Climate change is projected to reduce carrying capacity and redistribute species richness in North Pacific pelagic marine ecosystems

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Physical Drivers of Epipelagic Change

- Warming and Stratification
  - Warming ocean
    - Increased vertical stratification
      - Reduced nutrient input into euphotic zone
- Winds and Gyre Expansion
  - Poleward expansion of Hadley circulation
    - Poleward shift of mid-latitude storm tracks
      - Altered ocean surface wind stress curl
        - Poleward expansion of oligotrophic gyres

Cabré *et al*. 2014; Chang *et al*. 2012; Scheff and Frierson 2012; Yongyun *et al*. 2013; Xu *et al*. 2012

Model Suite

- Canadian Center for Climate Modeling and Analysis Earth system model (**CanESM2**)
- NOAA Geophysical Fluid Dynamics Laboratory Earth System Model
  - Generalized ocean layer dynamics (**GFDL-ESM2G**)
  - Modular Ocean Model 4 (**GFDL-ESM2M**)
- NASA Goddard Institute for Space Sciences ModelE2 Earth System Model
  - Carbon cycle coupled to the HYCOM ocean model (**GISS-E2-H-CC**)
  - Carbon cycle coupled to the Russell ocean model (**GISS-E2-R-CC**)
- HadGEM2 of the Met Office Unified Model
  - Coupled Carbon Cycle (**HadGEM2-CC**)
  - Full Earth System (**HadGEM2-ES**)
- Institut Pierre Simon Laplace
  - Low resolution CM5A (**IPSL-CM5A-LR**)
  - Medium resolution CM5A (**IPSL-CM5A-MR**)
  - Low resolution CM5B (**IPSL-CM5B-LR**)
- Max-Planck-Institute für Meteorolgie Earth System Model
  - Low resolution (**MPI-LR**)
  - Medium resolution (**MPI-MR**)
- Meteorological Research Institute Earth System Model Version 1 (**MRI**)

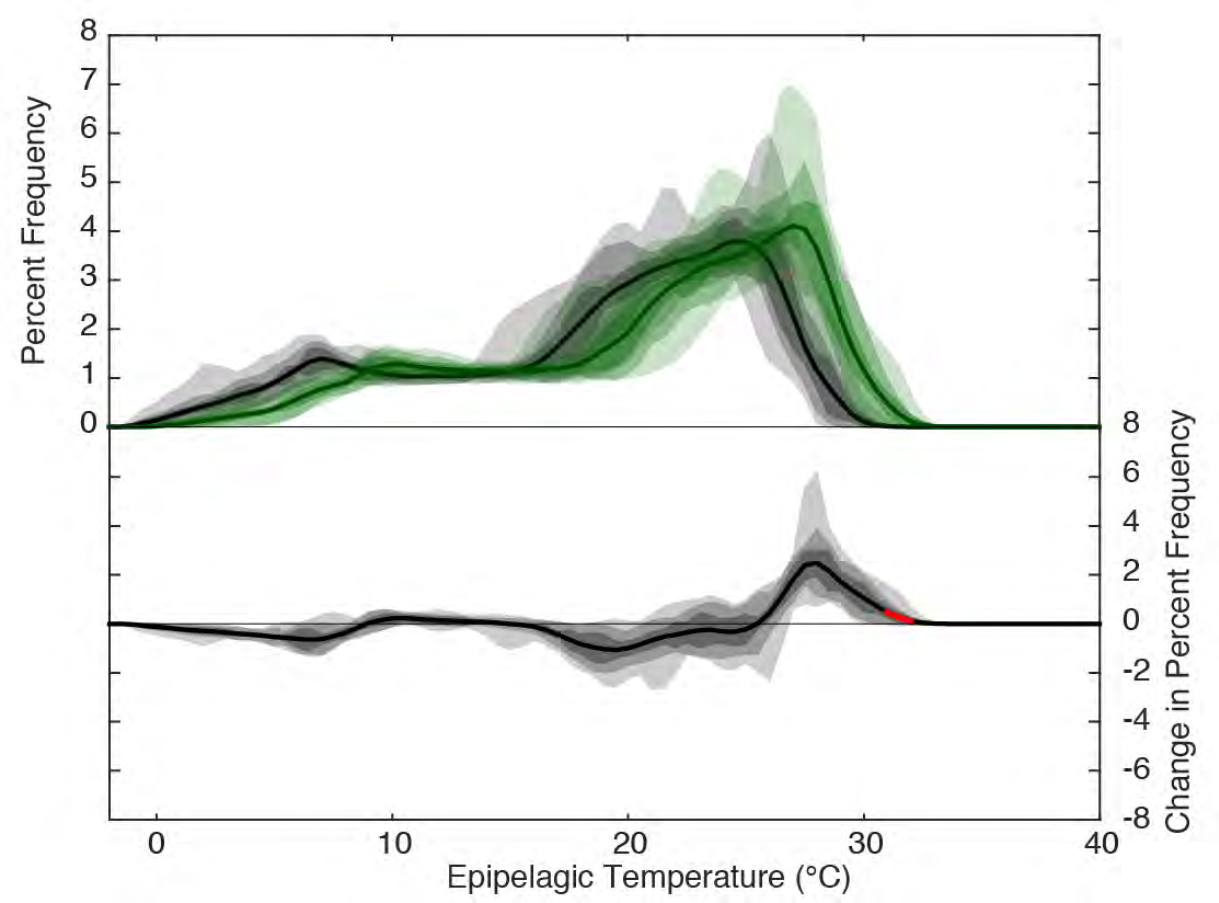
Christian *et al*. 2010; Collins *et al*. 2011;
Dufresne *et al*. 2013; Dunne *et al*. 2013; Giorgetta *et al*. 2013; Romanou *et al*. 2014; Schmidt *et al*. 2014; Taylor *et al*. 2012; Yukimoto *et al*. 2011

Methods

- RCP8.5
- Overall habitat change
  - Temperature
  - Food availability: zooplankton density
- Epipelagic habitat change over 21st century
  - Upper 200 m integrated
- Fishery impacts
  - Trophic amplification
  - Change in species richness
  - Change in carrying capacity
- Time periods of interest
  - Beginning of 21st century: 1986 – 2005 mean (historical)
  - End of 21st century: 2081 – 2100 mean (projection)

Change in Epipelagic Habitat

- Increasing and new epipelagic temperatures



Multi-Model Mean

1986 – 2005 mean

2081 – 2100 mean

Model Agreement

33%

67%

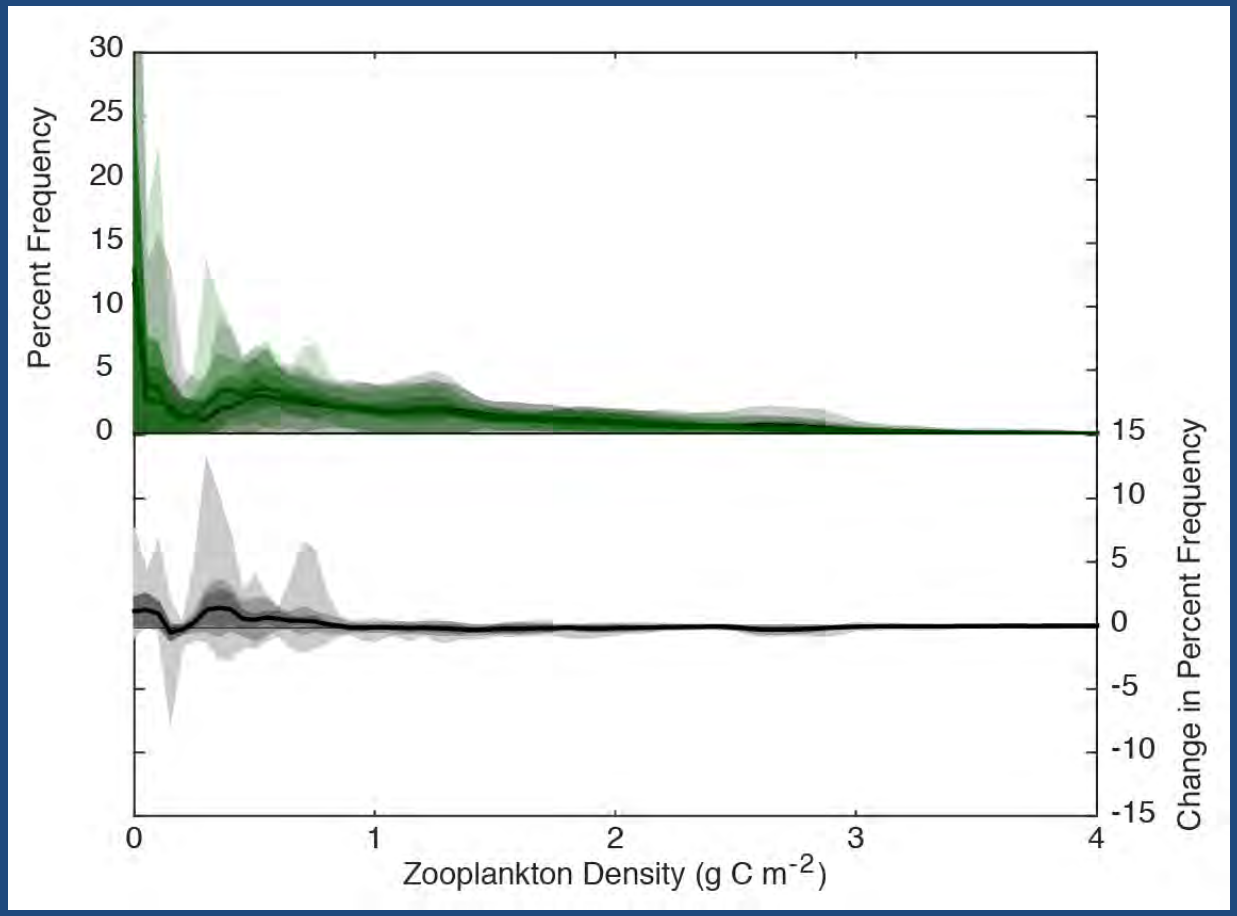
100%

50%

Boyce *et al*. 2008; Grenouillet and Comte 2014; Lehodey *et al*. 2011, 2013; Monterro-Serro *et al*. 2015; Pinskey *et al*. 2013; Storch *et al*. 2014; Walsh *et al*. 2015

Change in Epipelagic Habitat

- Declining zooplankton densities



Multi-Model Mean

1986 – 2005 mean

2081 – 2100 mean

Model Agreement

33%

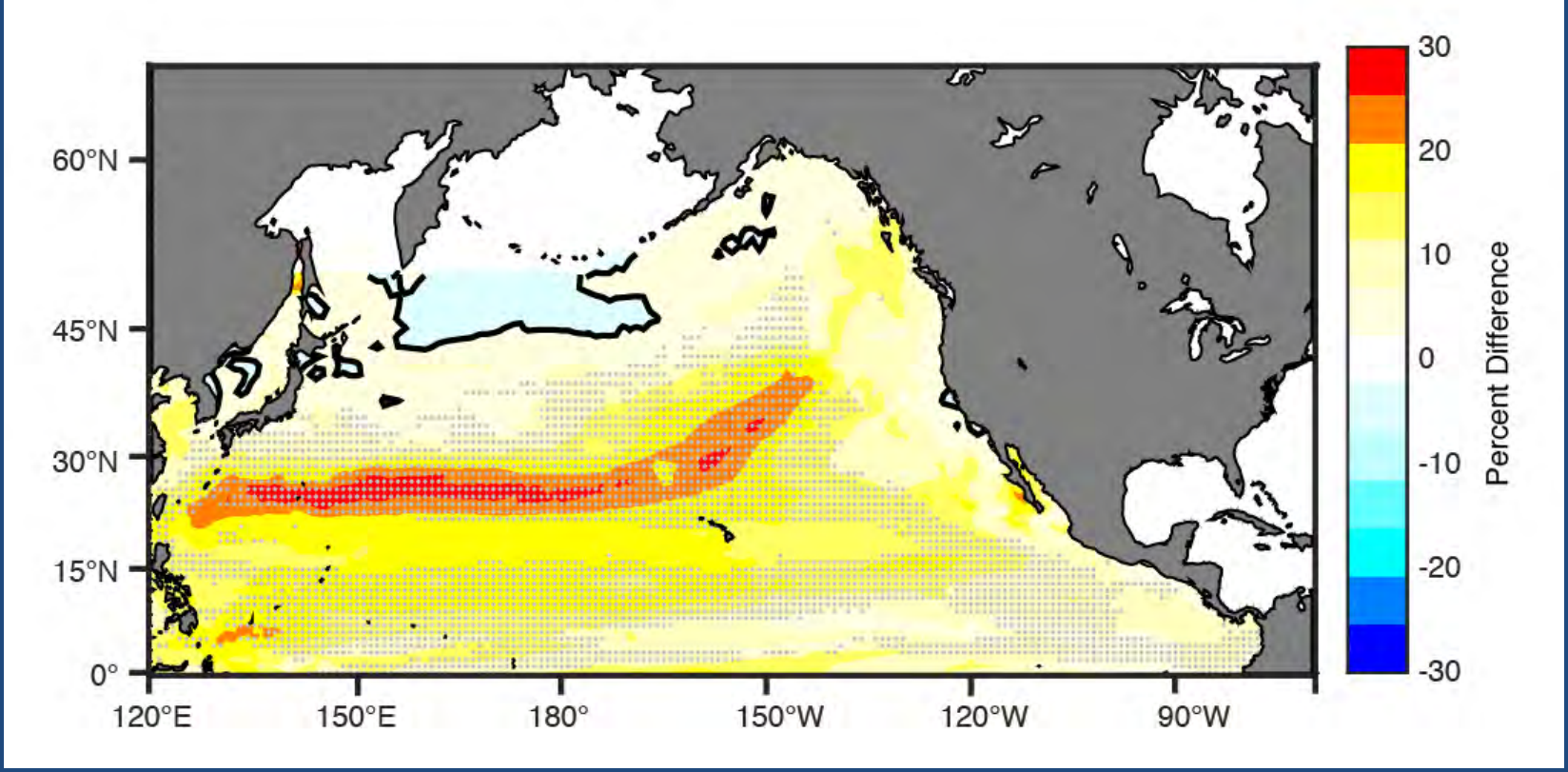
67%

100%

Cabré *et al*. 2014; Polovina *et al*. 2011; Sarmiento *et al*. 2004

Trophic Amplification

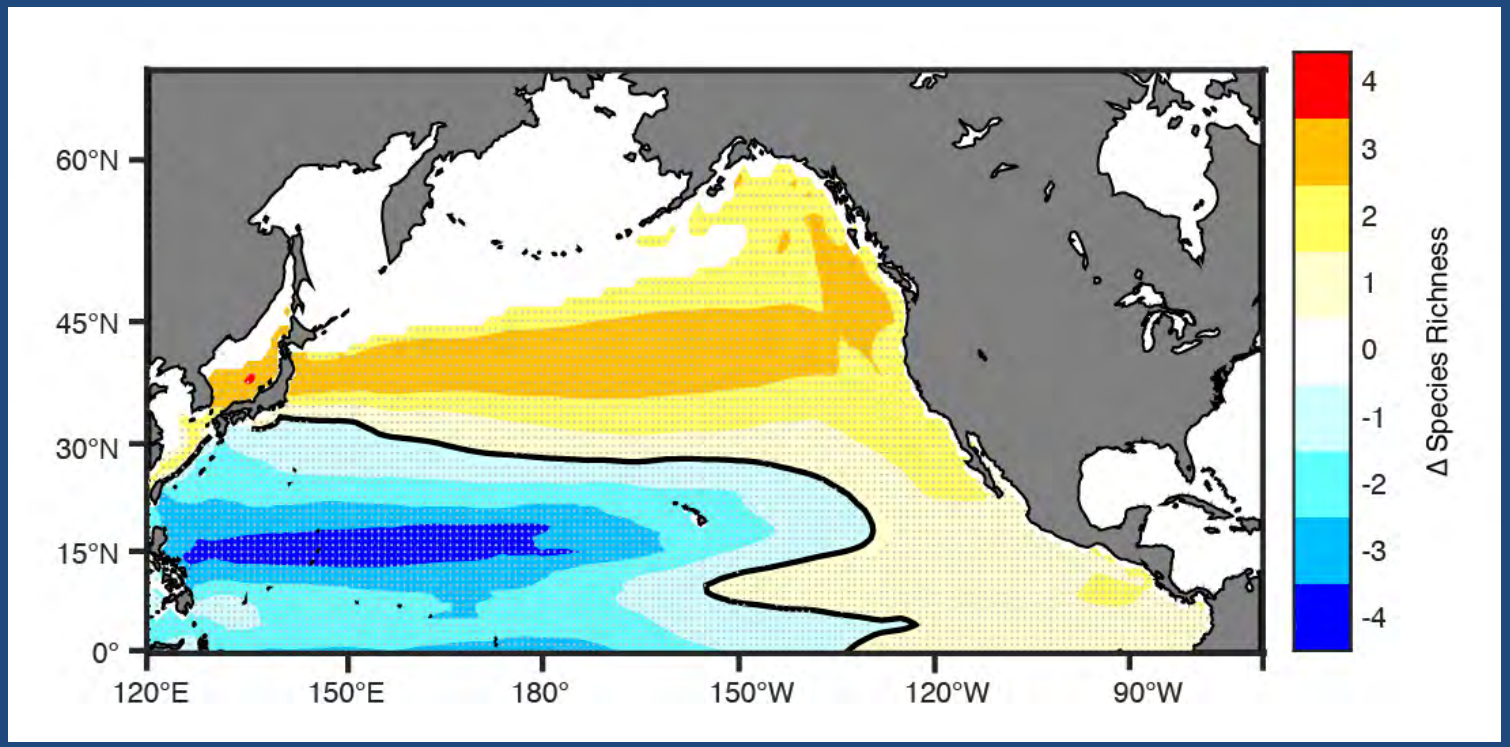
- Percent by which zooplankton declines exceed phytoplankton declines



Bell *et al*. 2013; Chust *et al*. 2014; Lefort *et al*. 2015; Locarnini *et al*. 2013; Stock *et al*. 2014

Change in Species Richness

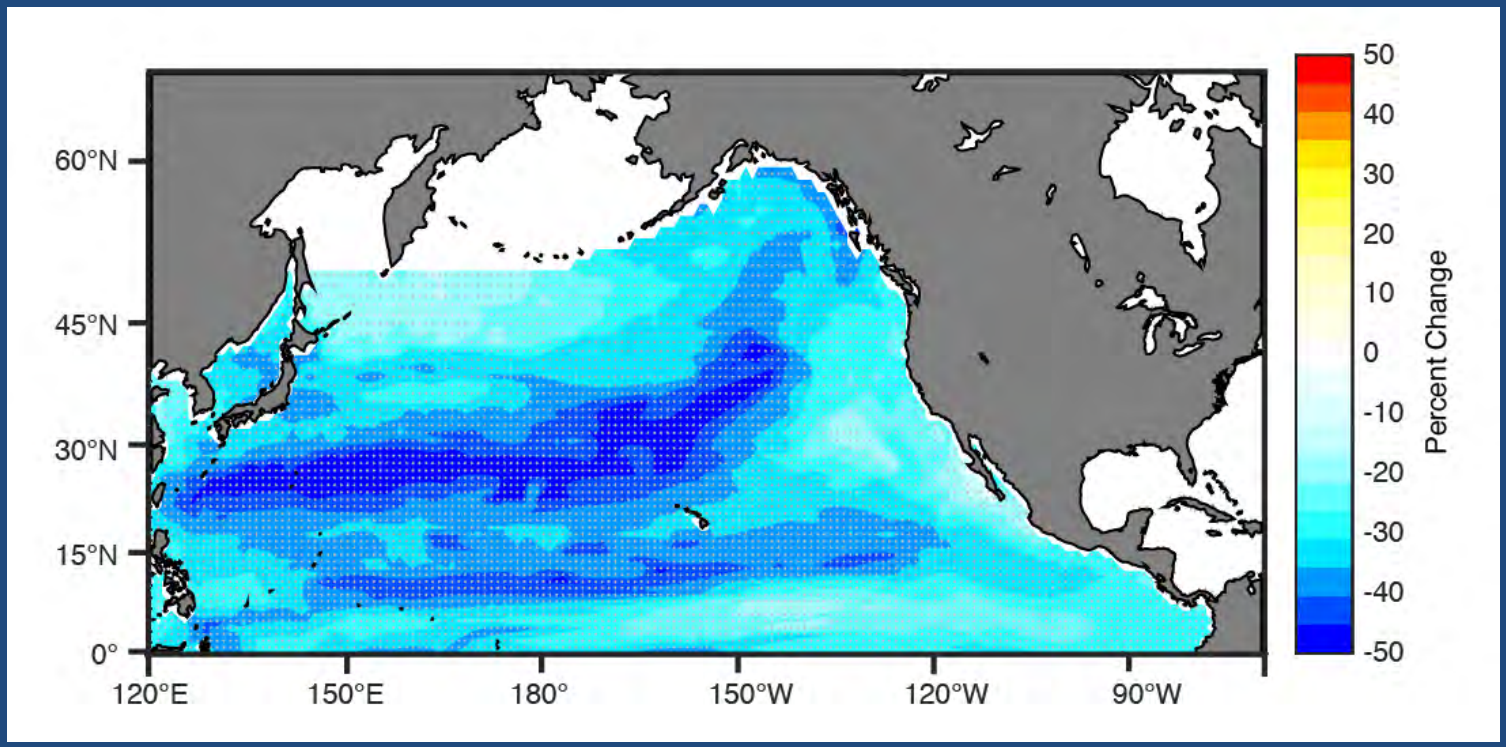
- Indo-Pacific tuna and billfish species richness
- $SR = -0.0033T^3 + 0.1156T^2 - 0.4675T$



Boyce *et al*. 2008; Locarnini *et al*. 2013

Change in Carrying Capacity

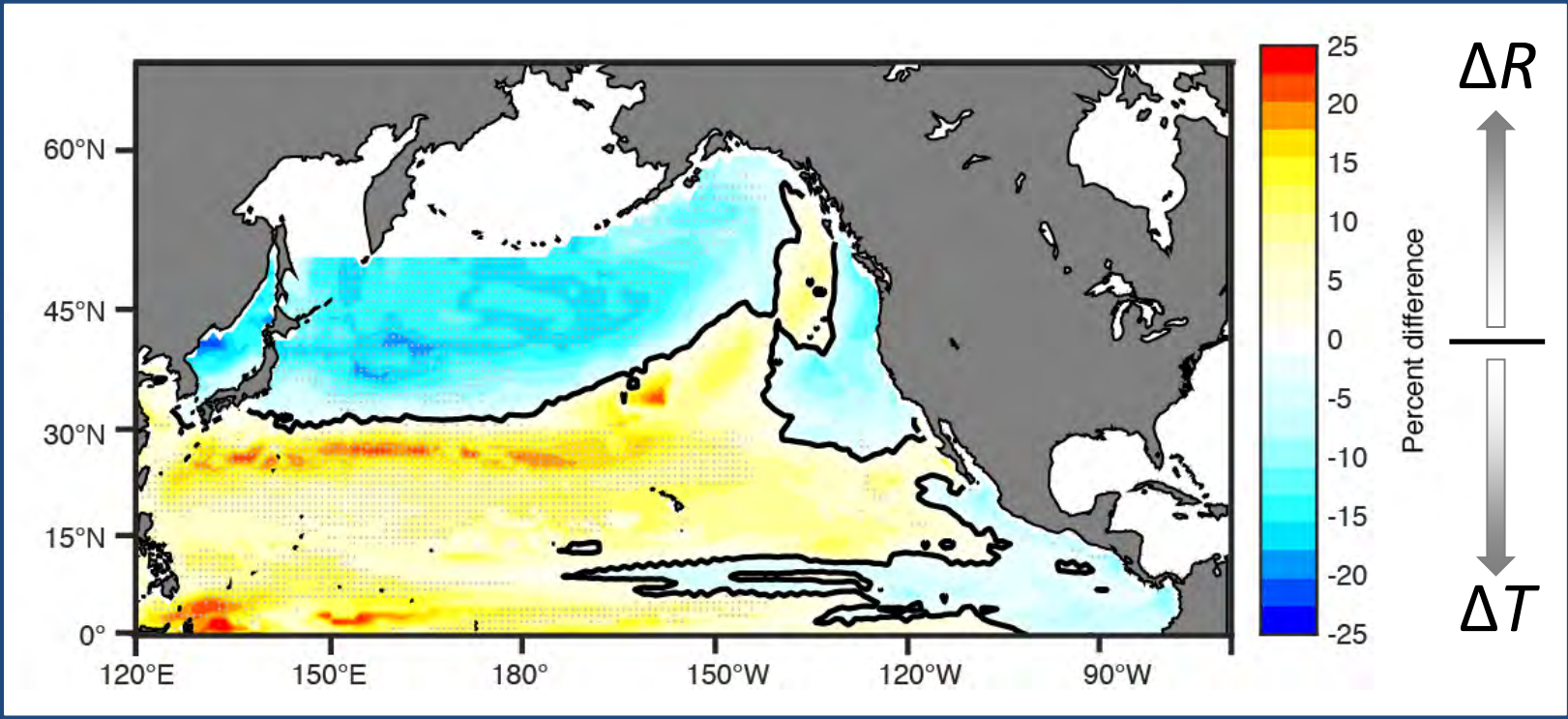
- Potential carrying capacity
- $\boldsymbol{K} \propto [\boldsymbol{R}]\, M^{-3/4}\, e^{E/k\boldsymbol{T}}$



Blanchard *et al*. 2005; Brown *et al*. 2004; Lefort *et al*. 2015; Locarnini *et al*. 2013; Polovina and Woodworth-Jefcoats 2013; UN 2011; Ward and Myers 2005; Woodworth-Jefcoats *et al*. 2015

Driver of Changing Carrying Capacity

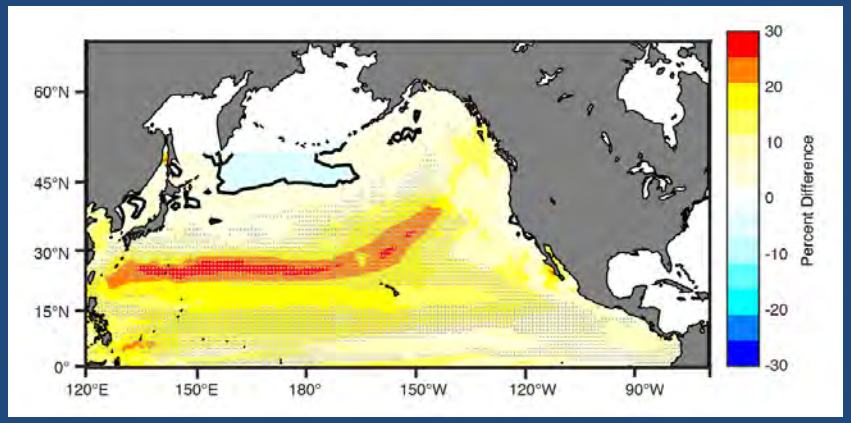
- Declining food availability vs. rising temperature
- $|\%\Delta R| - |\%\Delta e^{E/kT}|$



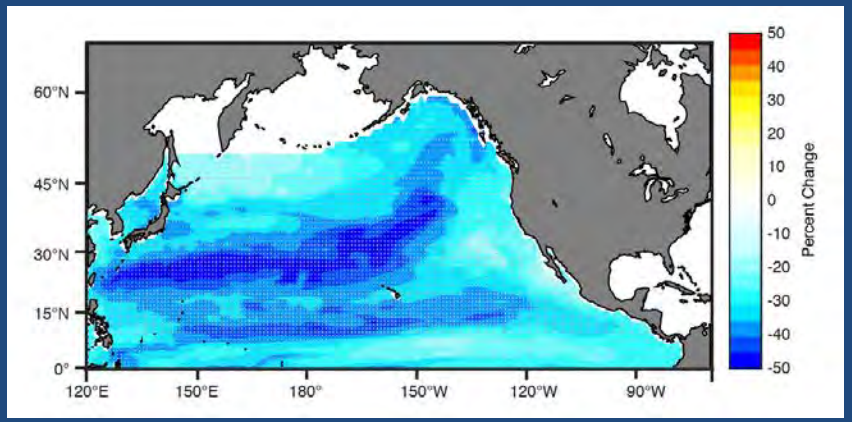
Particularly Vulnerable Areas

- Greatest changes projected around periphery of subtropical gyre
  - Transition Zone
  - Tuna spawning grounds

Trophic Amplification



Potential Carrying Capacity

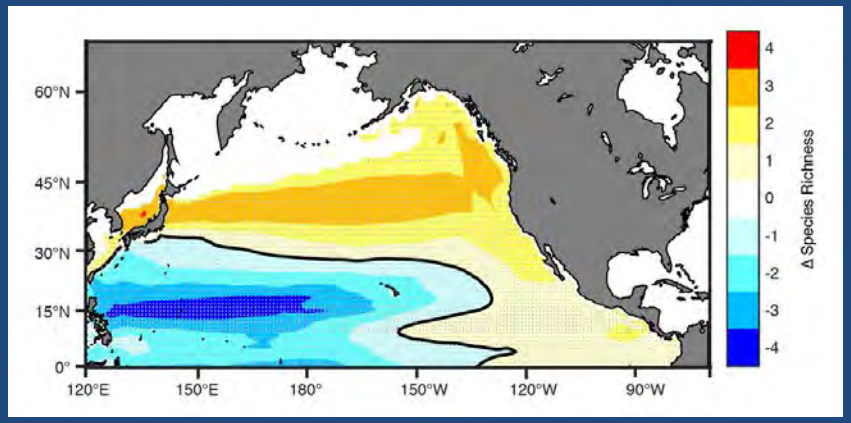


Block *et al*. 2011; Hazen *et al*. 2013; Howell *et al*. 2015; Polovina *et al*. 2001, 2015; Woodworth-Jefcoats *et al*. 2013

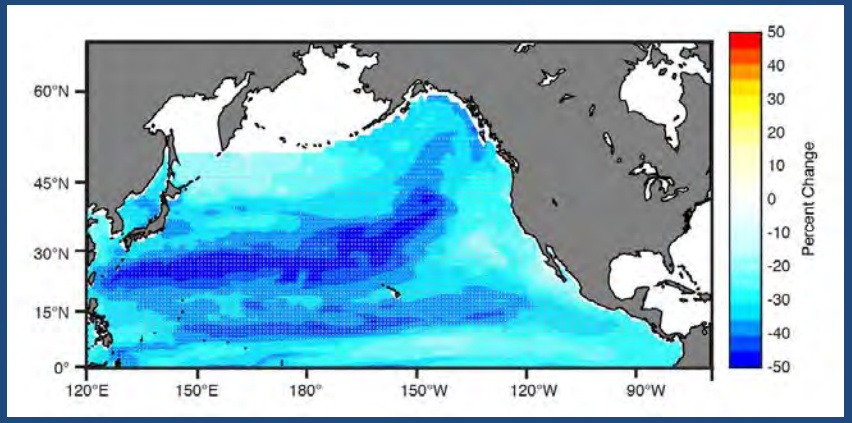
Applications to Fishery Management

- Potential early warning thresholds
  - Catch composition
  - Yield

Species Richness



Potential Carrying Capacity



Caveats

- Temperature and food availability
  - Additional variables important
- Physical climate influences
  - Species and trophic interactions influential
- Epipelagic realm
  - Mesopelagic realm and migrators
- RCP8.5
  - Additional RCPs

Abecassis *et al*. 2013;
Bond and Lavers 2014; Bopp *et al*. 2013; Grenouillet and Comte 2014; Howell *et al*. 2010; Lefort *et al*. 2015; Ockendon *et al*. 2014

Conclusions

- Warming thermal habitat and declining food availability are projected to reshape North Pacific epipelagic habitat
- Potential carrying capacity may decline by 2 – 5% per decade
- Up to 3 – 4 fewer tuna and billfish species in subtropics, similar increase in temperate latitudes
- May significantly impact commercial fish catch composition, magnitude, and distribution

Global Change Biology

Global Change Biology (2016), doi: 10.1111/gcb.13471

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Acknowledgements

- Matt Church, Megan Donahue, Charlie Stock, and Axel Timmermann for helpful insight and ideas
- Climate model data providers:
  - World Climate Research Programme's Working Group on Coupled Modelling
  - Individual climate modeling groups
  - U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison
  - The Global Organization for Earth System Science Portals
  - CMIP5 data portal: pcmdi9.llnl.gov/