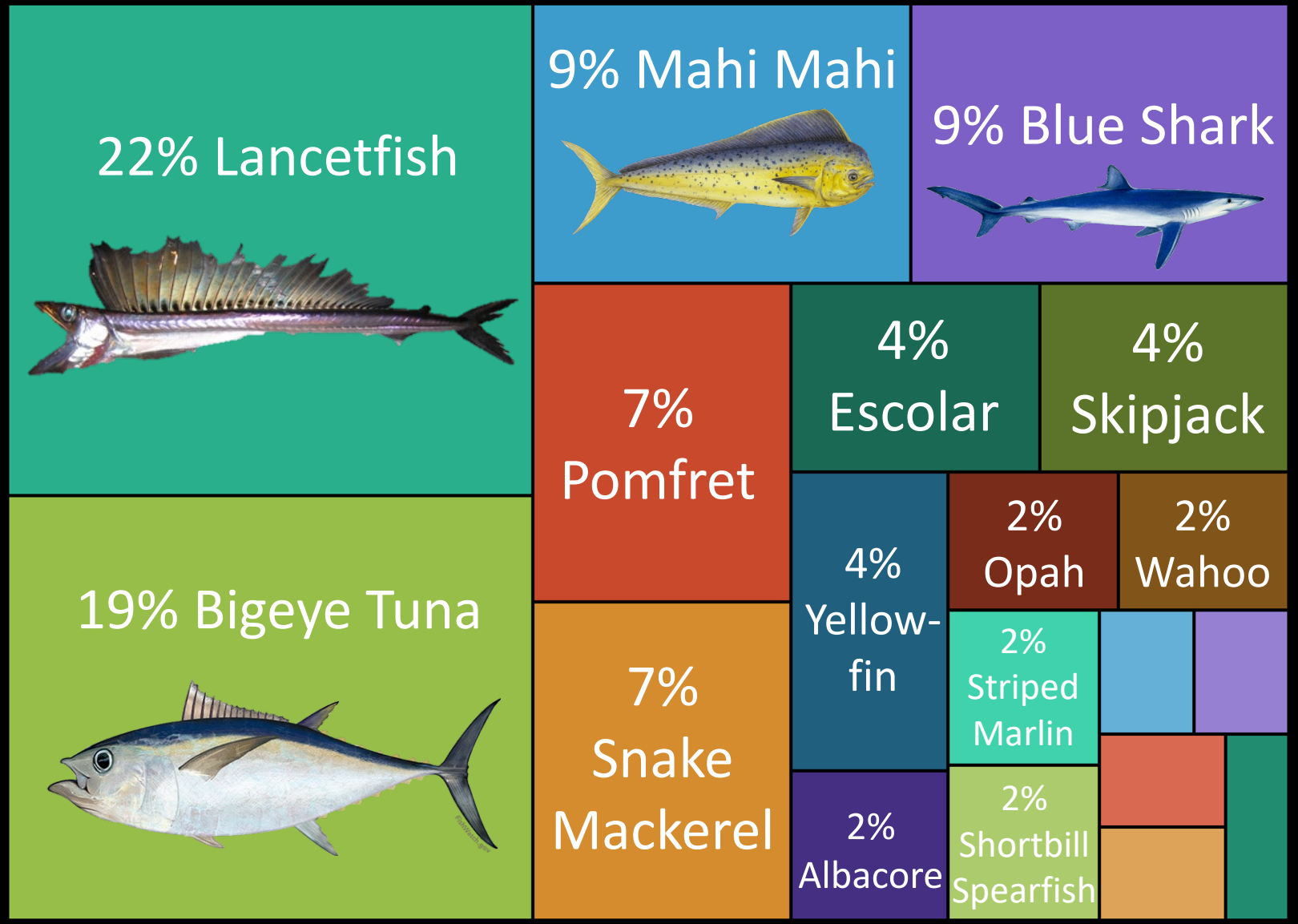
- Total landings
  - $106 million (6th in US)
  - 32 million pounds (26th in the US)
  - 40% of US tuna landings

- Larger economic impact
  - 9,900 jobs
  - $867 million sales impact
  - 57% of US tuna landings revenue



NOAA National Marine Fisheries Service

Hawaii's Longline Fishery for Bigeye Tuna – Catch



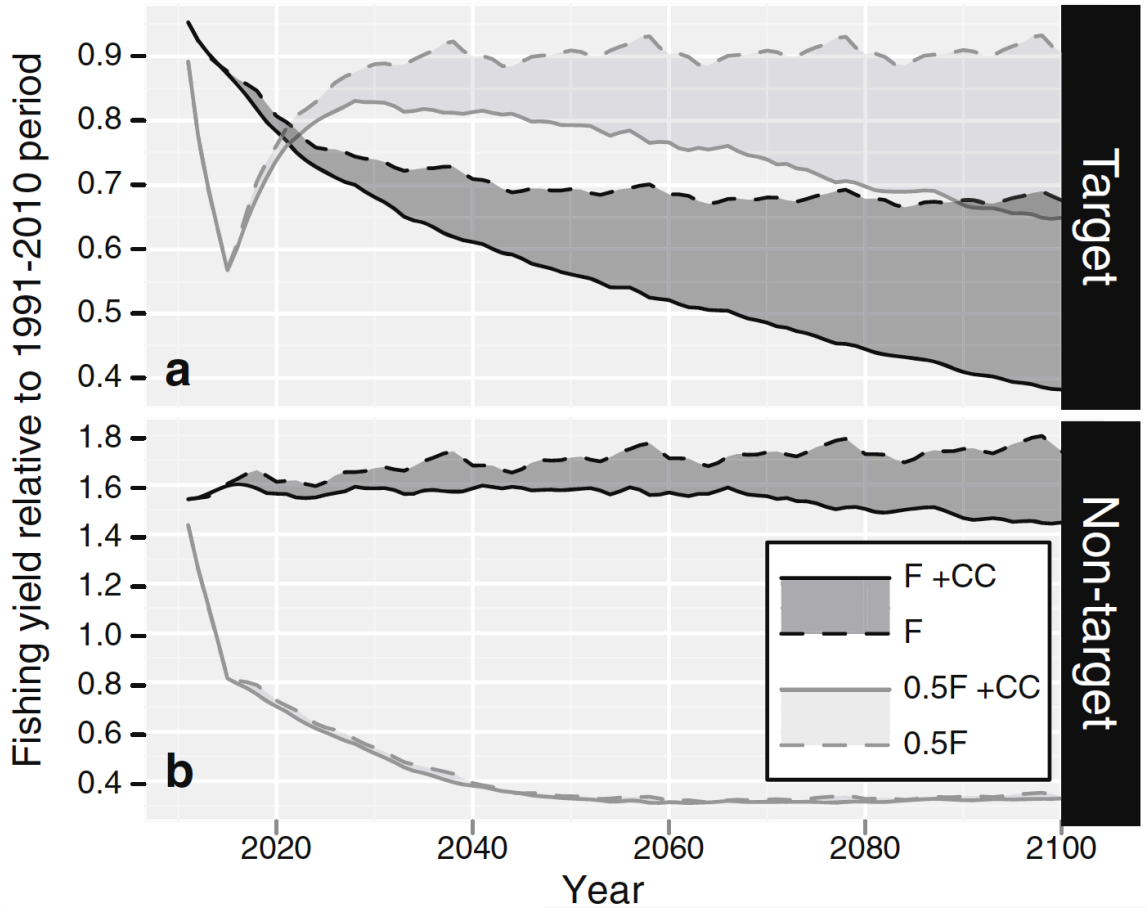
Roughly 1% each

Bigeye Thresher Shark
Swordfish
Pelagic Stingray
Blue Marlin
Shortfin Mako Shark

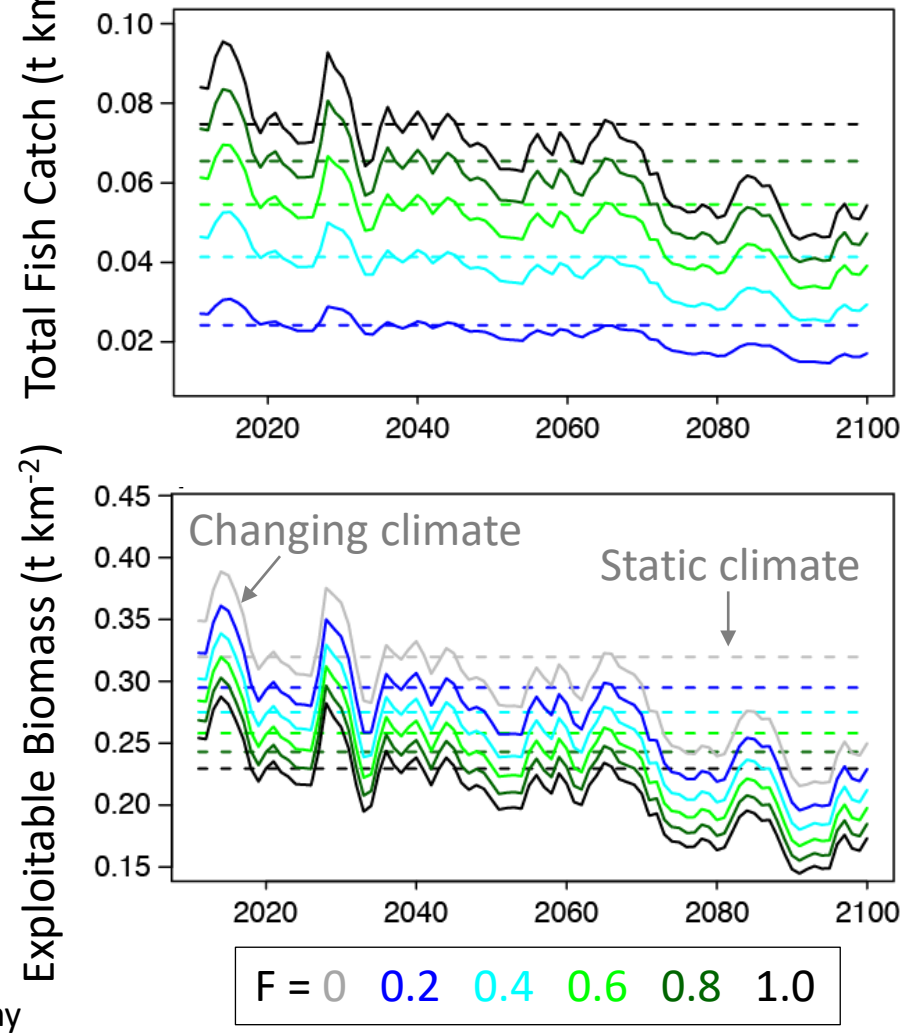
Fish images from FishWatch.gov, NOAA Fisheries, and SeafoodWatch.org

Projected Climate Change Effects

Ecopath with Ecosim Model

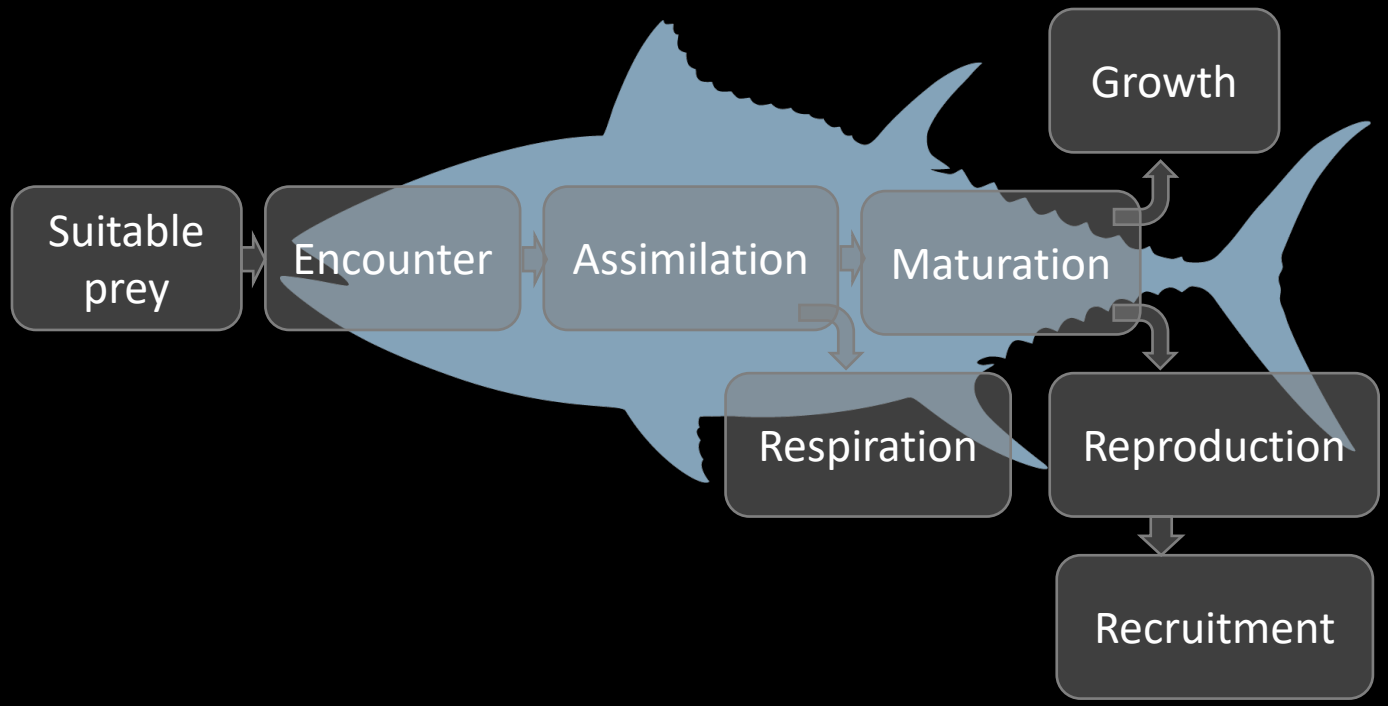


Size-based Food Web Model



Howell et al. 2013 Climatic Change; Woodworth-Jefcoats et al. 2015 Progress in Oceanography

mizer processes



Methods in Ecology and Evolution
British Ecological Society
Methods in Ecology and Evolution 2014, **5**, 1121–1125 doi: 10.1111/2041-210X.12256

APPLICATION

mizer: an R package for multispecies, trait-based and community size spectrum ecological modelling

Finlay Scott[1,2]*, Julia L. Blanchard[3] and Ken H. Andersen[4]

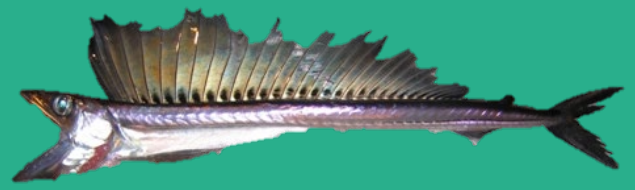
[1]*Maritime Affairs Unit, IPSC, European Commission Joint Research Centre, Via Enrico Fermi 2749, I – 21027 Ispra (VA), Italy;* [2]*Centre for the Environment Fisheries and Aquaculture Science (CEFAS), Pakefield Road, Lowestoft NR33 0HT, UK;* [3]*Department of Animal and Plant Sciences, University of Sheffield, Alfred Denny Building, Western Bank, Sheffield S10 2TN, UK; and* [4]*Centre for Ocean Life, National Institute of Aquatic Resources, Technical University of Denmark, 2920 Charlottenlund Slot, Charlottenlund, Denmark*

R package available at:
https://github.com/sizespectrum/mizer

Figure modified from Scott *et al*. 2014
Tuna image courtesy of Amanda Dillon

Species Modeled

22% Lancetfish



9% Mahi Mahi

9% Blue Shark

19% Bigeye Tuna

7% Pomfret

7% Snake Mackerel

4% Escolar

4% Skipjack

4% Yellow-fin

2% Opah

2% Wahoo

2% Striped Marlin

2% Albacore

2% Shortbill Spearfish

Roughly 1% each

Bigeye Thresher Shark

Swordfish

Pelagic Stingray

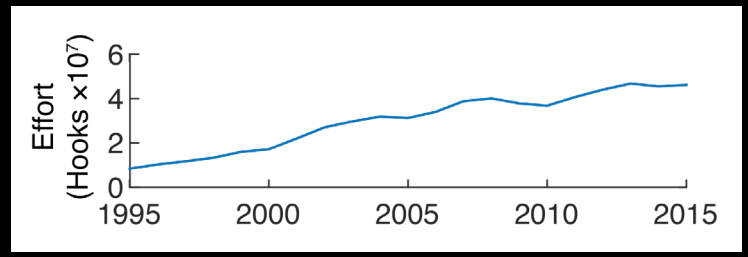
Blue Marlin

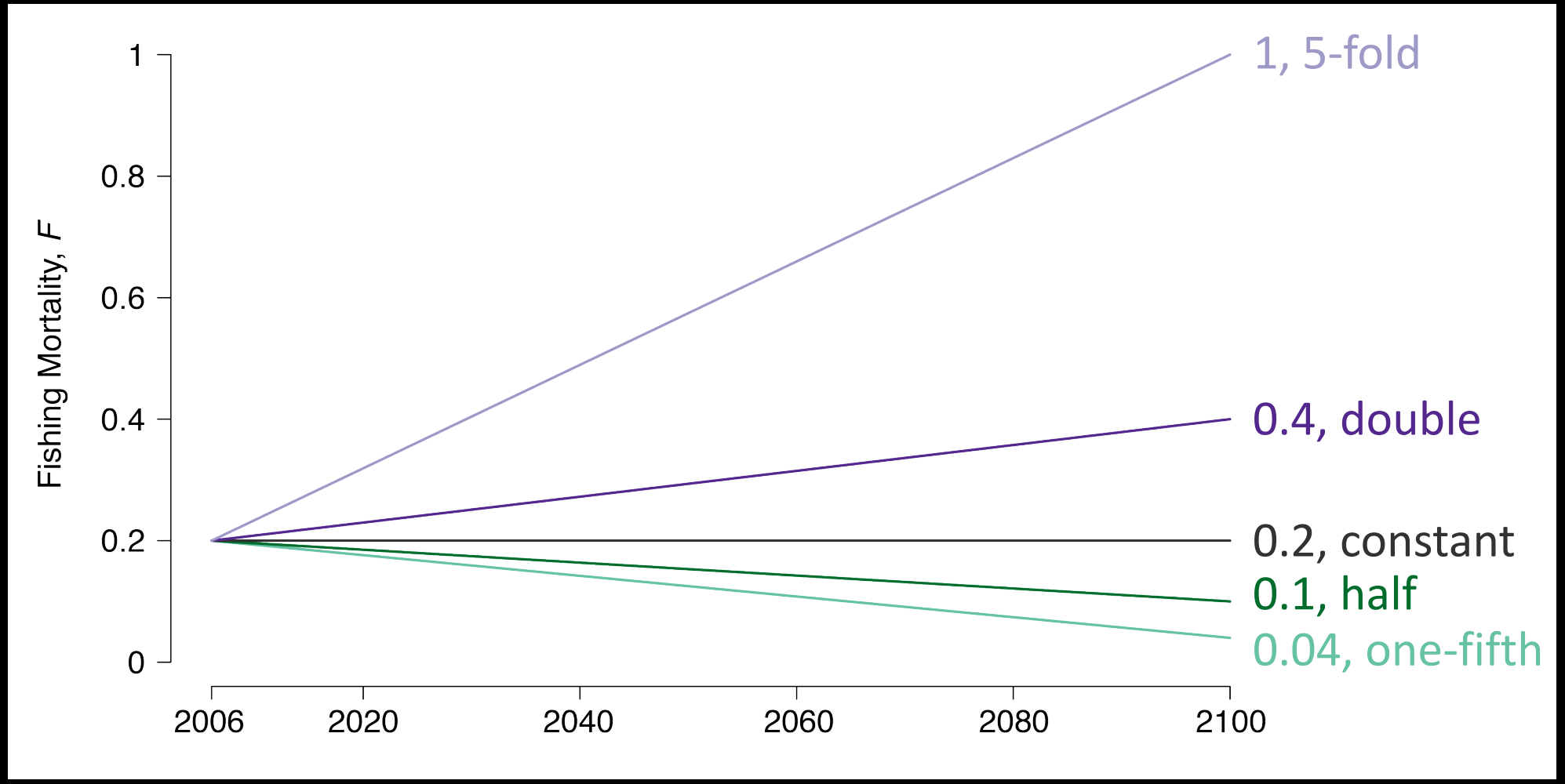
Shortfin Mako Shark

Fish images from FishWatch.gov, NOAA Fisheries, and SeafoodWatch.org

Fishing Scenarios

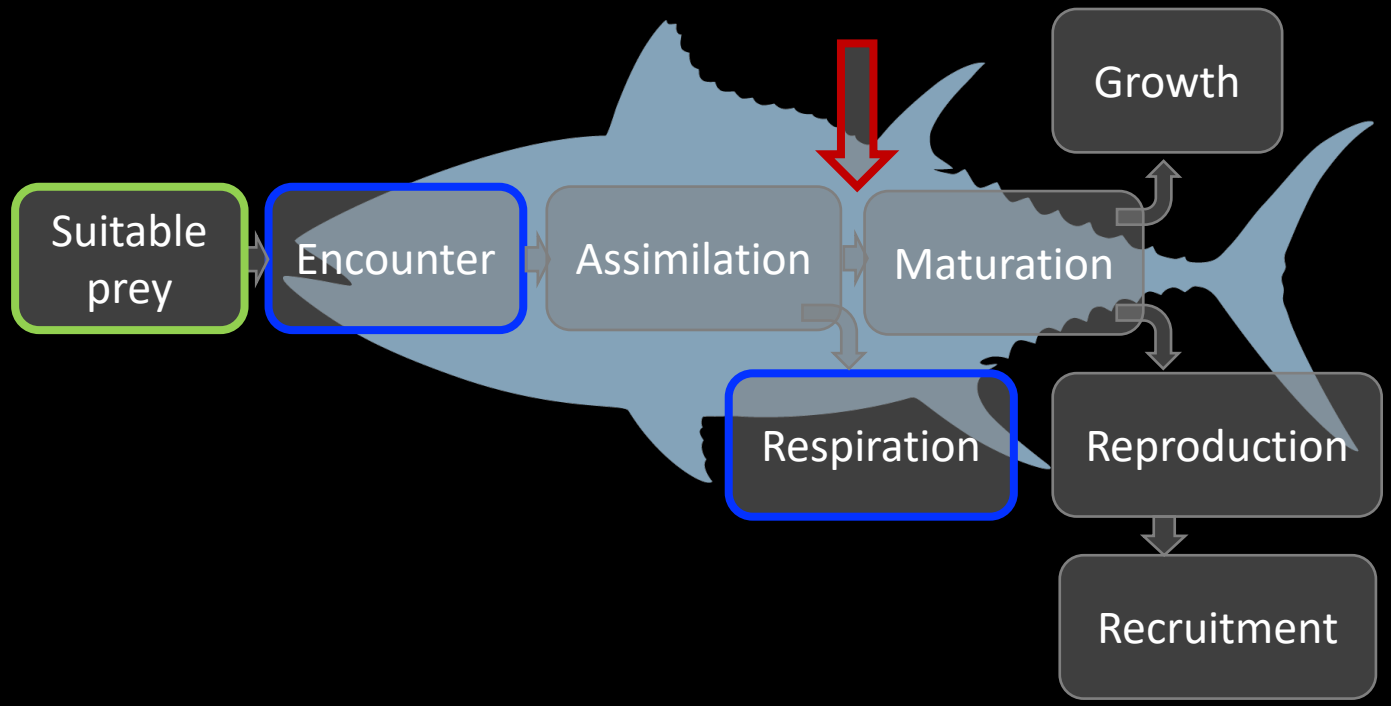
- Range of fishing mortality values





therMizer

Phyto- and Zooplankton densities | Temperature | Fishing mortality



R package available at:
https://github.com/pwoodworth-jefcoats/Size-Based-Modeling

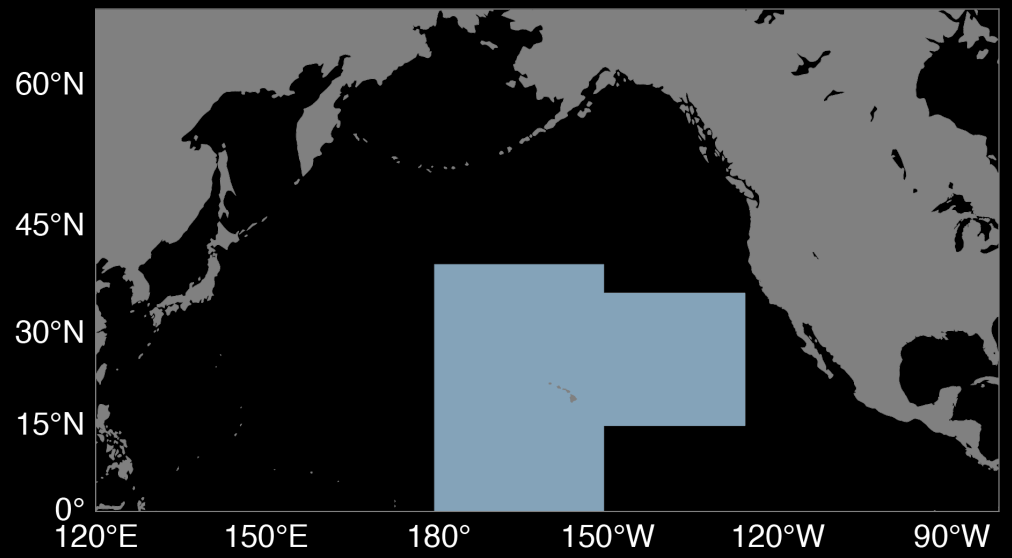


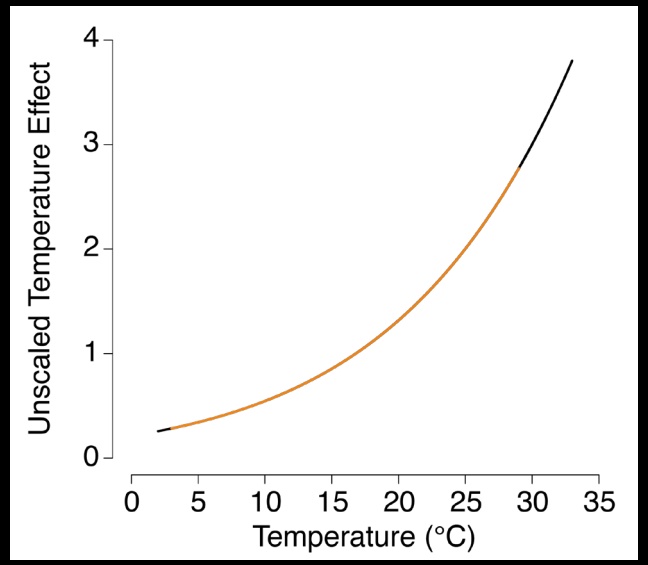
Figure modified from Scott *et al*. 2014
Tuna image courtesy of Amanda Dillon

therMizer Temperature effect on respiration

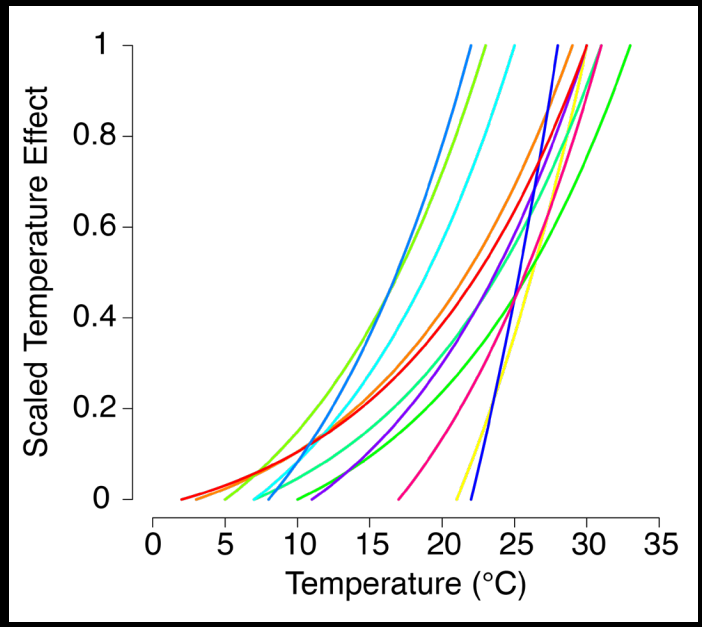
Boltzmann factor or
Arrhenius relation:

$$e^{\left(25.22-\frac{0.63}{(8.52\times10^{-5})(T+273)}\right)}$$

Brown *et al*. 2004; Jennings *et al.* 2008



Scale by subtracting minimum
and dividing by range



Multiplier for metabolic costs

Species
- Lancetfish
- Bigeye
- Mahi mahi
- Blue shark
- Skipjack
- Yellowfin
- Albacore
- Opah
- Wahoo
- Striped marlin
- Swordfish
- Blue marlin

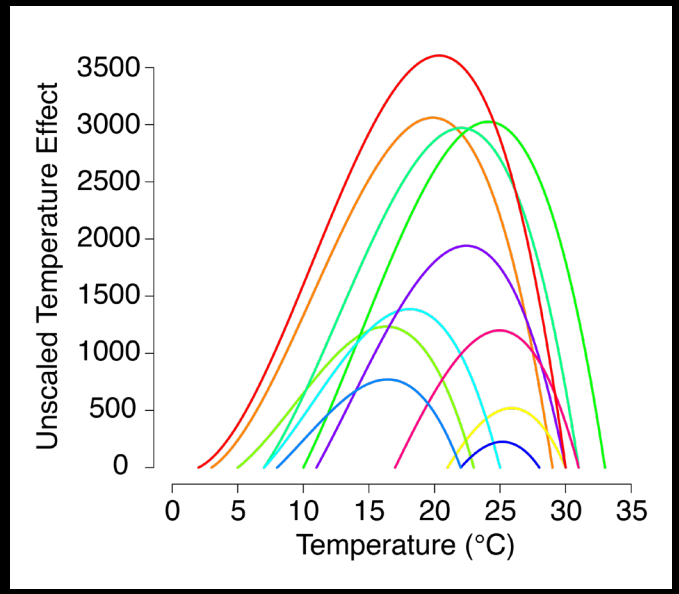
Woodworth-Jefcoats et al. 2019, Frontiers in Marine Science

therMizer Temperature effect on encounter rate

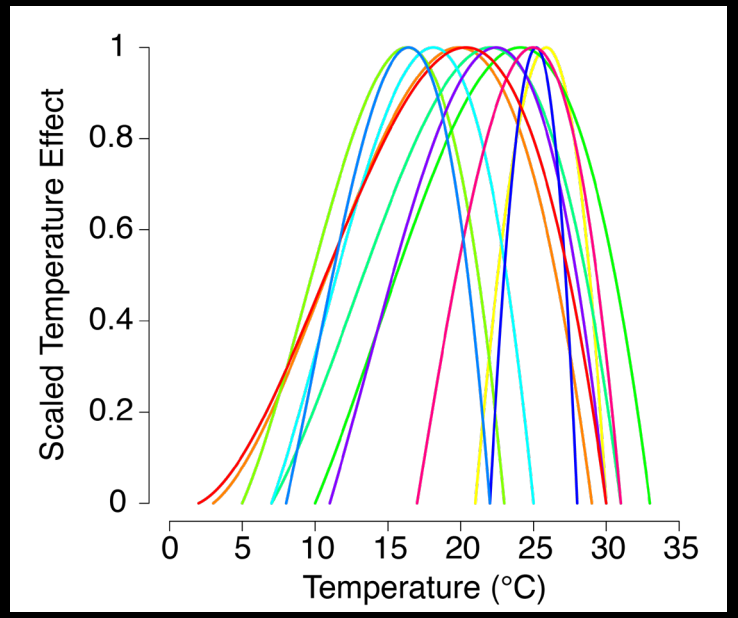
Thermal optimum from generic polynomial rate equation:

$$T(T - T_{min})(T_{max} - T)$$

Pörtner and Peck 2010; van der Heide *et al*. 2006



Scale by dividing by maximum



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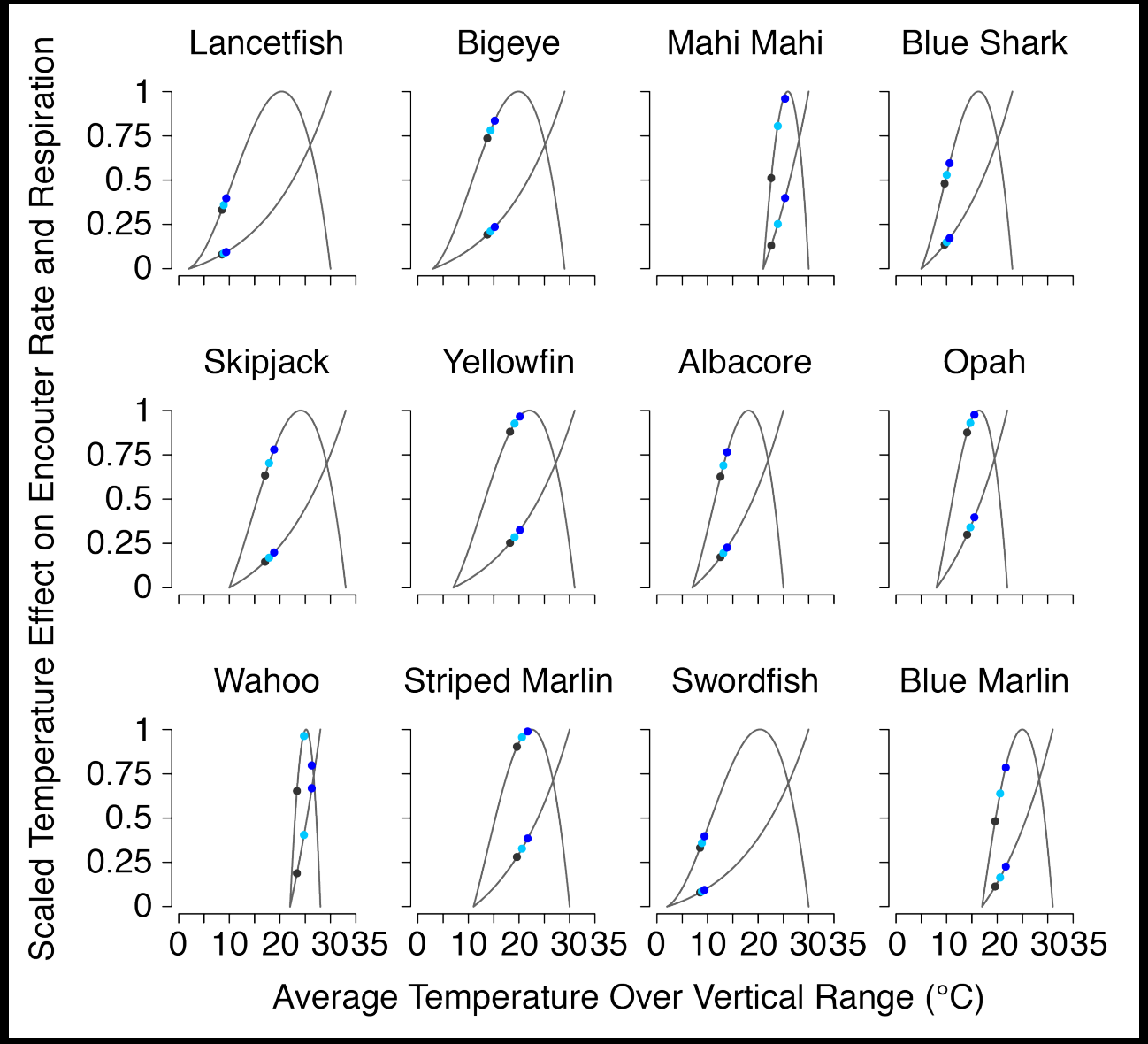
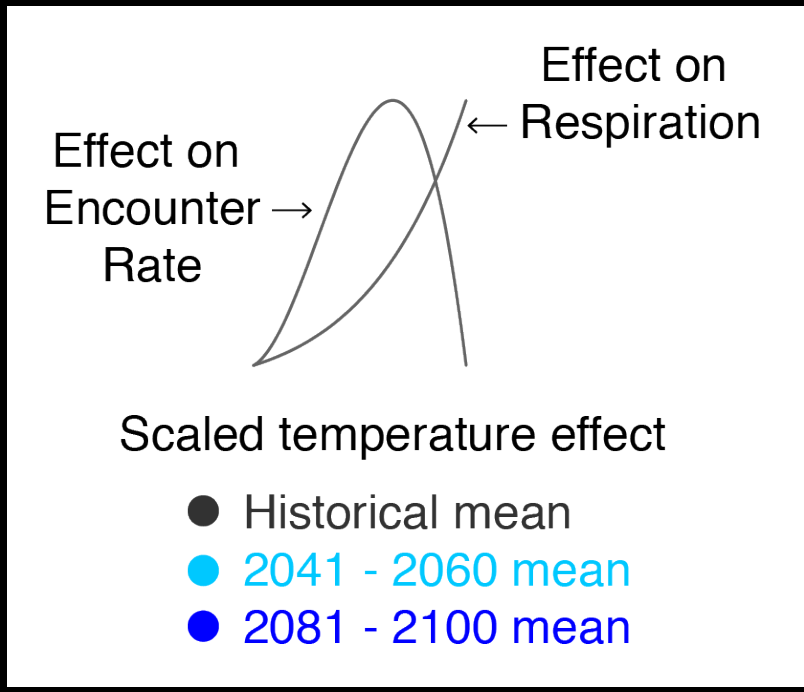
Woodworth-Jefcoats et al. 2019, Frontiers in Marine Science

therMizer Temperature effects

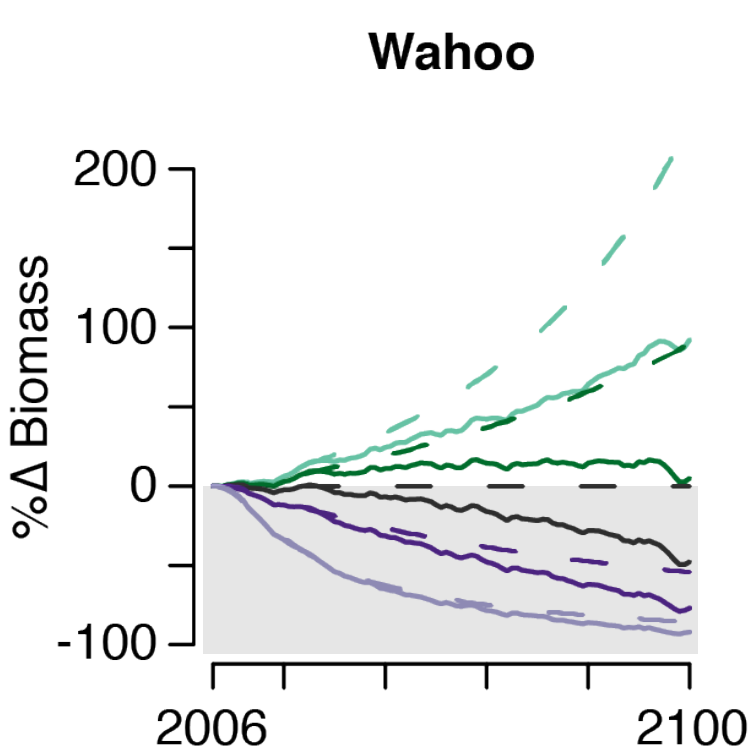




Woodworth-Jefcoats et al. 2019, Frontiers in Marine Science

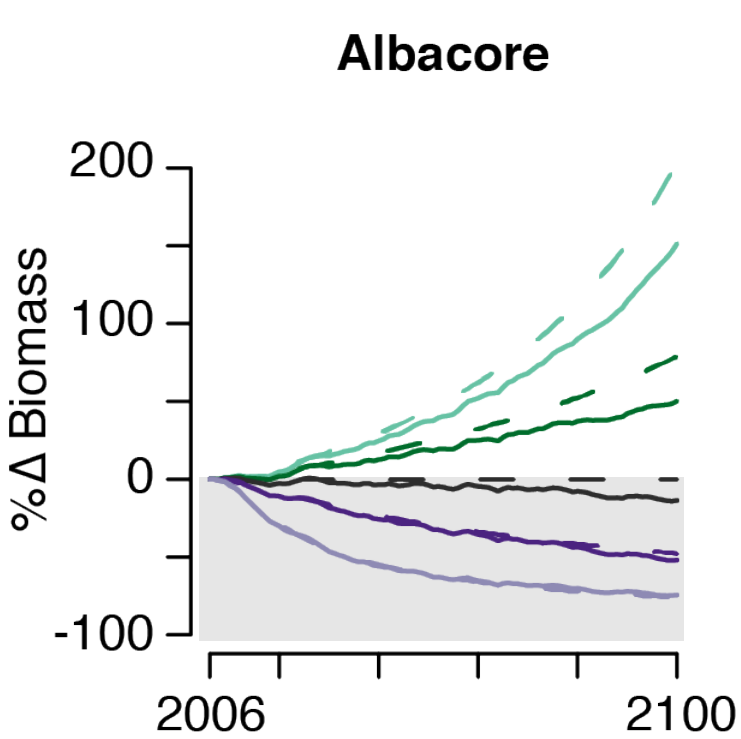
therMizer Results – Total Biomass

5-Fold Double
Constant
Fifth Half



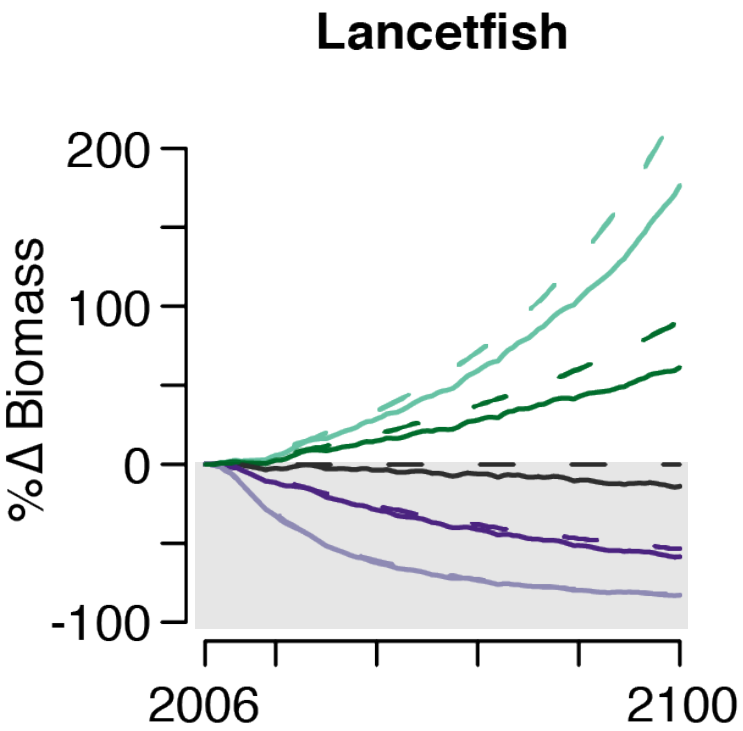
Max depth = 20m

Boettiger et al. 2012, Froese and Pauly 2017



Max depth = 600m

Boettiger et al. 2012, Froese and Pauly 2017



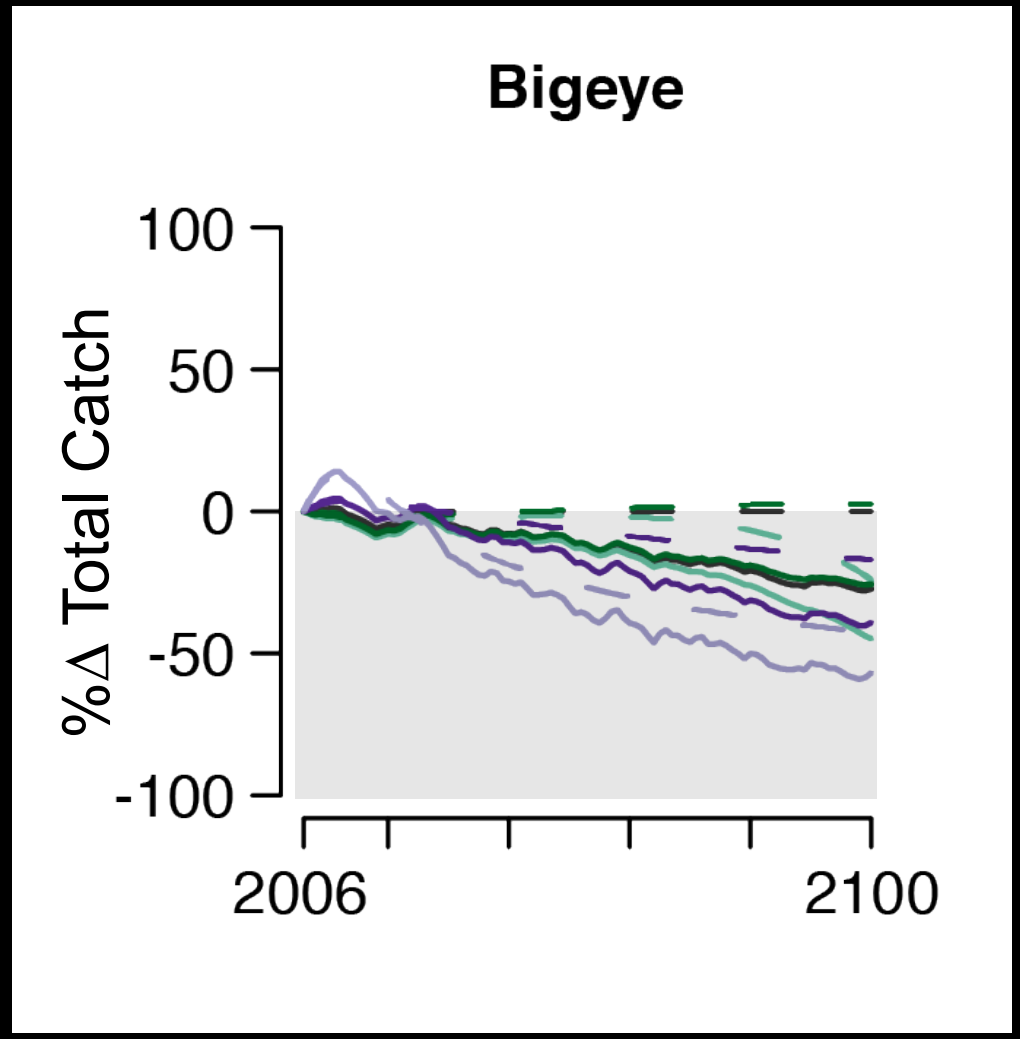
Max depth = 1200m

Portner et al. 2017

Woodworth-Jefcoats et al. 2019, Frontiers in Marine Science

therMizer Results – Total Catch

5-Fold Double
Constant
Fifth Half



25% decline

37% decline

55% decline

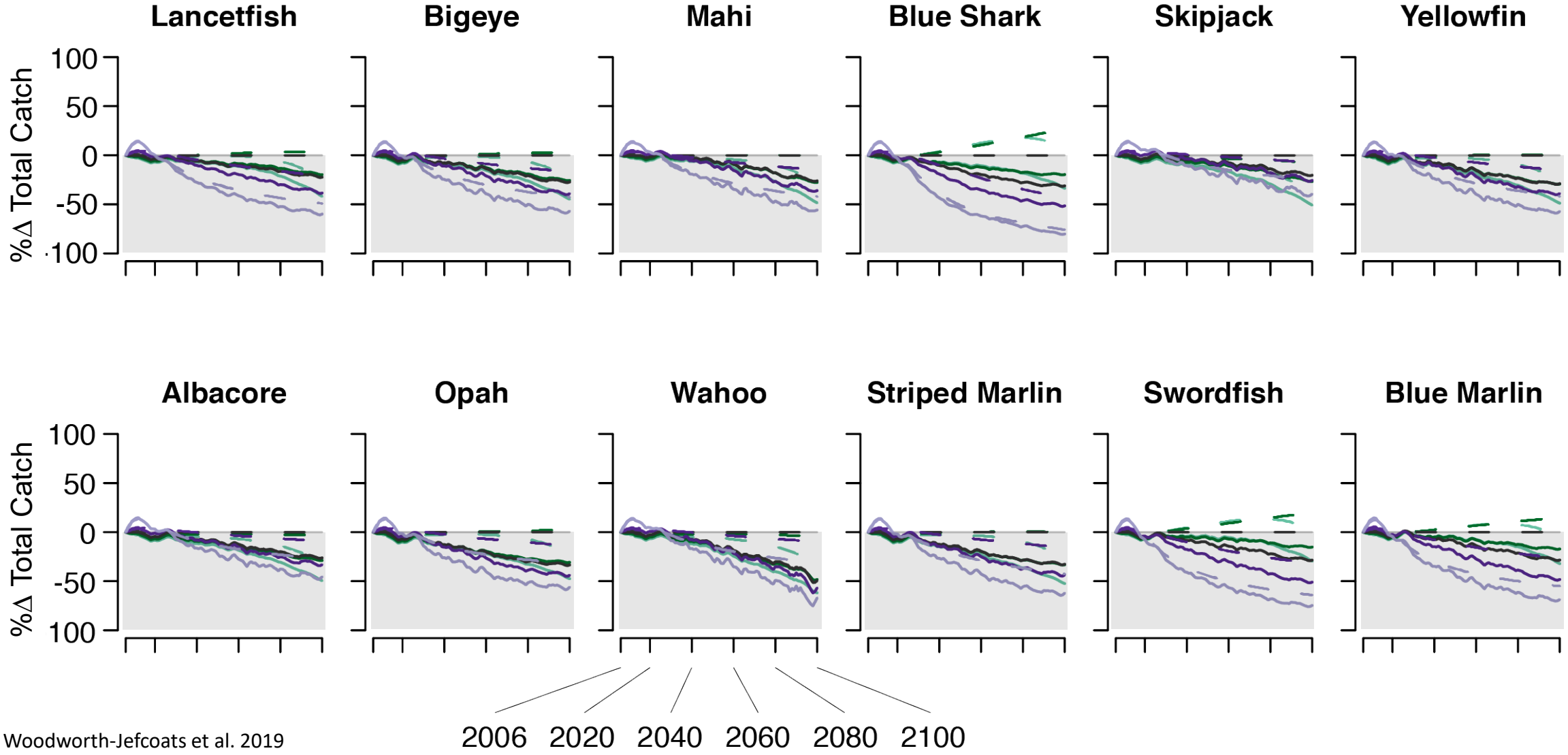
23% decline

35% decline

Woodworth-Jefcoats et al. 2019, Frontiers in Marine Science

therMizer Results – Total Catch

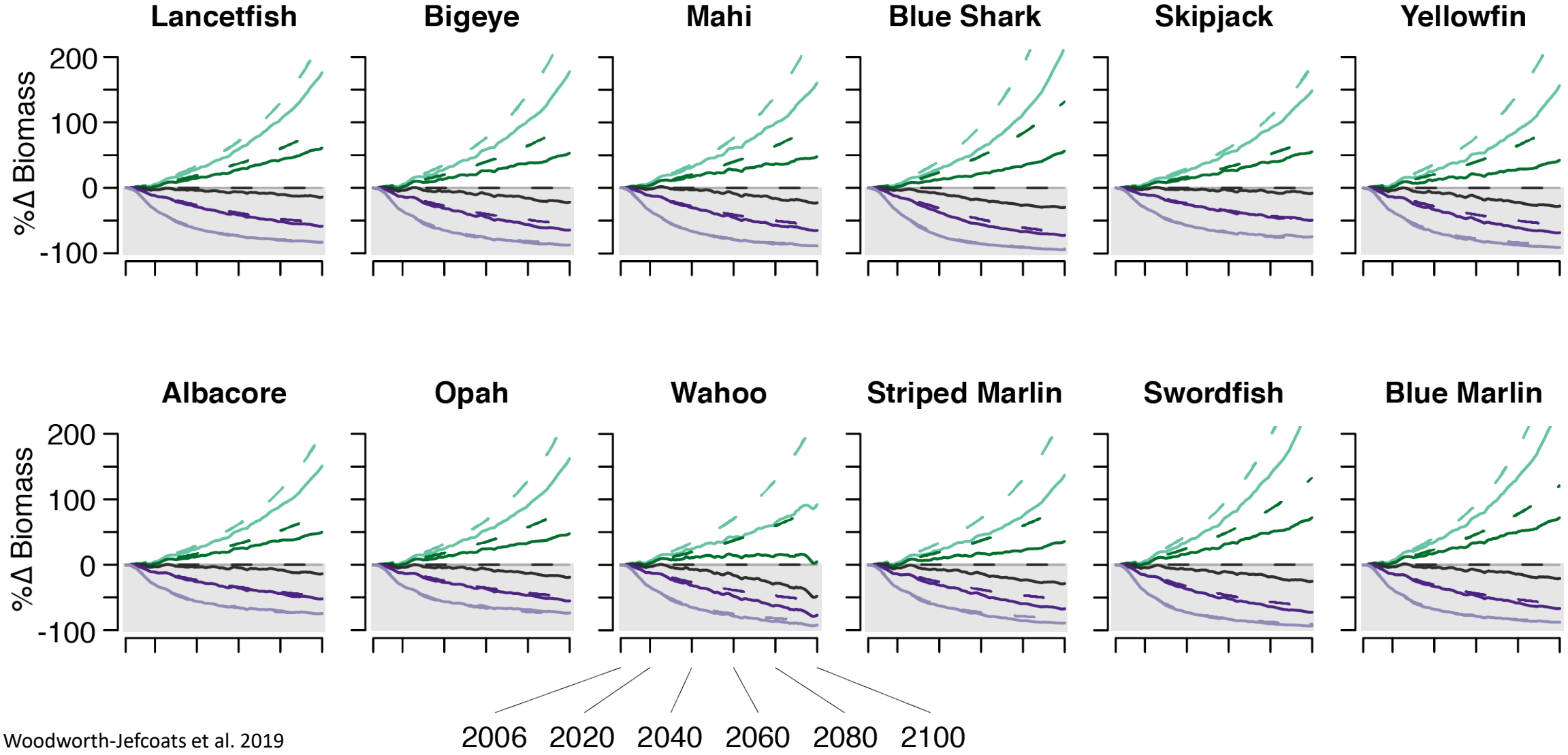
5-Fold Double
Constant
Fifth Half



Woodworth-Jefcoats et al. 2019

therMizer Results – Total Biomass

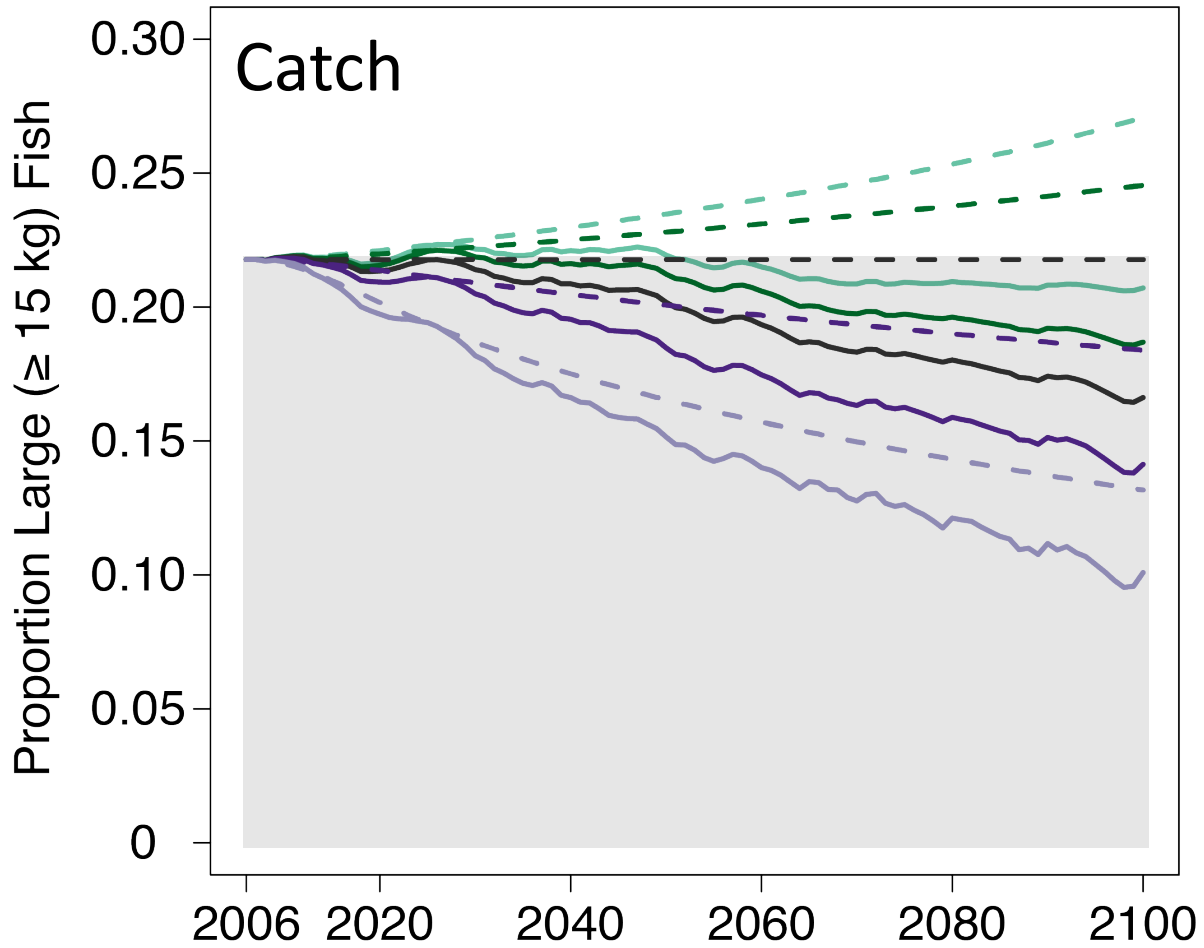
5-Fold Double
Constant
Fifth Half

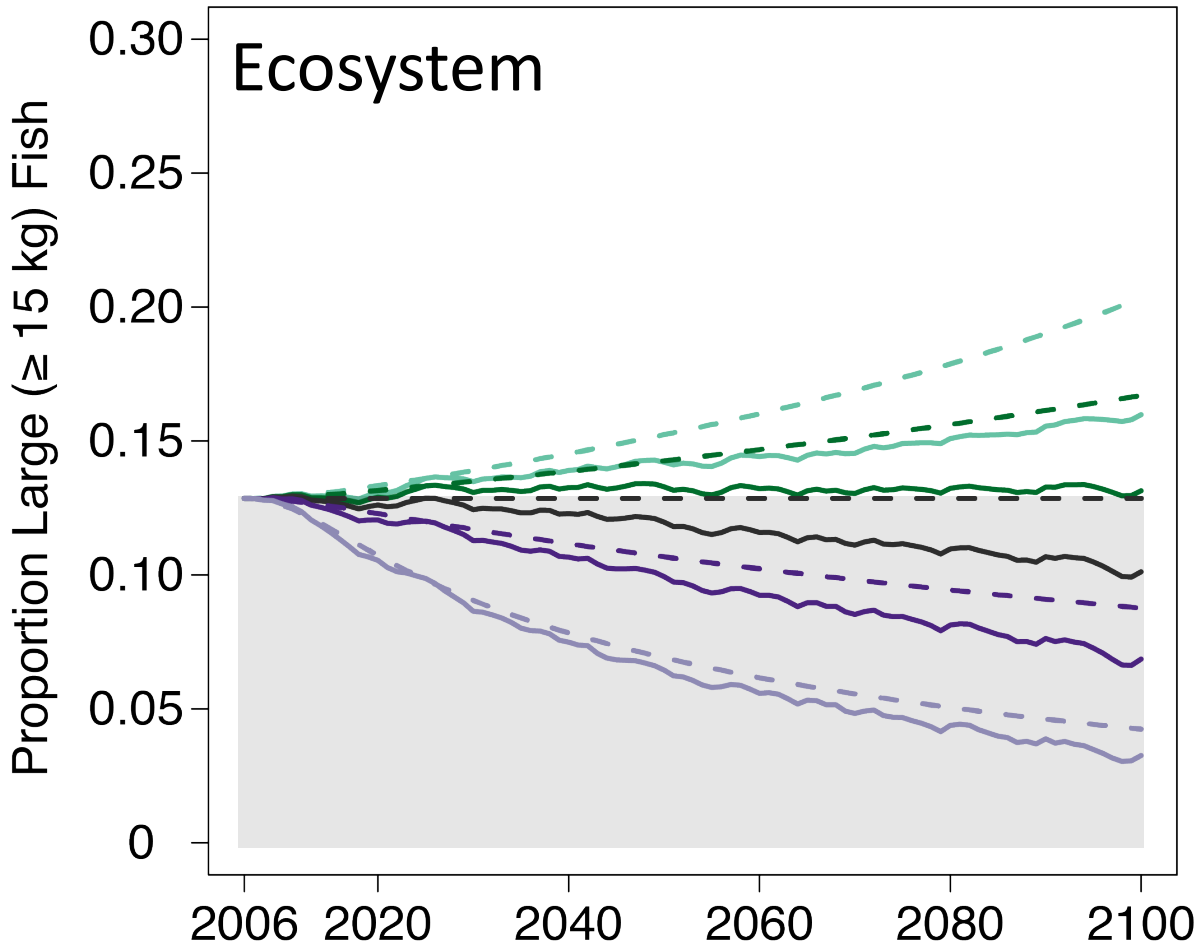


Woodworth-Jefcoats et al. 2019

therMizer Results – Size Structure

5-Fold Double
Constant
Fifth Half





Woodworth-Jefcoats et al. 2019 Frontiers in Marine Science

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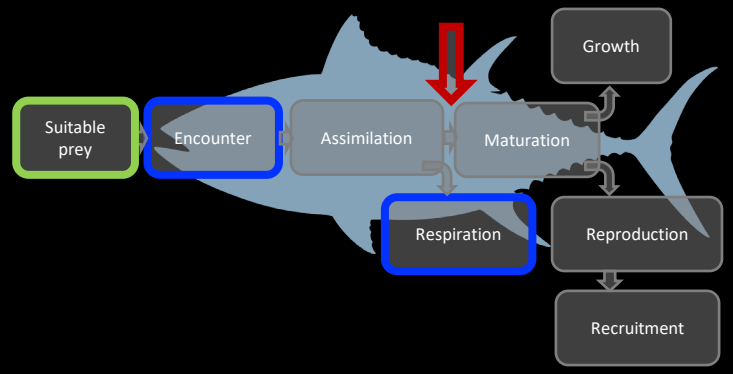
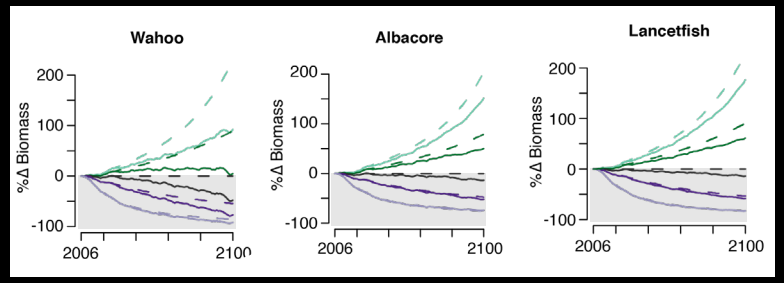
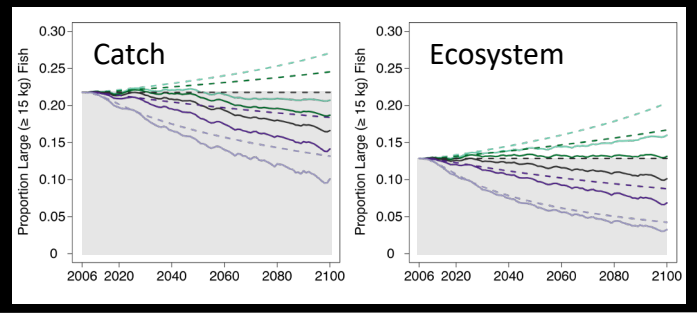


therMizer, size-structured food web model with: individual fish species, dynamic climate, thermal optima



Climate change reduces yield across all species, severity varies based in part on thermal habitat



Reducing fishing mortality may enable ecosystem resilience in the face of climate change

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