# Models linking climate to fish: Habitat Shifts in North Pacific

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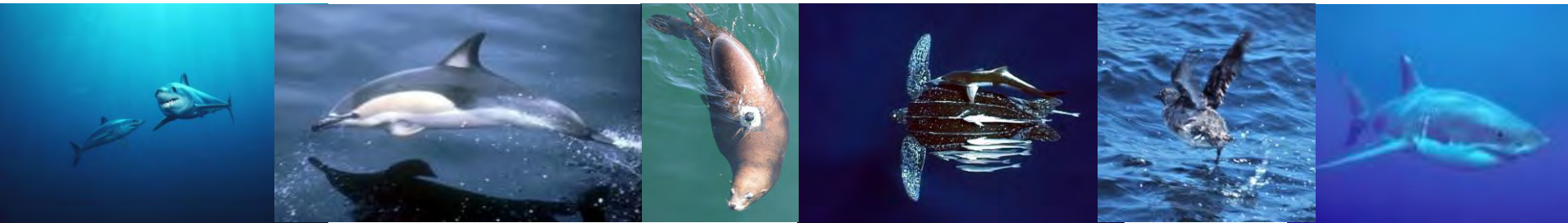
TAGGING OF PACIFIC PREDATORS

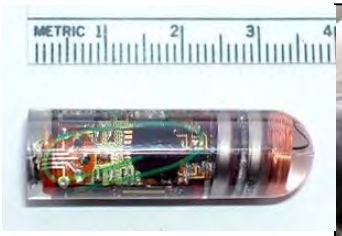
CENSUS OF MARINE LIFE

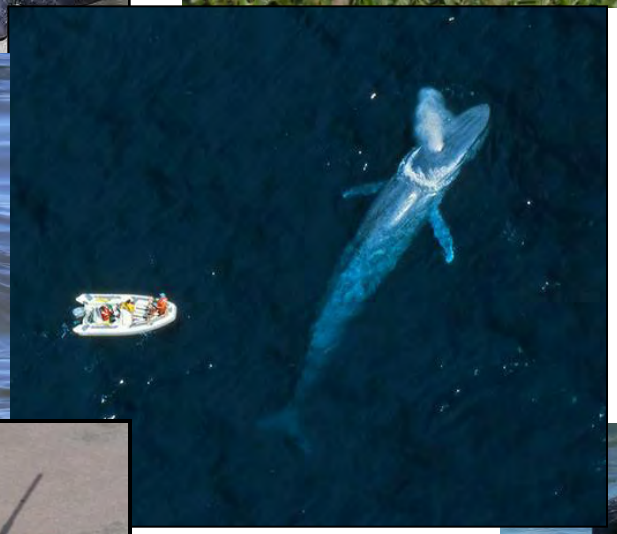


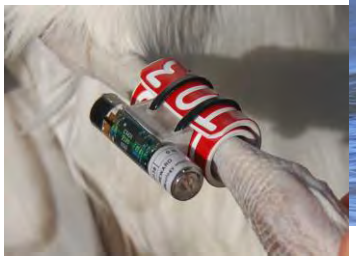
# Marine Top Predators

- **Integrate over food-web dynamics**
- **Long-lived, buffer environmental variability**
- **Key indicators of climate variability and change**
- **Face serious conservation issues**

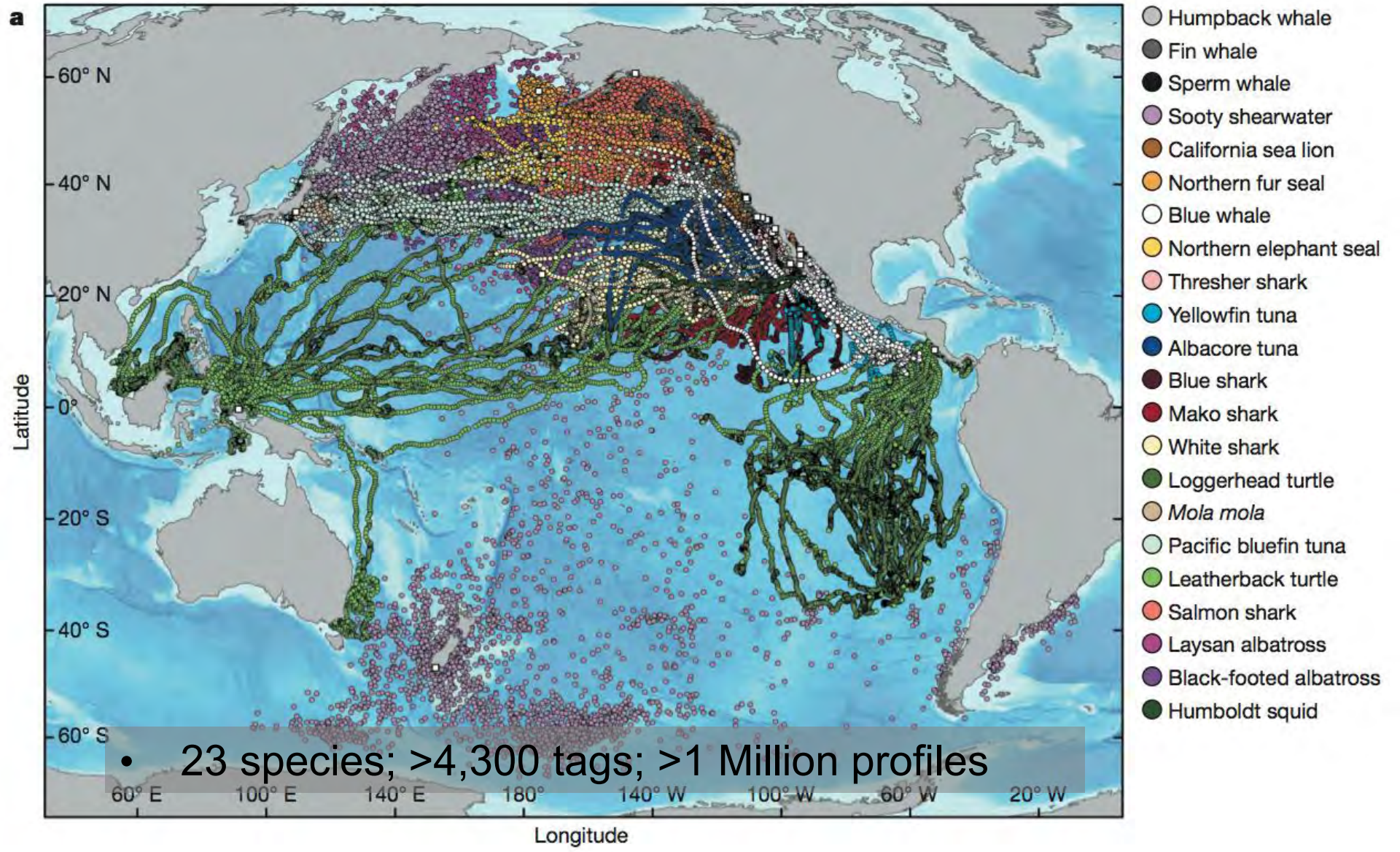
# Technical Approach: Multiple Tag Platforms





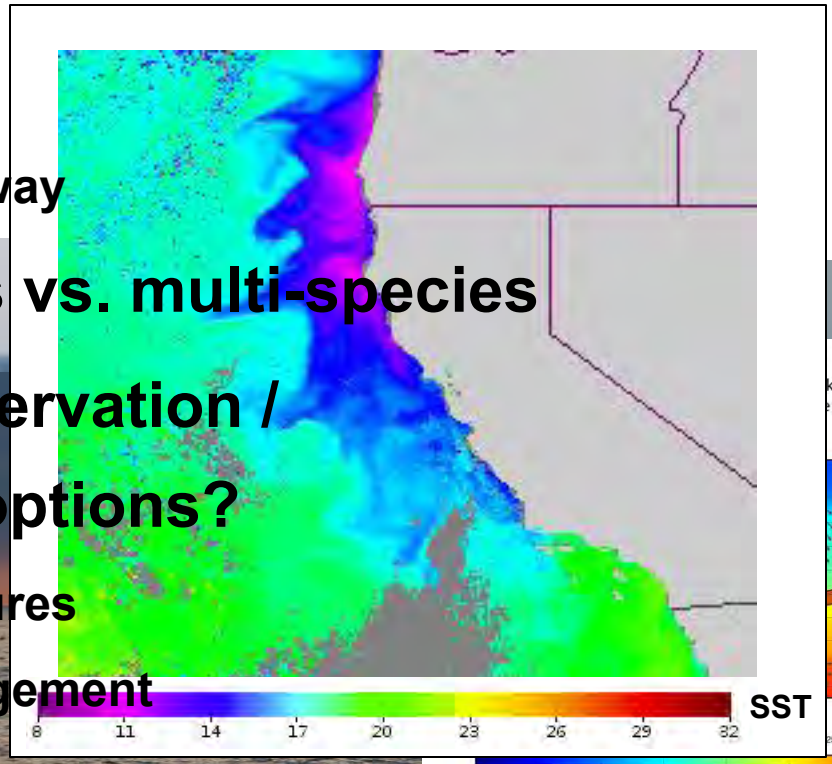
# Top Predators in the Pacific

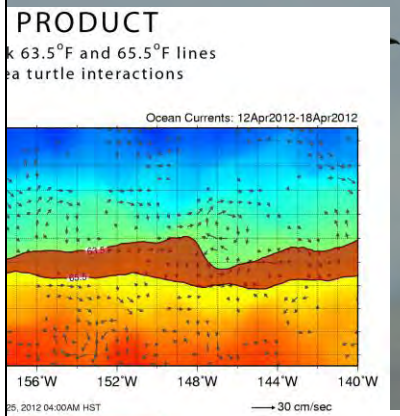


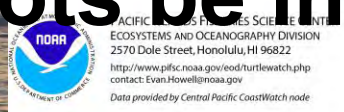

- 23 species; >4,300 tags; >1 Million profiles

# TOPP Synthesis: Hotspots

- **What is the physical forcing? How persistent/recurrent?**
- **Can we classify by ecological function?**
  - **Foraging**
  - **Reproduction**
  - **Migratory pathway**
- **Single-species vs. multi-species**
- **What are conservation / management options?**
  - **Time-area closures**
  - **Adaptive management**
- **Where will the hot spots be in the future?**

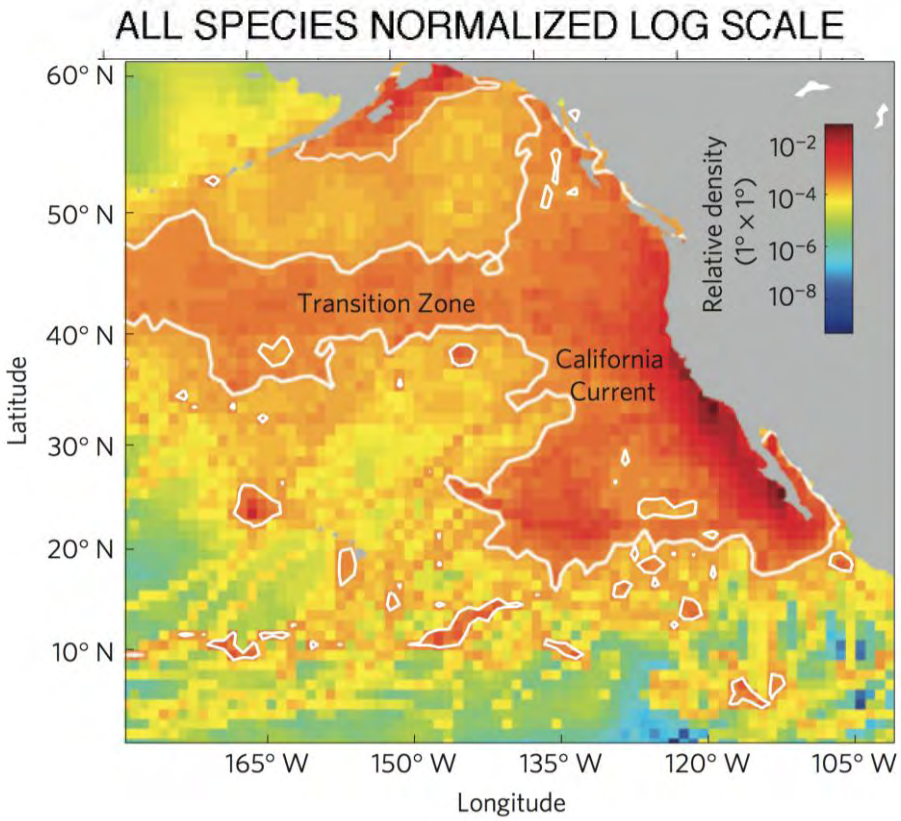


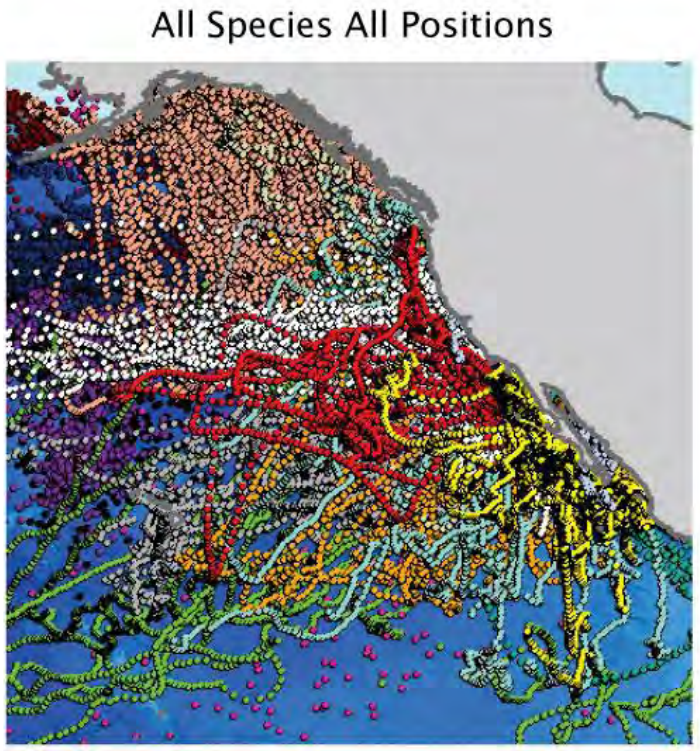



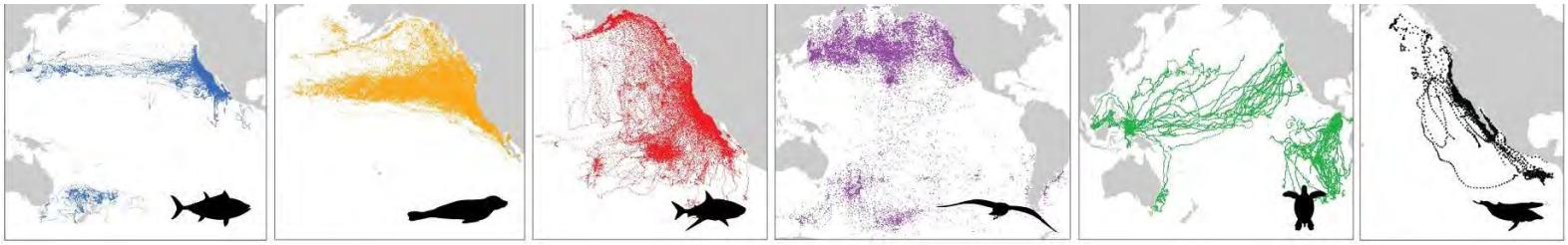

TURTLEWATCH

# TOPP Synthesis: Hotspots




Block et al. *Nature* 2011



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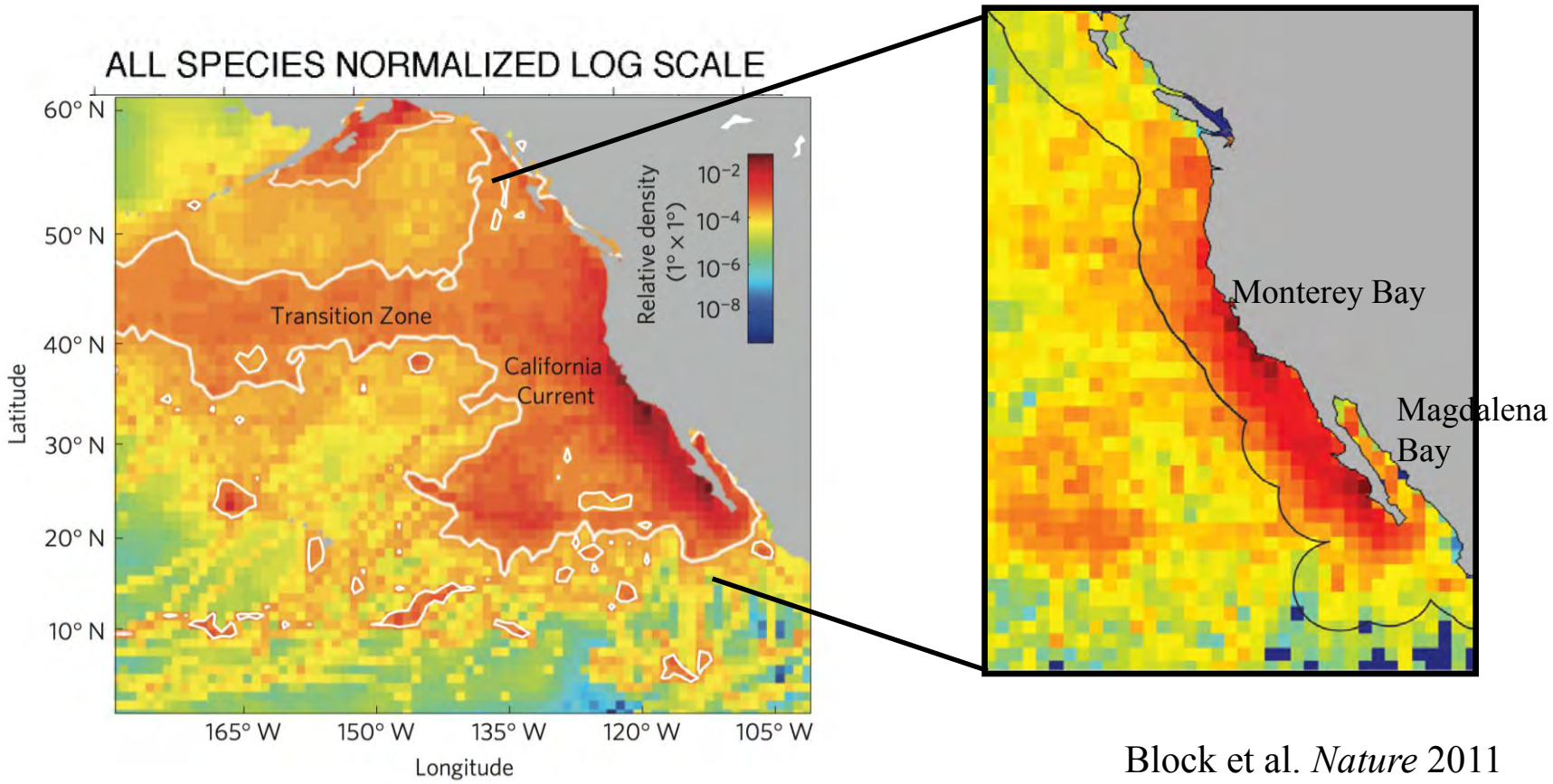
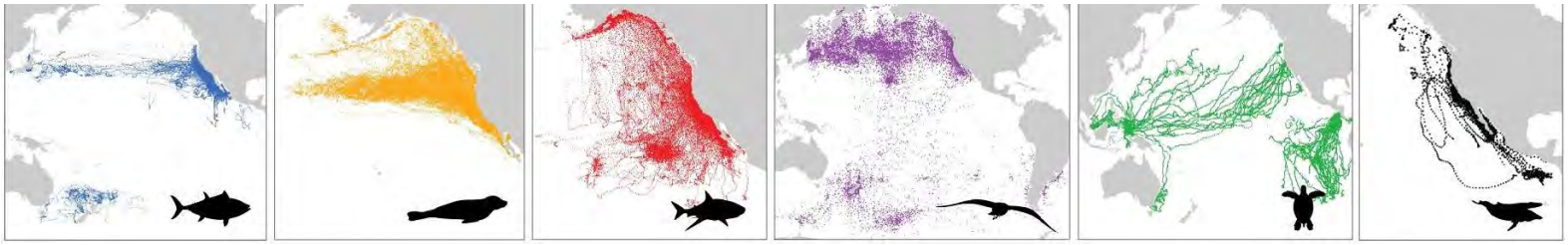
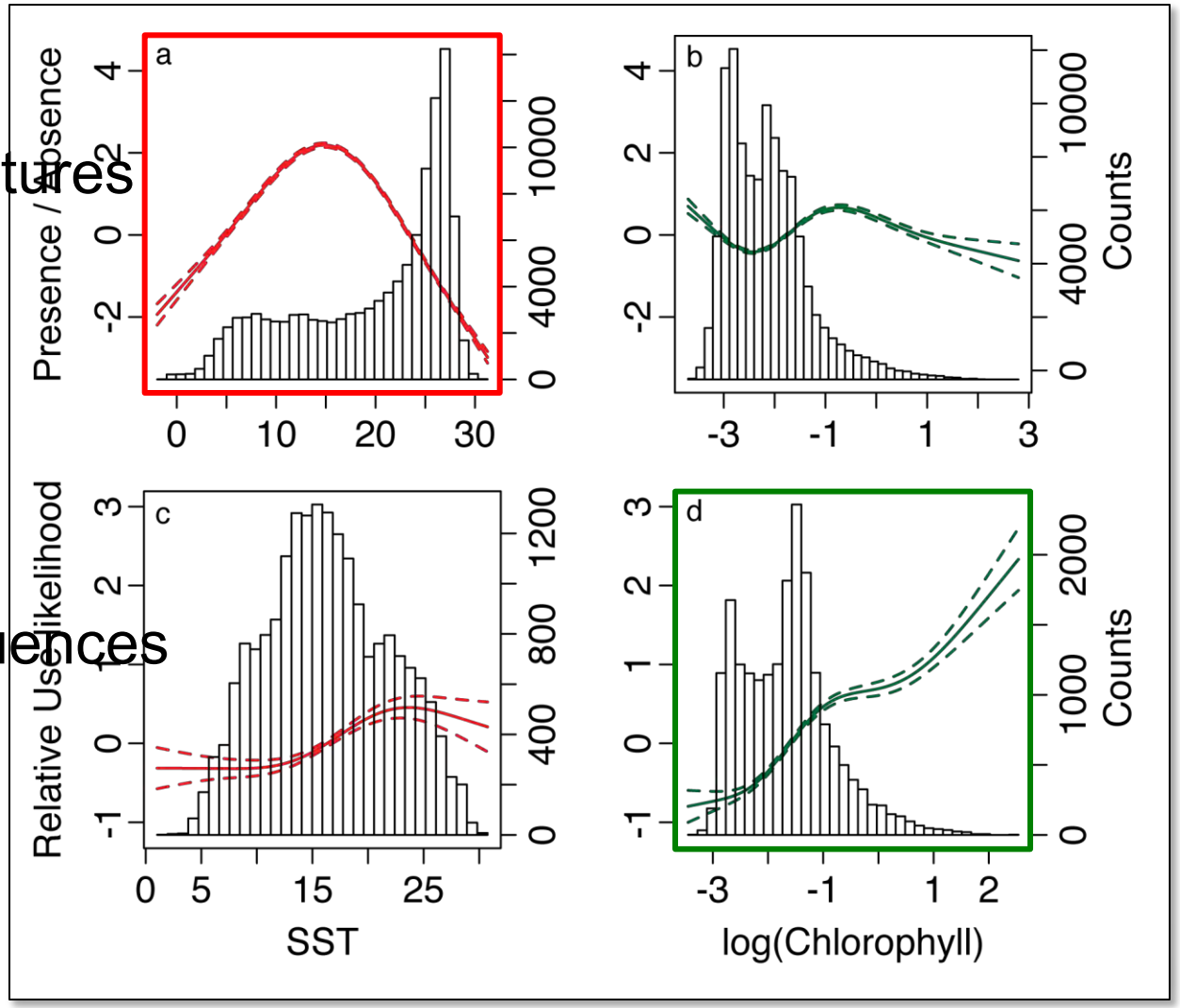



Block et al. *Nature* 2011



# TOPP Synthesis: Hotspots

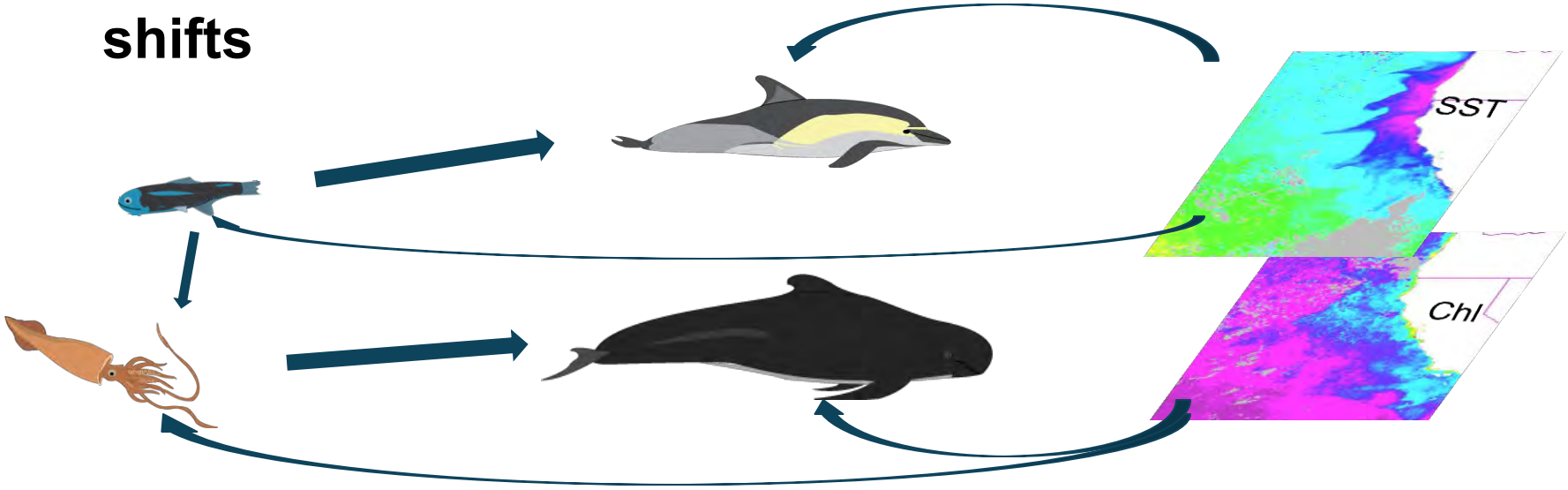
- SST structures habitat
- Chl-a influences use



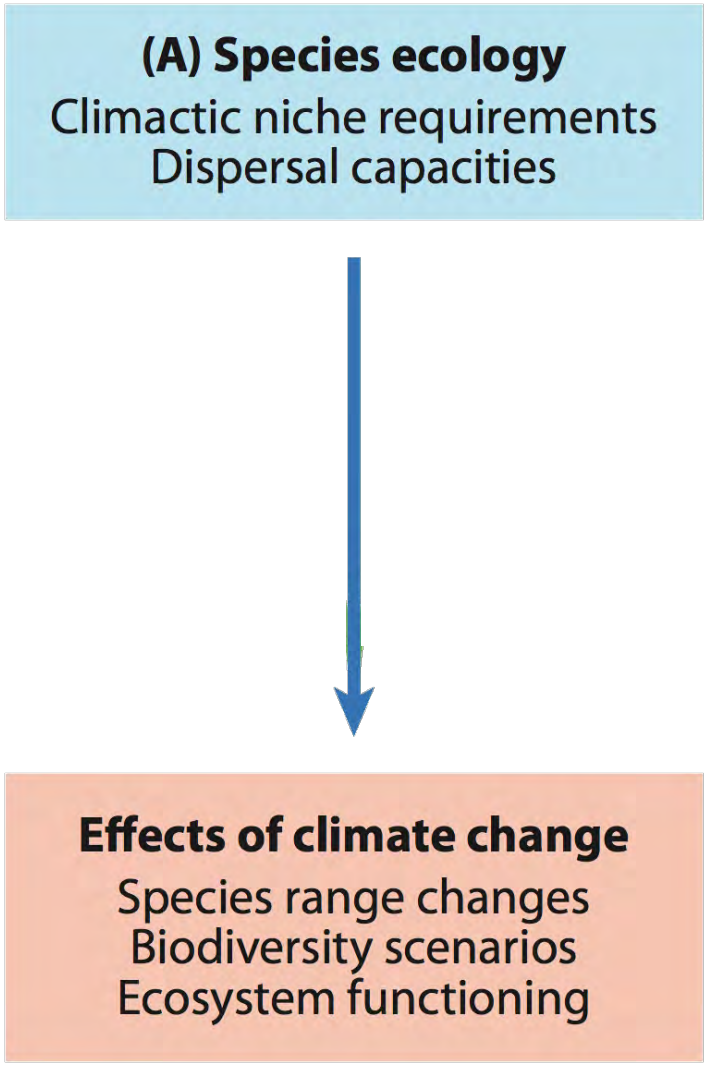

Block et al. *Nature* 2011

# Climate Change & Top Predators

- **Population effects – reproductive success / failure**
- **Food web effects – reduced density of prey, change in patchiness**
- **Phenology effects – timing of migration, reproduction**
- **<u>Spatial effects</u> – loss of habitat, range or distribution shifts**



# Climate Change Effects



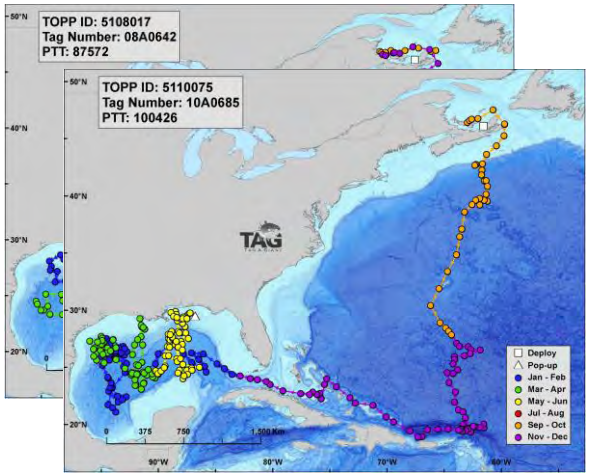

Lavergne et al. 2010

# Methods: habitat models

- Generalized additive models (GAMs) for each species using bathymetry and quarterly means of remotely sensed SST and Chl-a from 2000-2009.
- We predicted change in core habitat as a scenario driven exercise using GFDL's ESM 2.1 under **A2**:
  - Compared spatial shifts from 2001 to 2020 vs 2081 to 2100
  - Monthly, yearly, and 5 year running mean time series of habitat
- **Core habitat** for the time series was defined as top 25% of each species potential habitat.
- Bootstrapped confidence intervals to measure process error in the modeling framework.

# Species Distribution Modeling

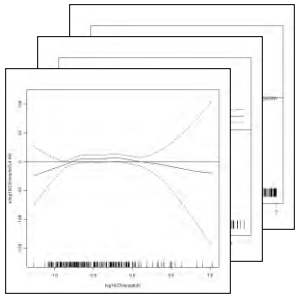
Distribution / behavioral data
e.g. sightings data, tag data, foraging events




Fit

Statistical models

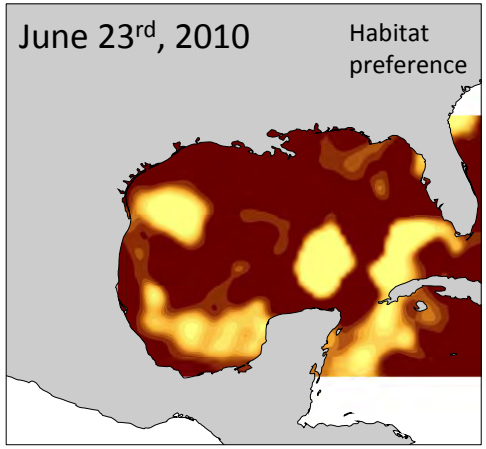
$$g(\mu) = \beta_0 + \beta_1 x_1 + \cdots + \beta_m x_m$$

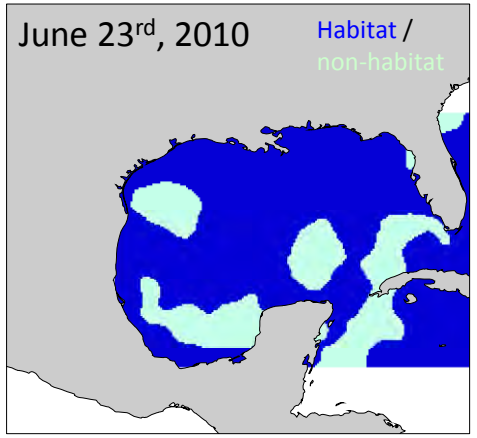


e.g. Generalized Additive Mixed Models

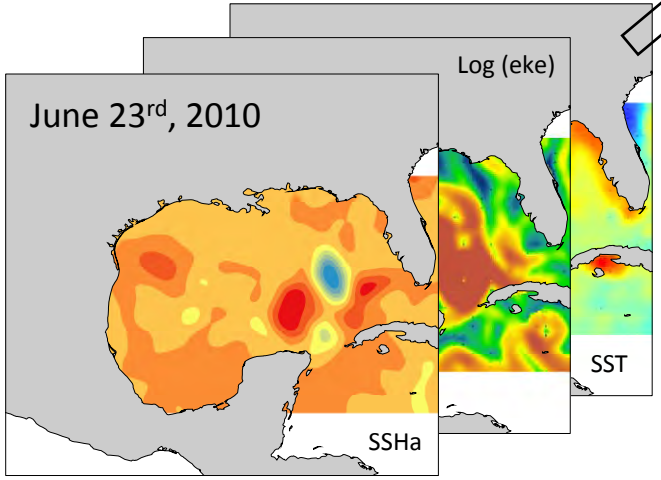
Predict

Probability of occurrence predicted from environmental covariates



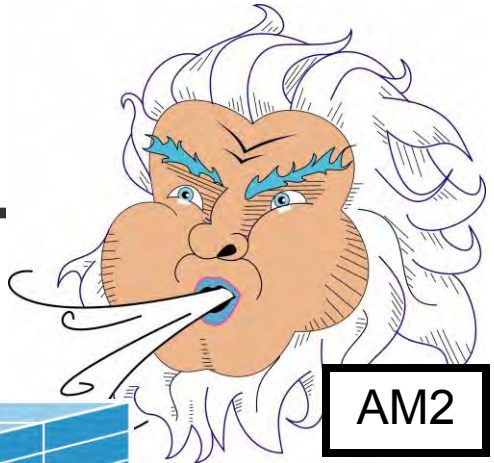




Sampled predictive data

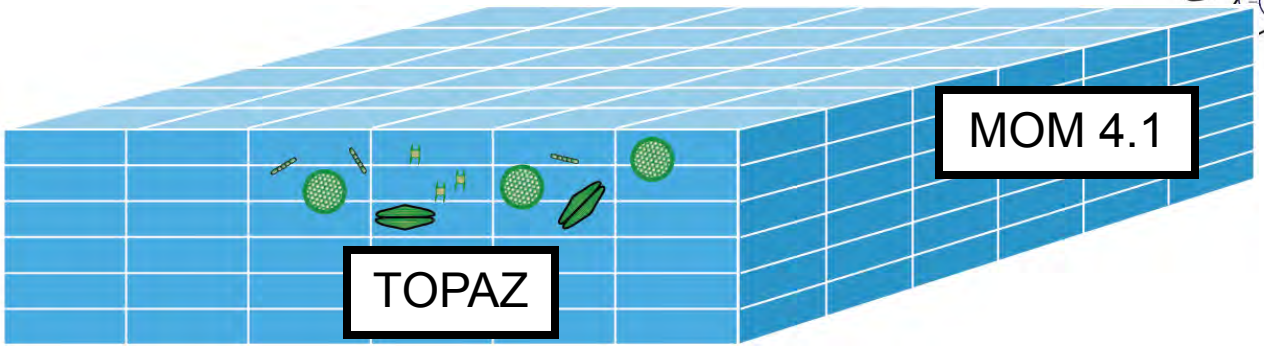


# Methods: GFDL ESM 2.1

An atmosphere-ocean general circulation model is coupled to an ocean biogeochemical model and forced with the **IPCC** emissions scenario **A2**.




Atmosphere: NOAA-GFDL **AM2** (Anderson et al., 2004); 2° x 2.5° horizontal resolution



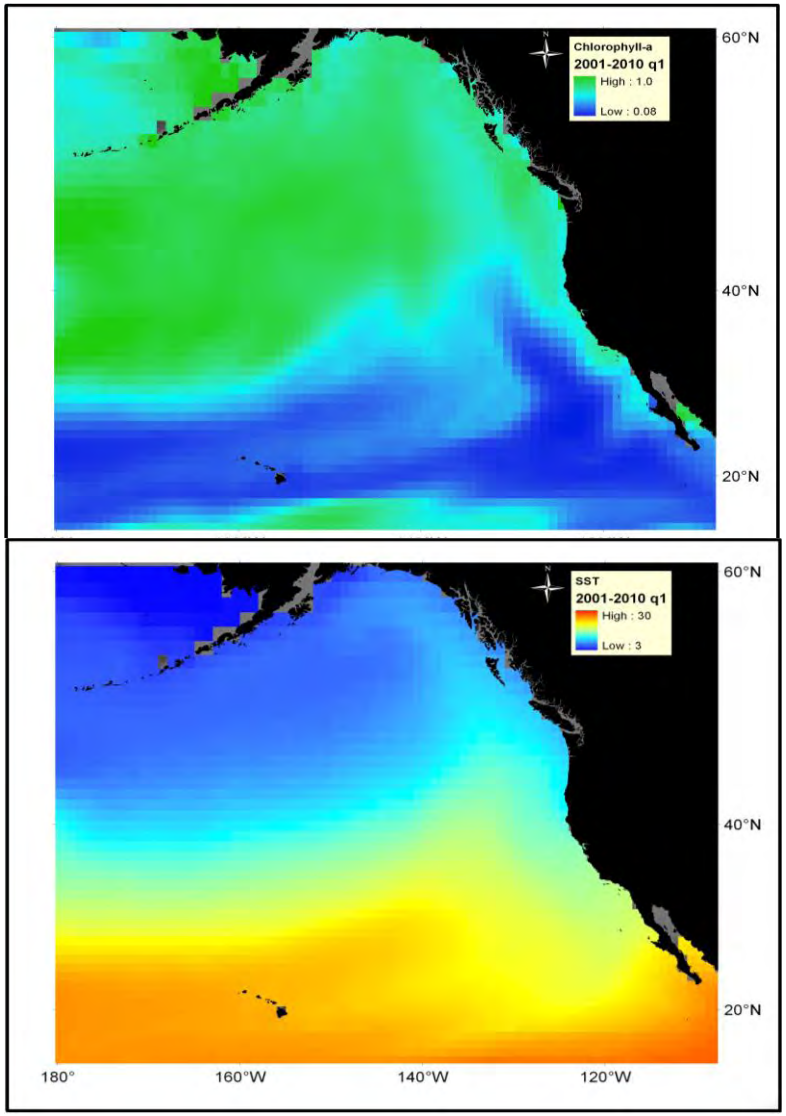

Ocean: NOAA-GFDL **MOM 4.1** (Modular Ocean Model; Pacanowski and Griffies, 1999); 1° x 1° horizontal resolution

Biology: NOAA-GFDL **TOPAZ** (Tracers of phytoplankton with Allometric Zooplankton) which includes N, P, Si and Fe cycles and three phytoplankton classes (Dunne *et al.*, 2007).

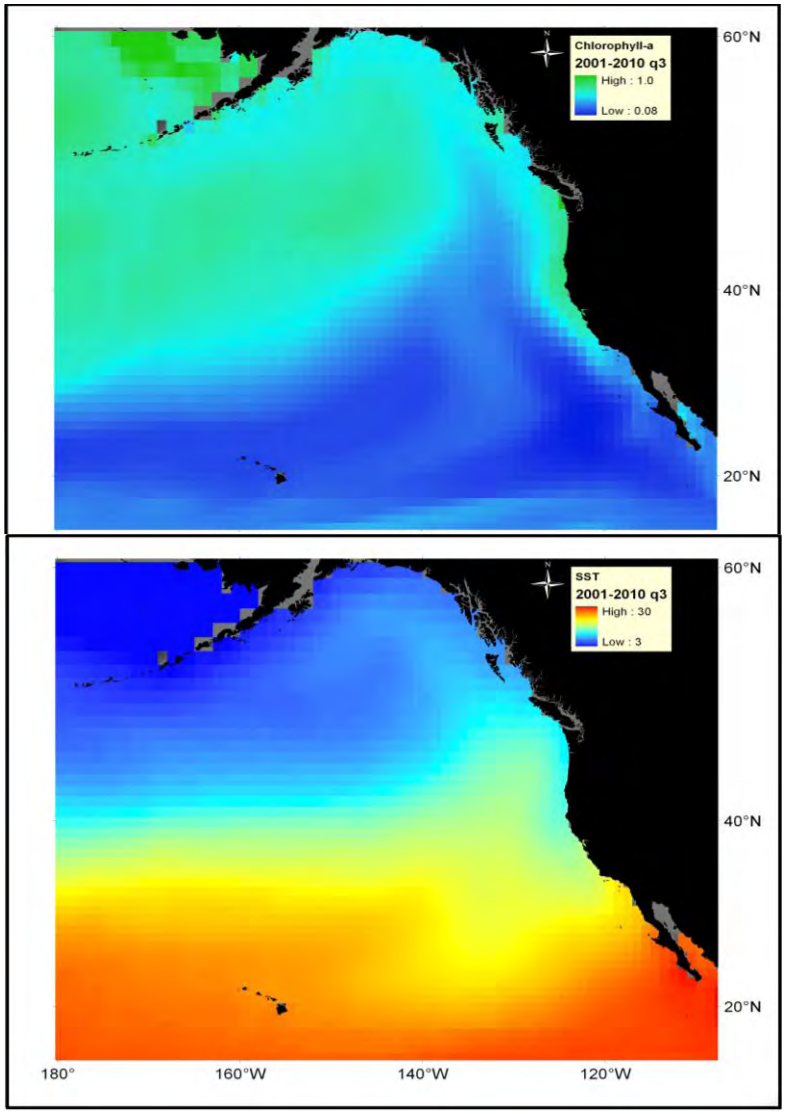
*Slide from Ryan Rykaczewski*

# Chlorophyll & SST: 2001 to 2010

Winter



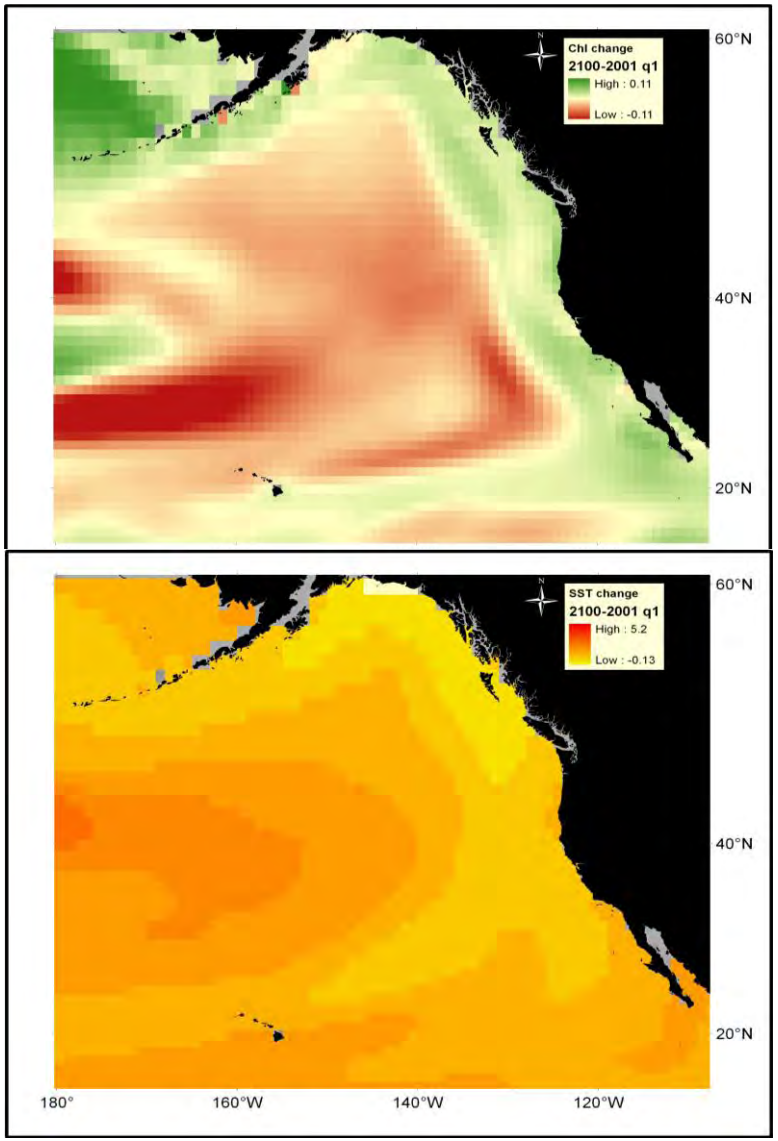

Summer



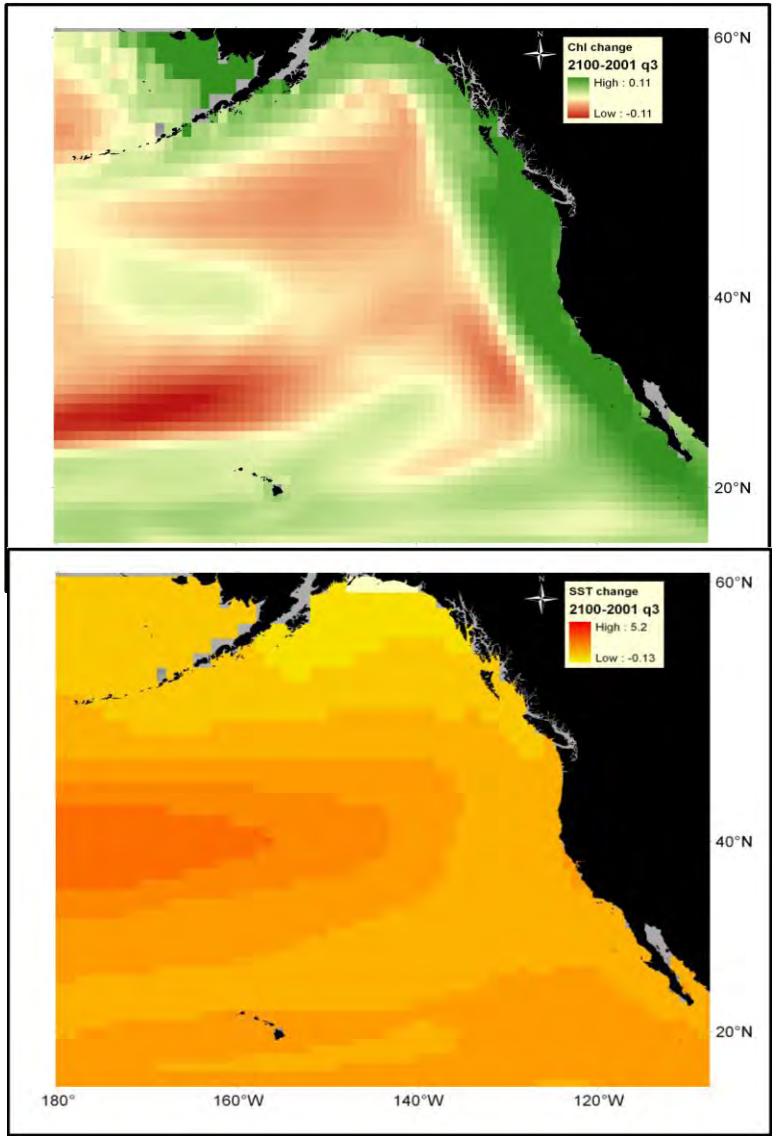

Hazen et al. 2012 *Nature Climate Change*

# Changes in Chl & SST: 2001-2100

Winter




Summer

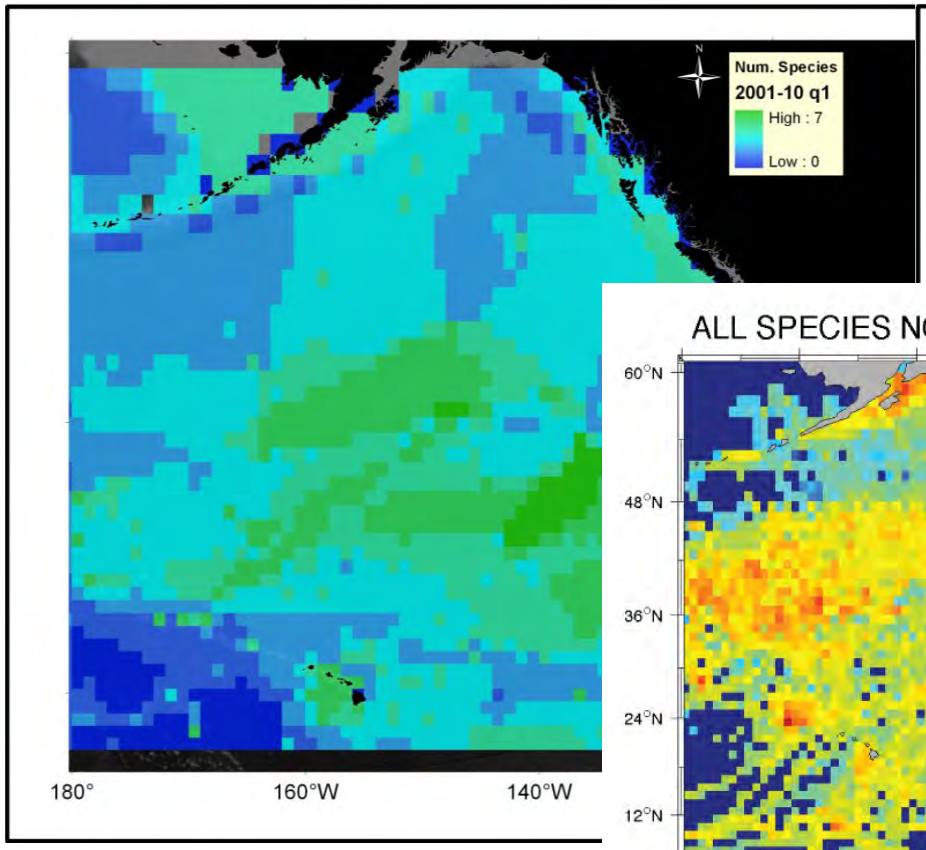


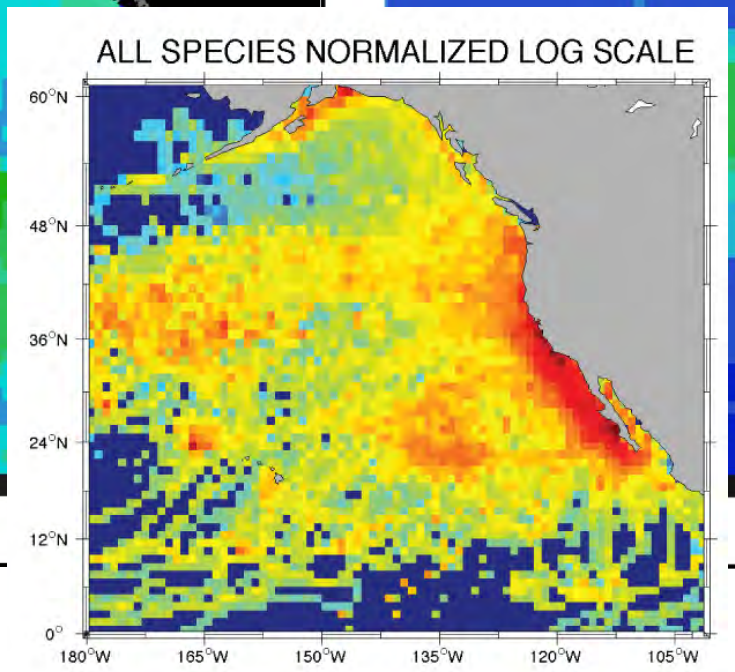

Hazen et al. 2012 *Nature Climate Change*

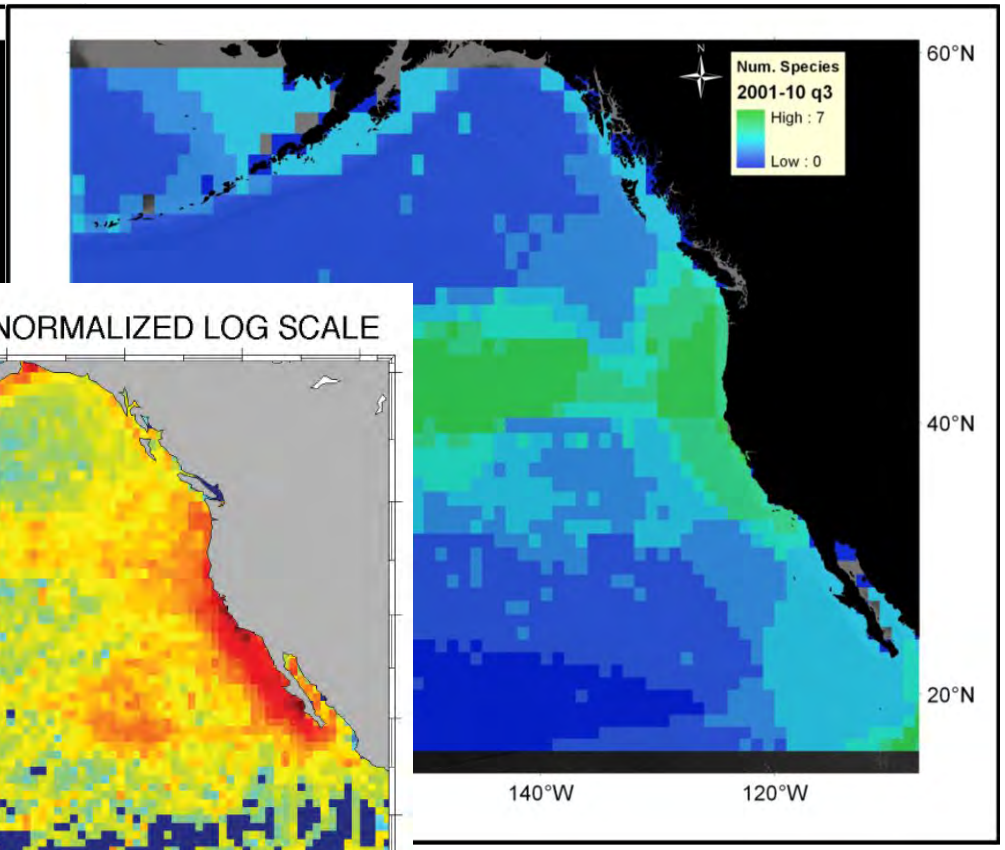
# Species Richness: 2001 to 2010

Winter

Summer



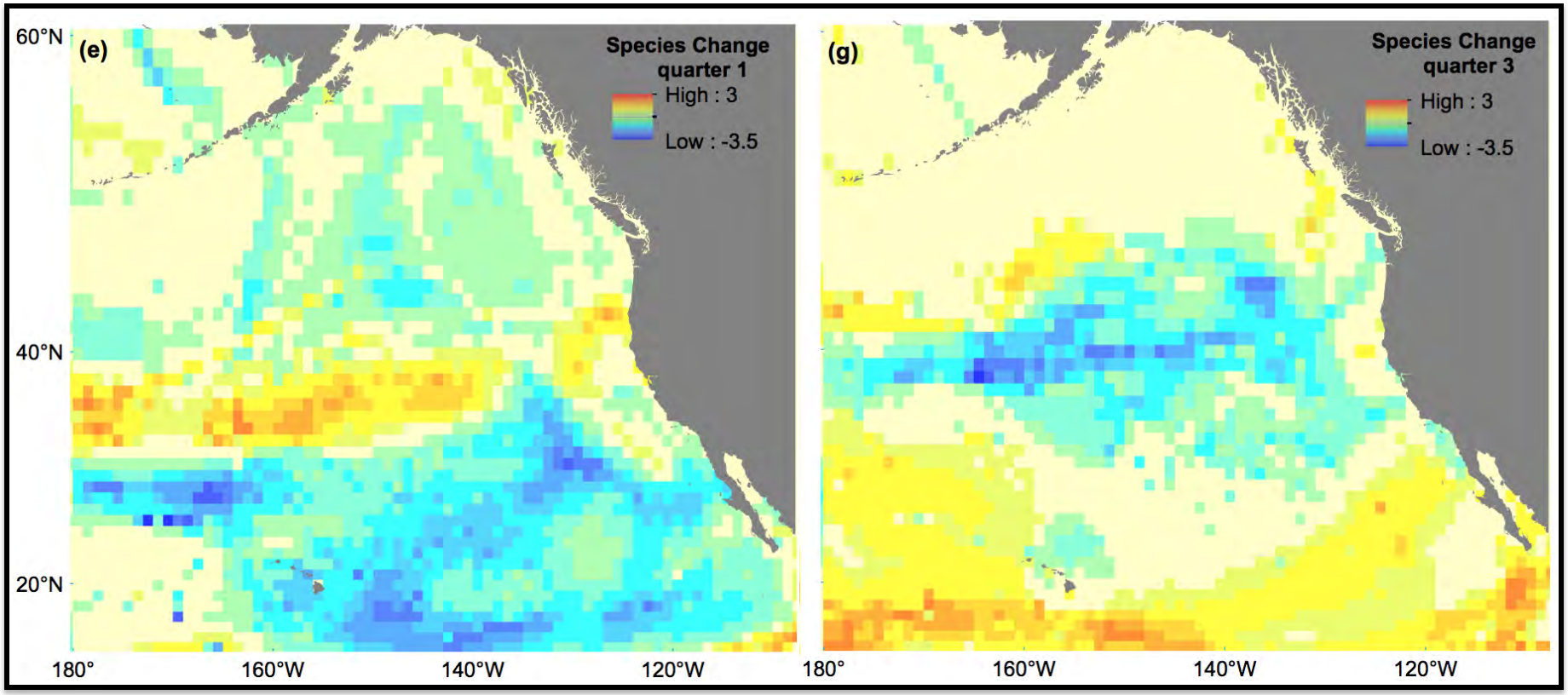



# Δ Species Richness: 2001-2100

Winter

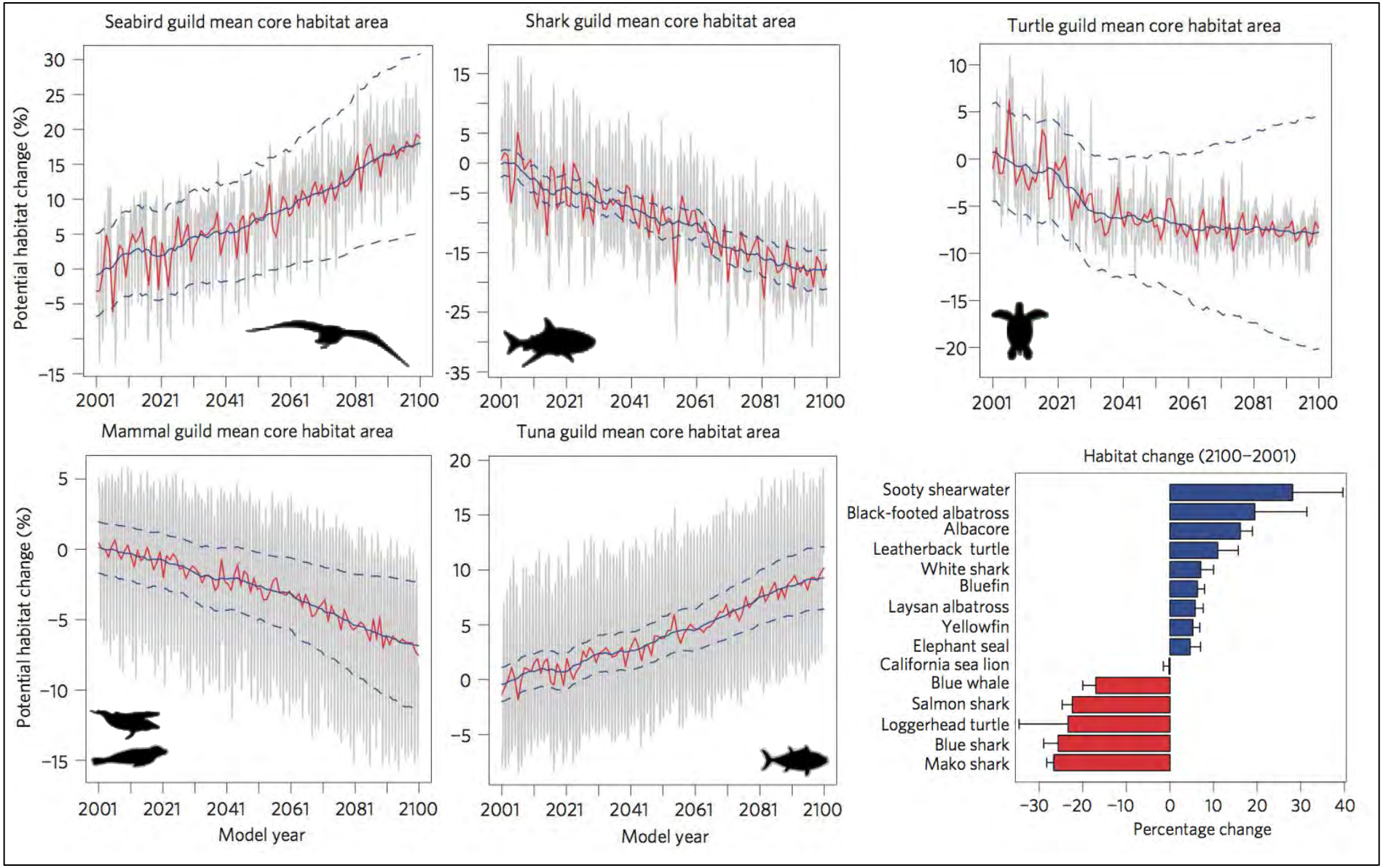
Summer




2001-2020 vs 2081-2100

Hazen et al. 2012 *Nature Climate Change*

# Core habitat: 2001 to 2100




Hazen et al. 2012 *Nature Climate Change*

# Caveats

- Predictions are scenarios, not actual "habitat" – tagged populations, not species
- Coastal processes are not well resolved in broad-scale climate prediction models
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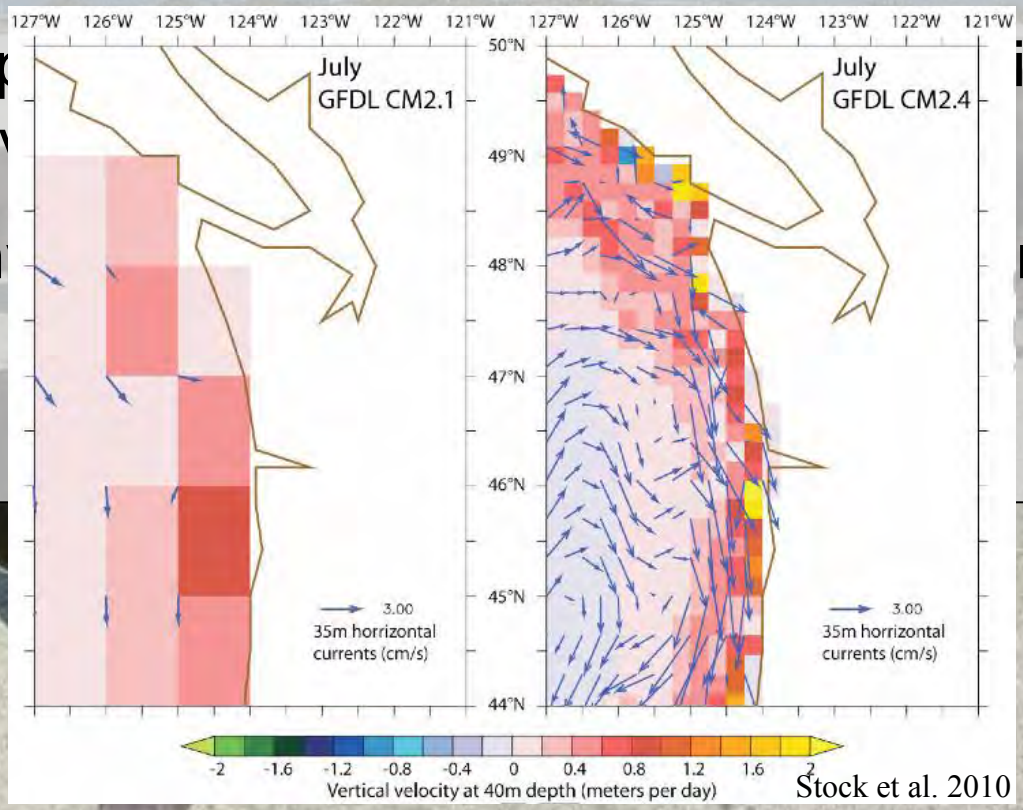



Stock et al. 2010

# Conclusions & Future Directions

- Seasonal patterns in diversity gain / loss e.g. around the transition zone
- Up to 35% changes in habitat use by frequency between 2001 and 2100
- Can use nested / downscaled models to get a better representation of coastal processes
- We should continue to use top predators as ocean sentinels but also should proactively plan for adaptive management

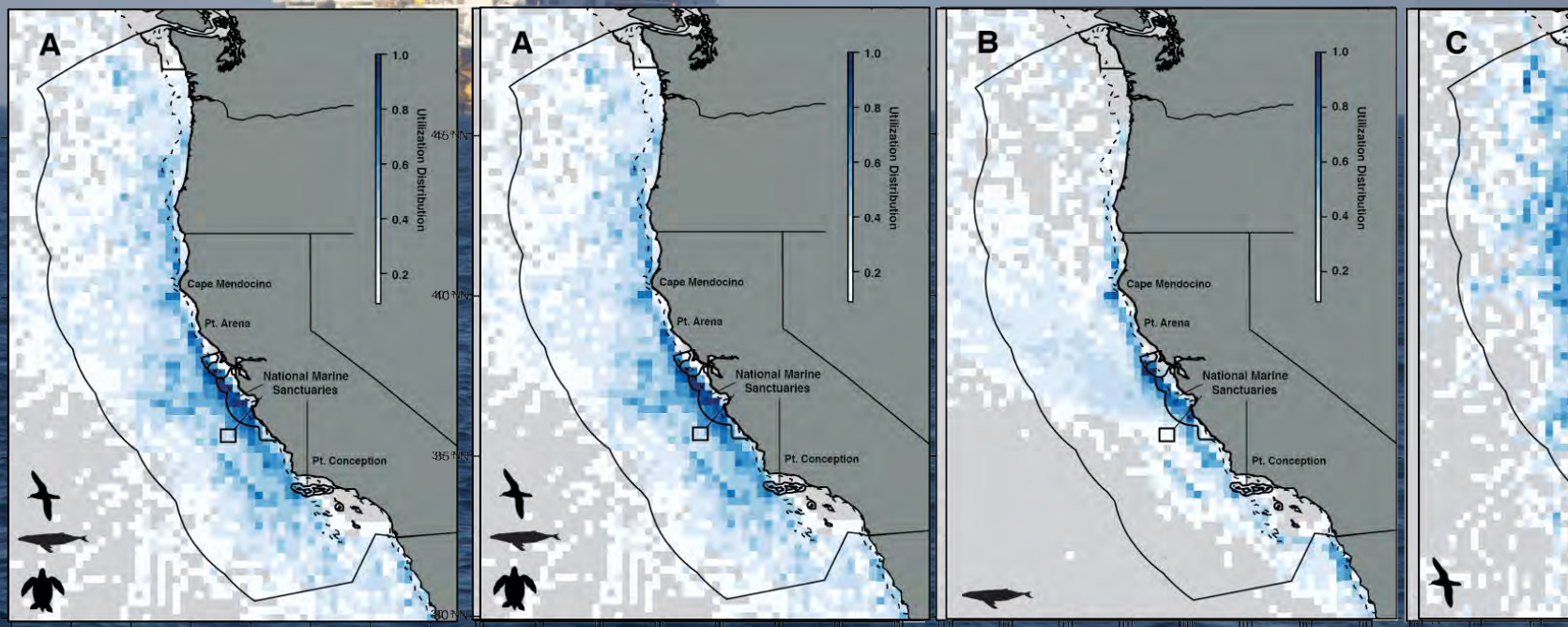
# Future Directions

- Use satellite data to model species and risk in near real time

Multiple risks:

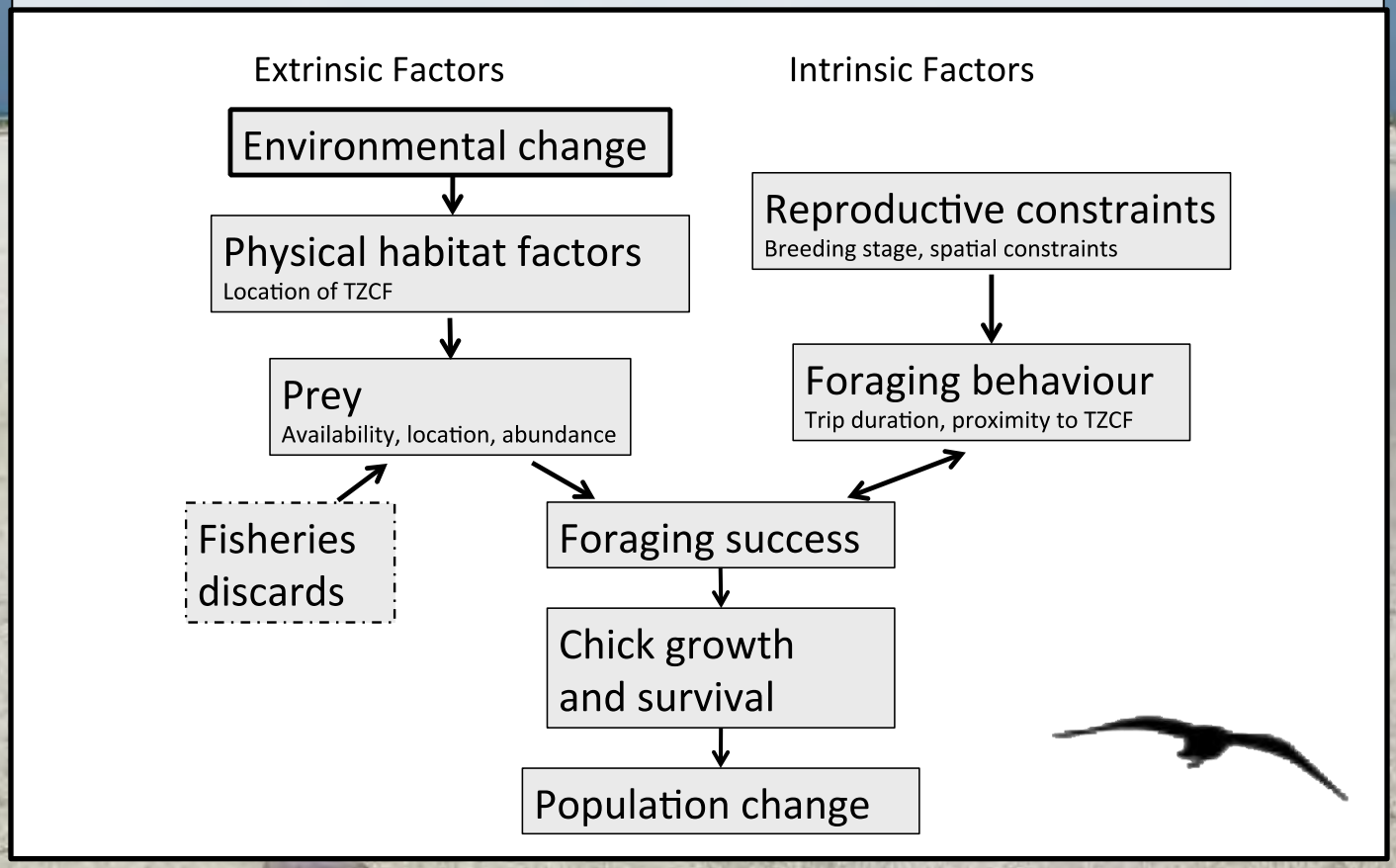
- ship strikes
- bycatch / entanglement,
- noise
- wind / wave power

Maxwell et al. in review *Nature Comm.*



# Data needs for top predators

- Mechanistic linkages from environment → life history



# Sponsors and Supporters

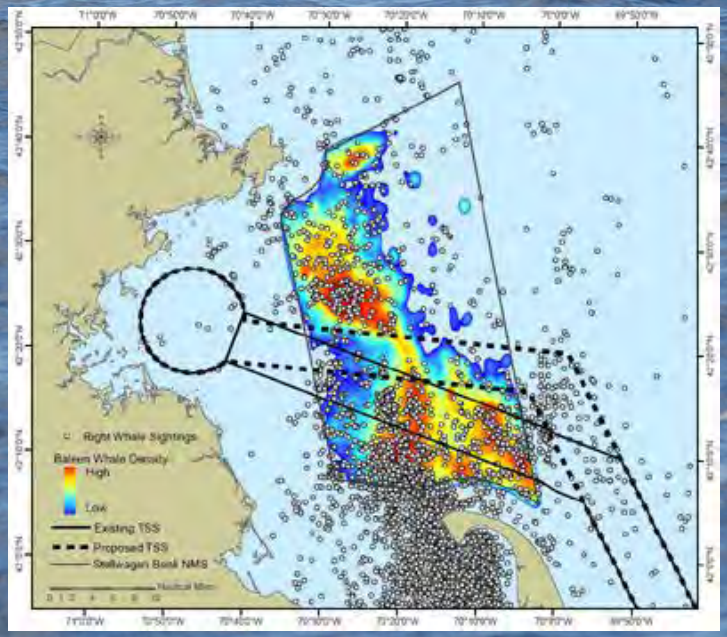

## TOPP Collaborators and Data Holders

Remote sensing data:

- Aviso/CNES (altimetry)
- NASA/GSFC (SeaWiFS ocean color)
- NOAA/NODC & JPL (SST)
- UCSD/SIO (Bathymetry)

# Future Research Directions

- Use satellite data to model species and risk (e.g. blue whales & ship strikes) in near real time

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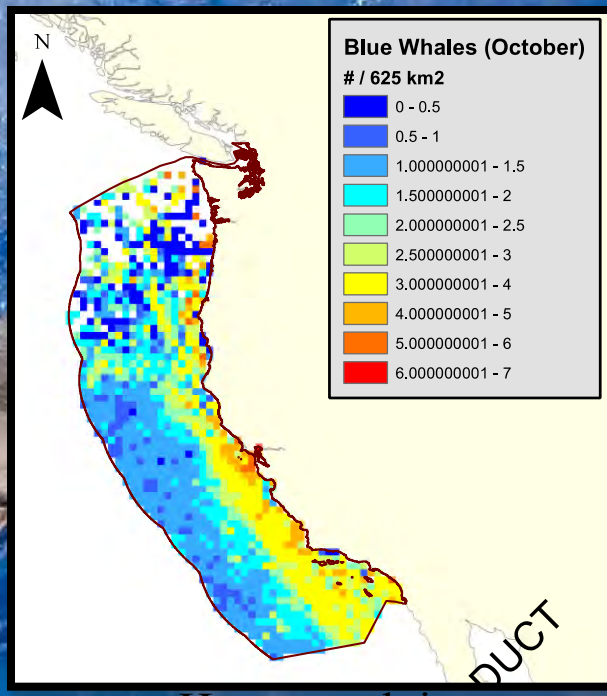


Hazen et al. in prep