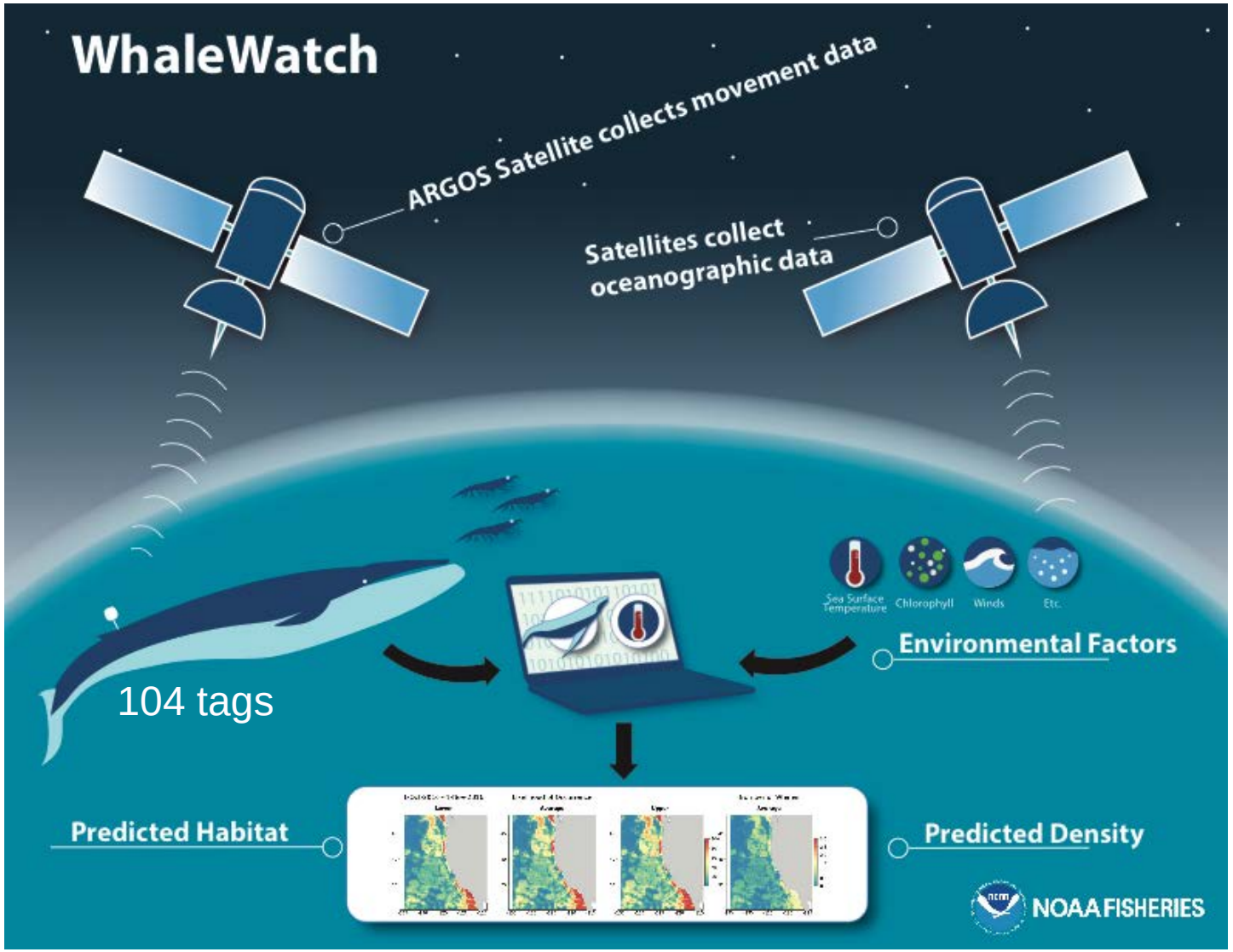
Dynamic ensemble models to predict blue whale distributions and risk exposure in near real-time



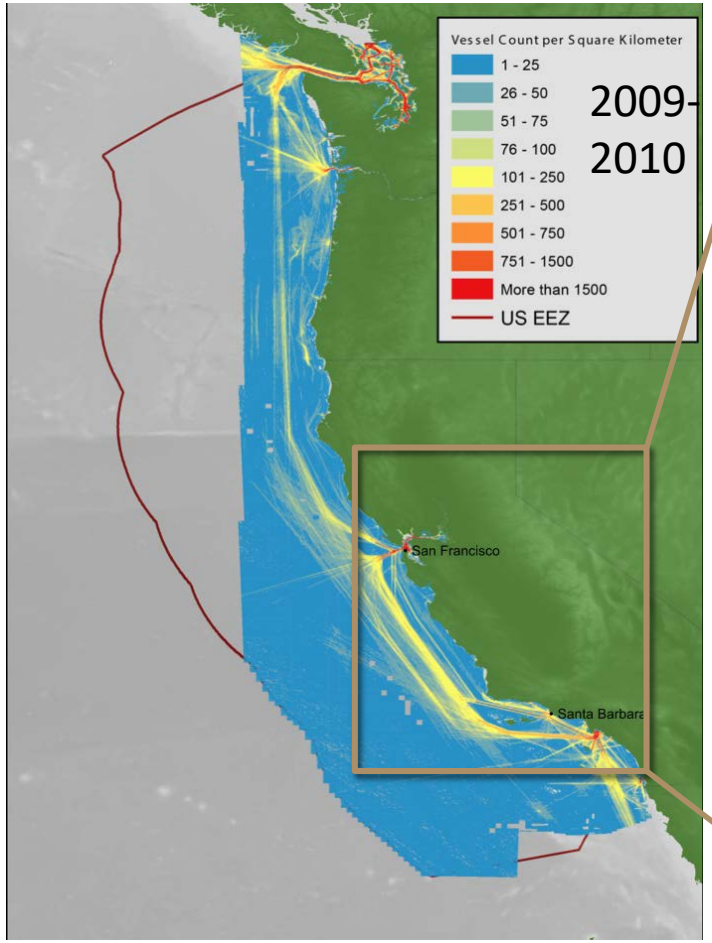
Briana Abrahms
February 12th 2019
Protected Species Assessment Working II

Motivation: Ship strikes as a threat to blue whales

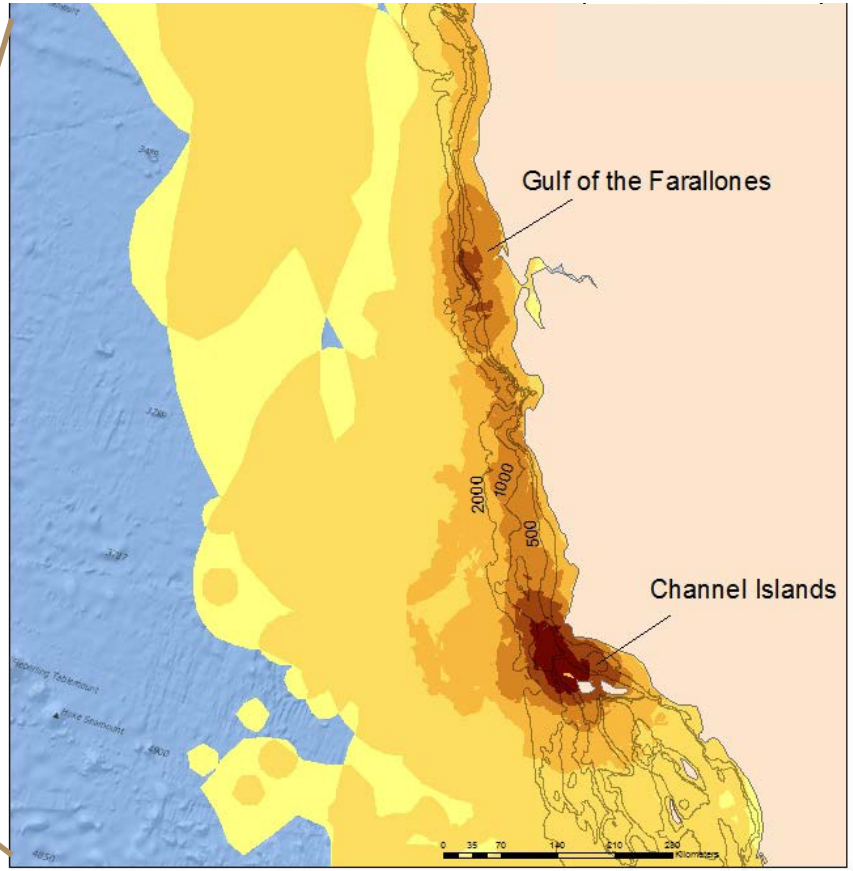
- Blue whale abundance globally is at 3-11% its pre-industrial level
- Ship strikes identified as major threat inhibiting population recovery (Berman-Kowalewski et al. 2010; Redfern et al. 2013, Rockwood et al. 2017)
- Most recent estimate of 20 blue whale ship strikes per year in California Current (Rockwood et al. 2017)

Flip Nicklin, Minden Pictures

Shipping and blue whale hotspots



Hazen et al. 2017 *J Appl Ecol*



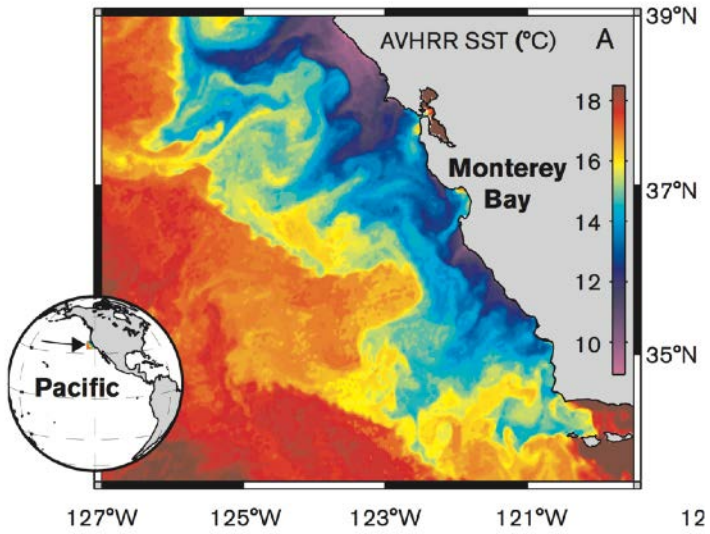
Blue whales have similar hotspots (1994-2008). Irvine et al. 2014 *PLOS One*

- High spatial overlap between shipping intensity and blue whale hotspots
- Southern CA Bight a hotspot for strikes (Rockwood et al. 2017, Redfern et al. 2013)

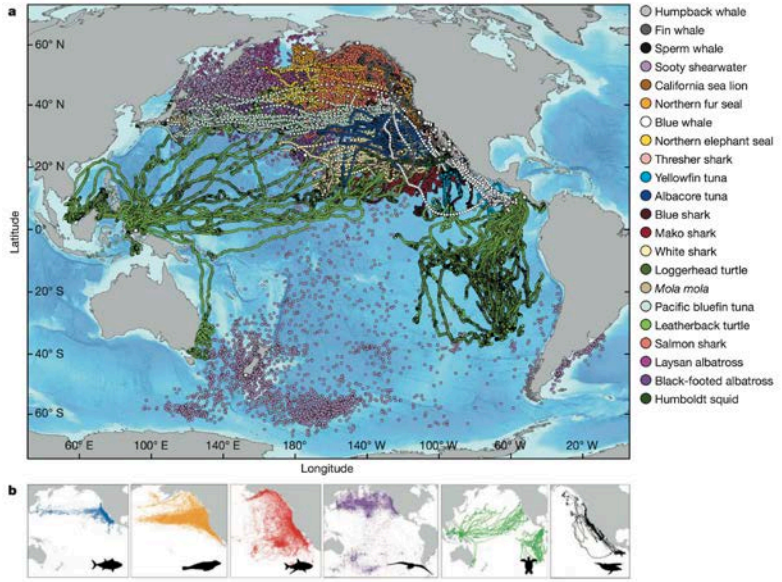
Dynamic Ocean Management

Uses real-time data on the shifting characteristics of the ocean to generate responsive spatial management strategies

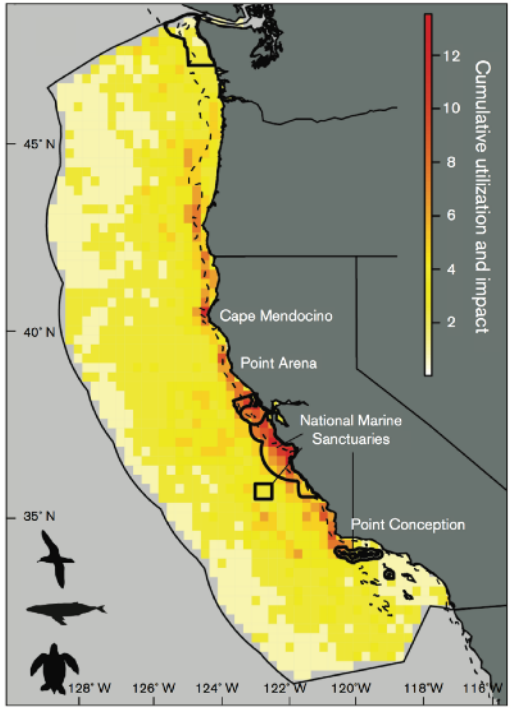
Hobday et al. 2014, Lewison et al. 2015, Maxwell et al. 2015, Hazen et al. 2018



Ryan et al. 2005



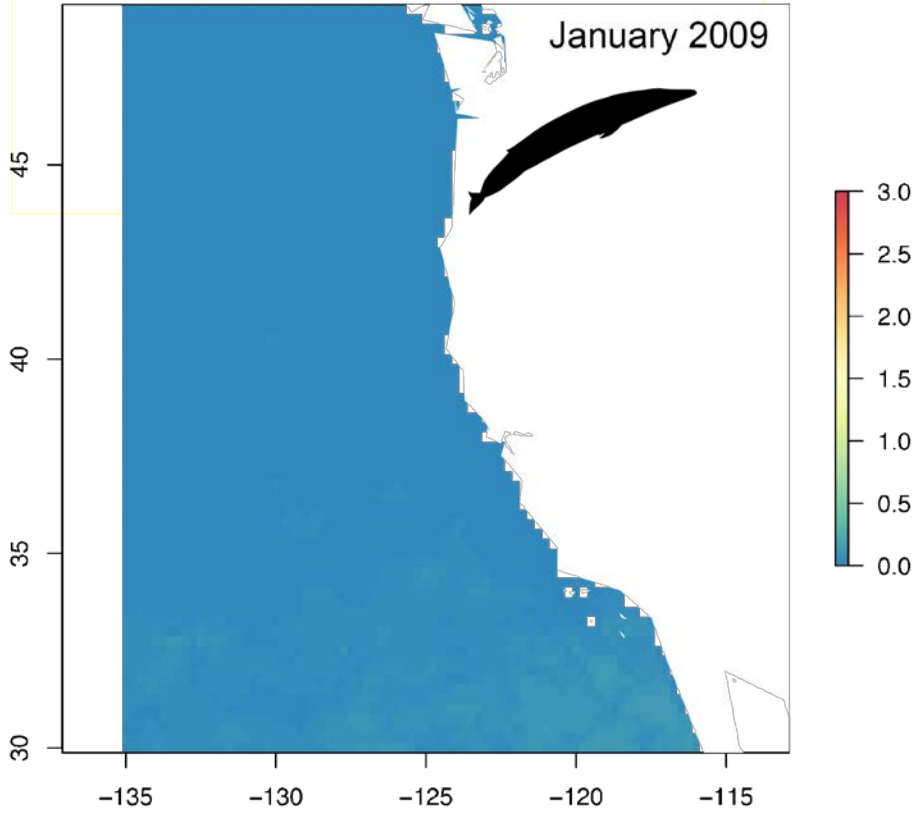
Block et al. 2011

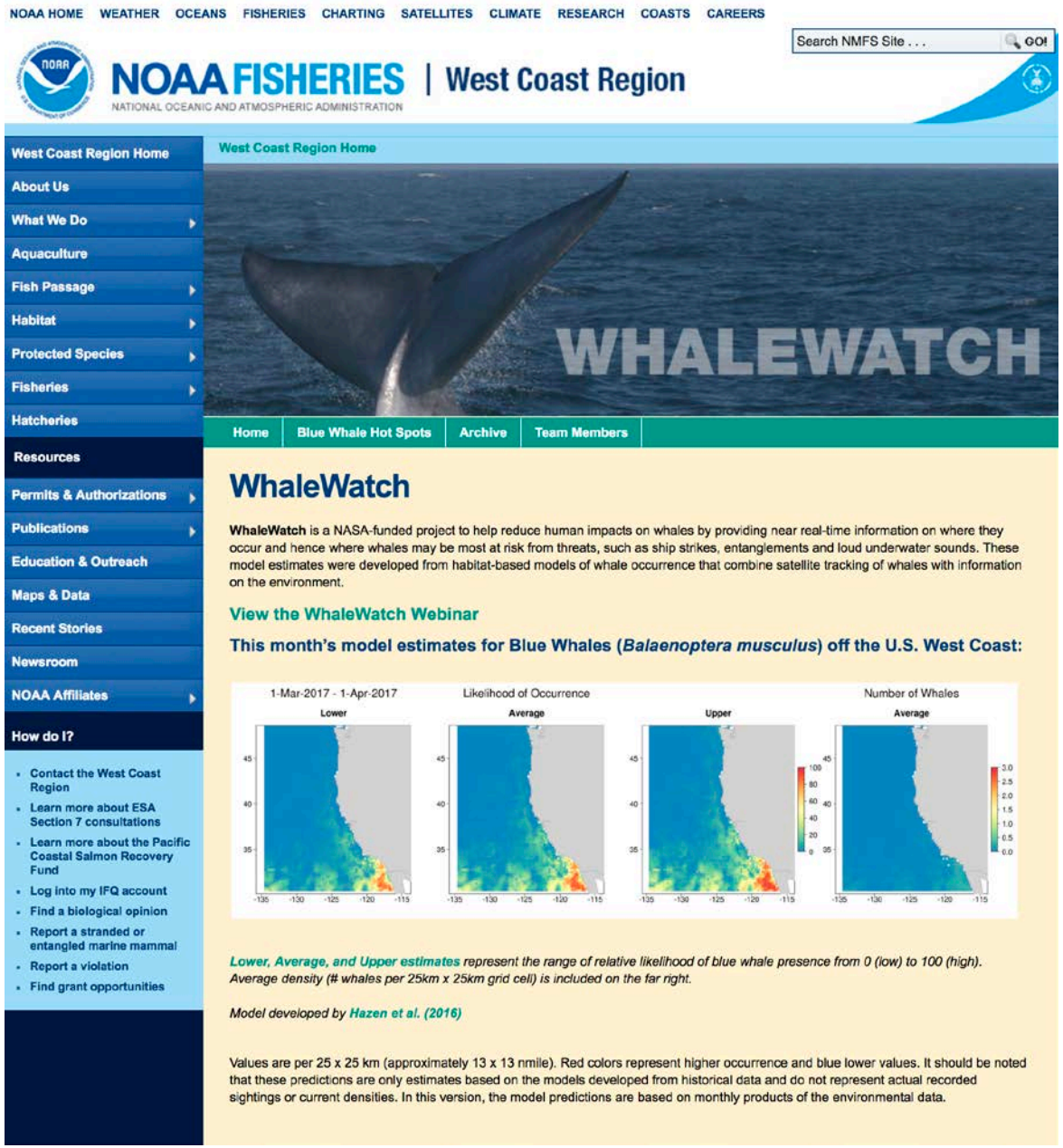


Maxwell et al. 2013

E.g. TurtleWatch WhaleWatch EcoCast An Eco-informatic Tool for Fisheries Sustainability Experimental Product

WhaleWatch 1.0: Monthly predictions at 25km scale, remotely sensed variables



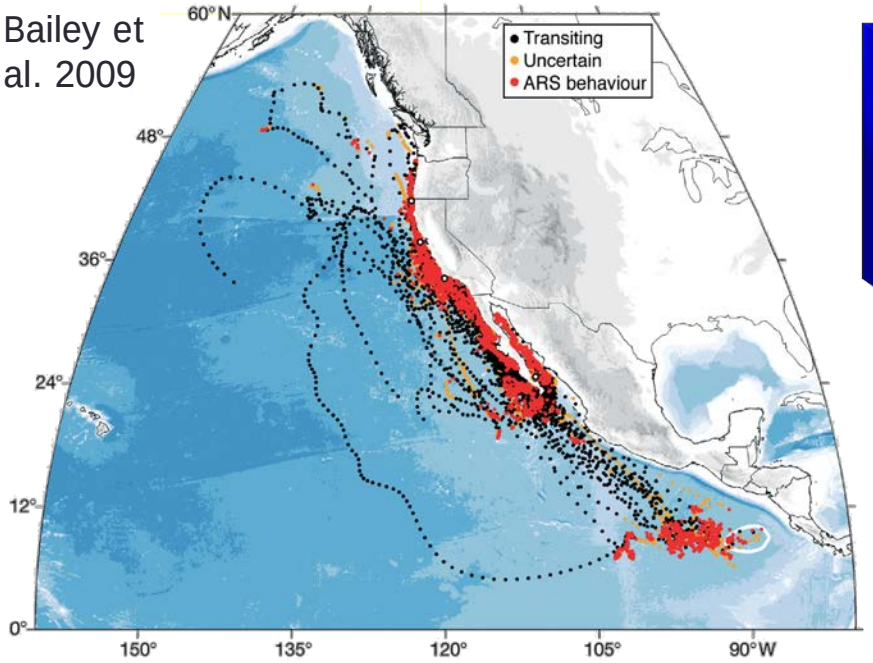


Hazen et al. 2017 J. Appl. Ecol.

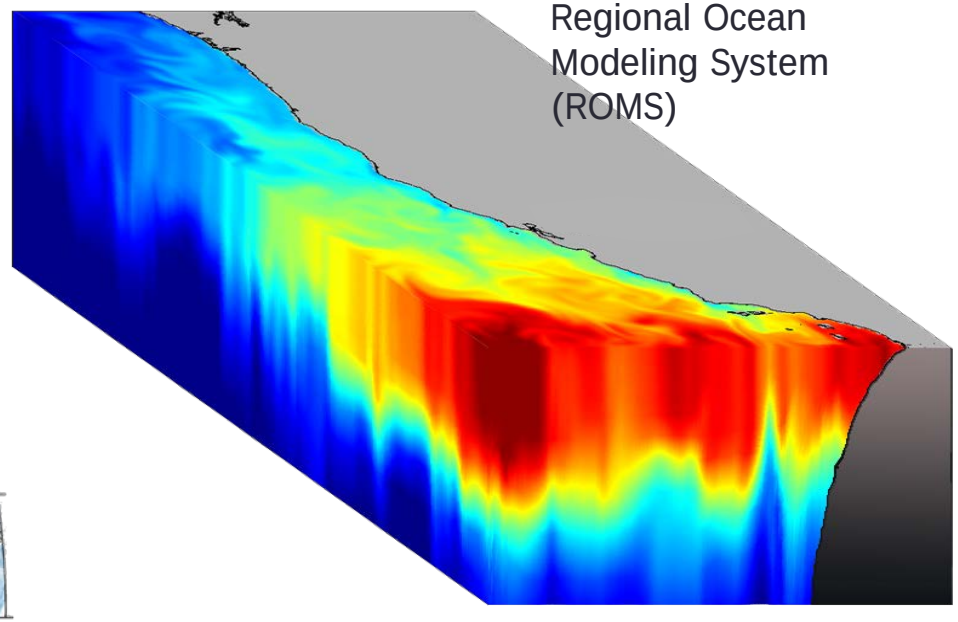
WhaleWatch 2.0: Objective

- Use regional ocean modeling (ROMS) data to develop a tool predicting blue whale habitat based on the current environmental conditions in the California Current.
- Models are built and being validated at **daily** and **10km** resolution to offer finer scale approaches towards reducing ship strike risk.

Bailey et al. 2009

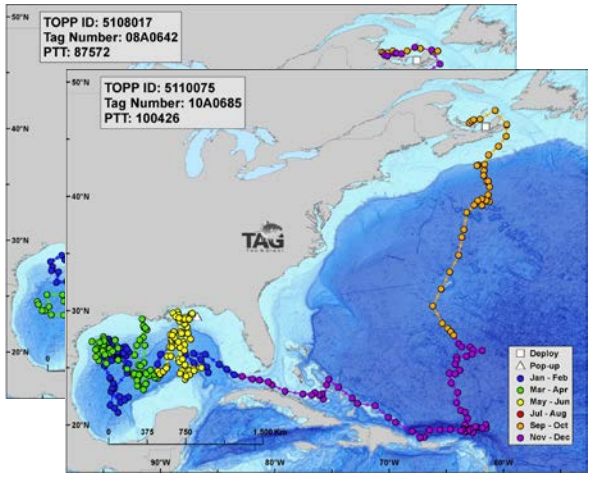


Regional Ocean Modeling System (ROMS)

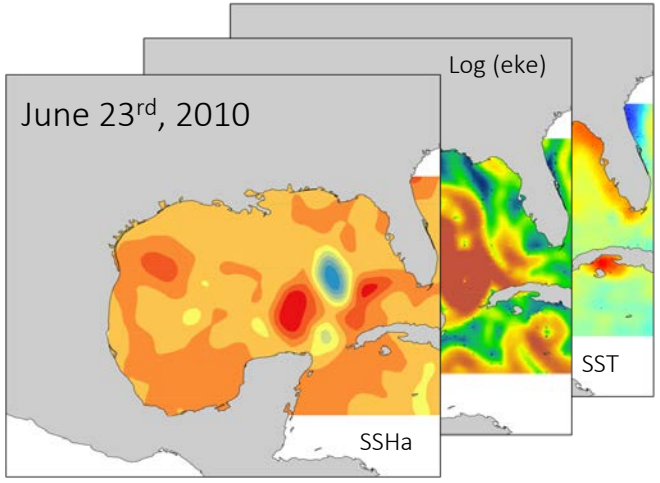


Approach: Species Distributional Modeling

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



Sampled predictive data



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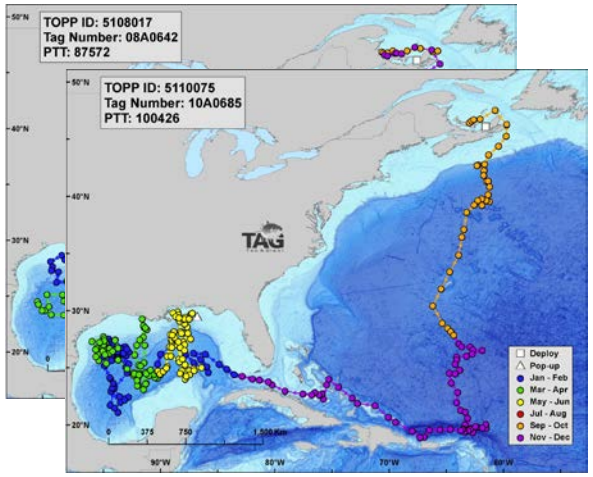
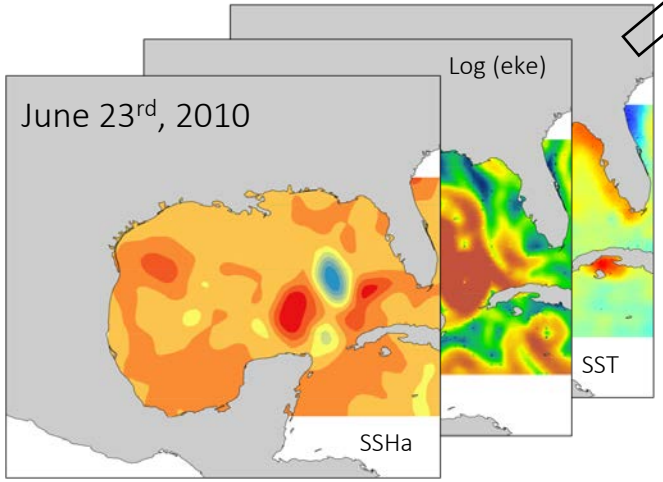


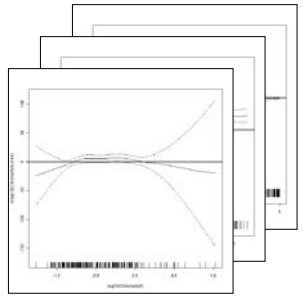
Fit

Statistical models

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

Sampled predictive data

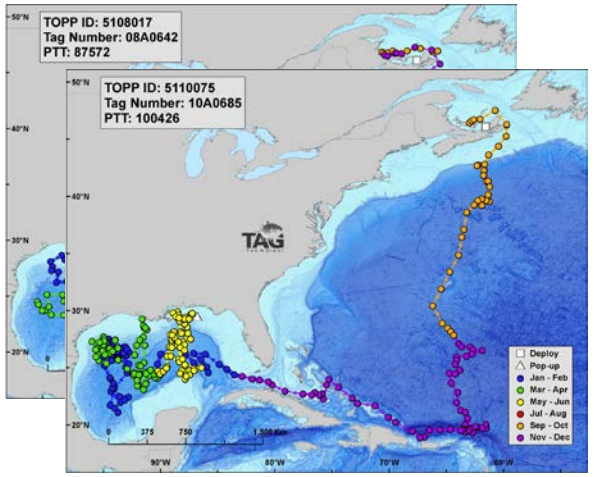




Generalized Additive Mixed Models,
Boosted Regression Trees

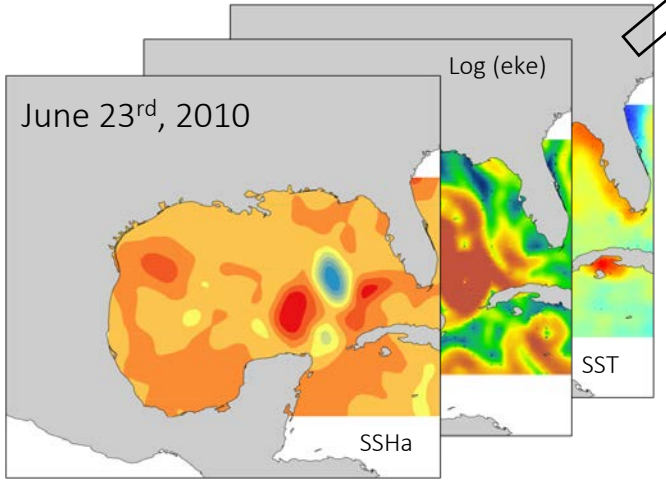
Approach: Species Distributional Modeling

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



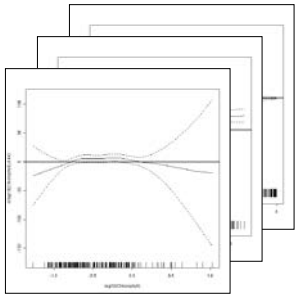
Fit

Sampled predictive data



Statistical models

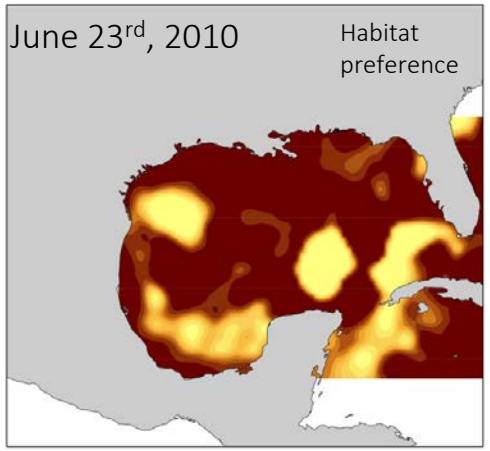
$$g(\mu) = \beta_0 + \beta_1 x_1 + \cdots + \beta_m x_m$$

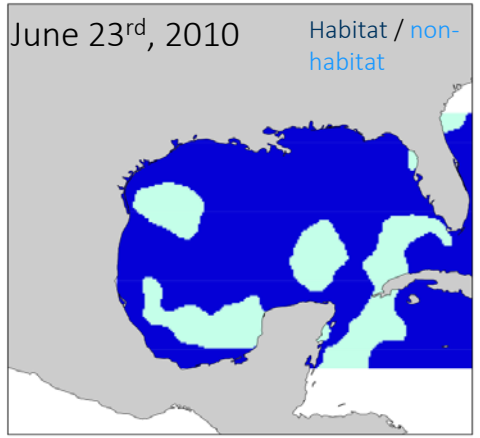


Generalized Additive Mixed Models, Boosted Regression Trees

Predict

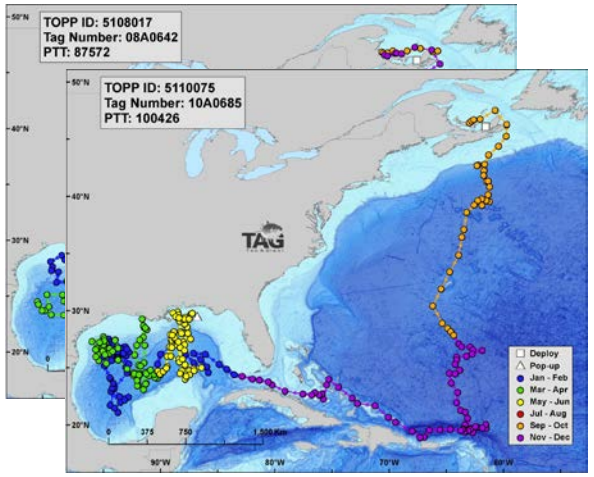
Probability of occurrence predicted from environmental covariates





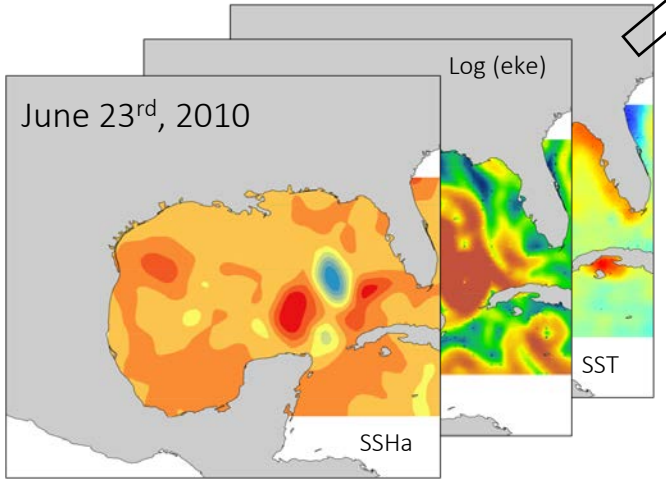
Approach: Species Distributional Modeling

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



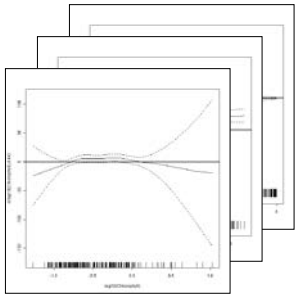
Fit

Sampled predictive data



Statistical models

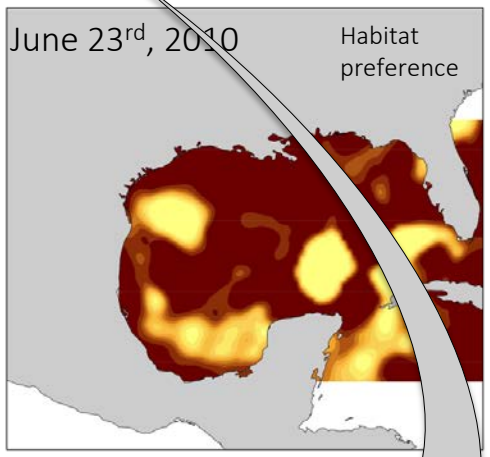
$$g(\mu) = \beta_0 + \beta_1 x_1 + \cdots + \beta_m x_m$$

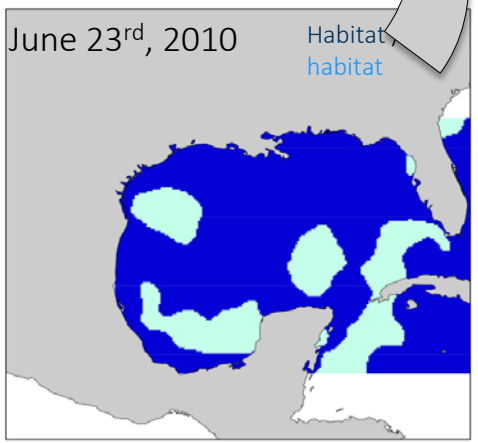


Generalized Additive Mixed Models, Boosted Regression Trees

Predict

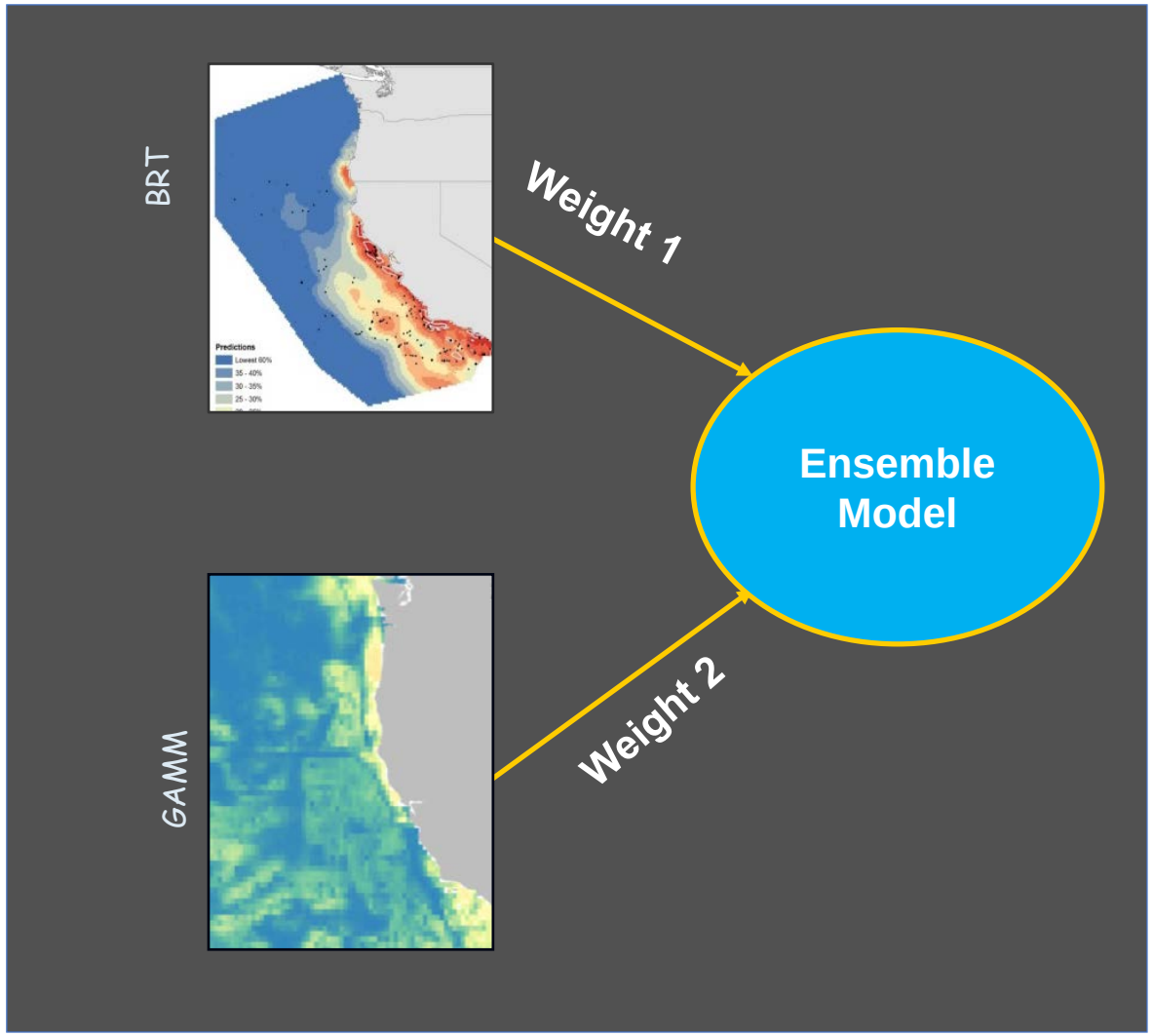
Probability of occurrence predicted from environmental covariates





Validate

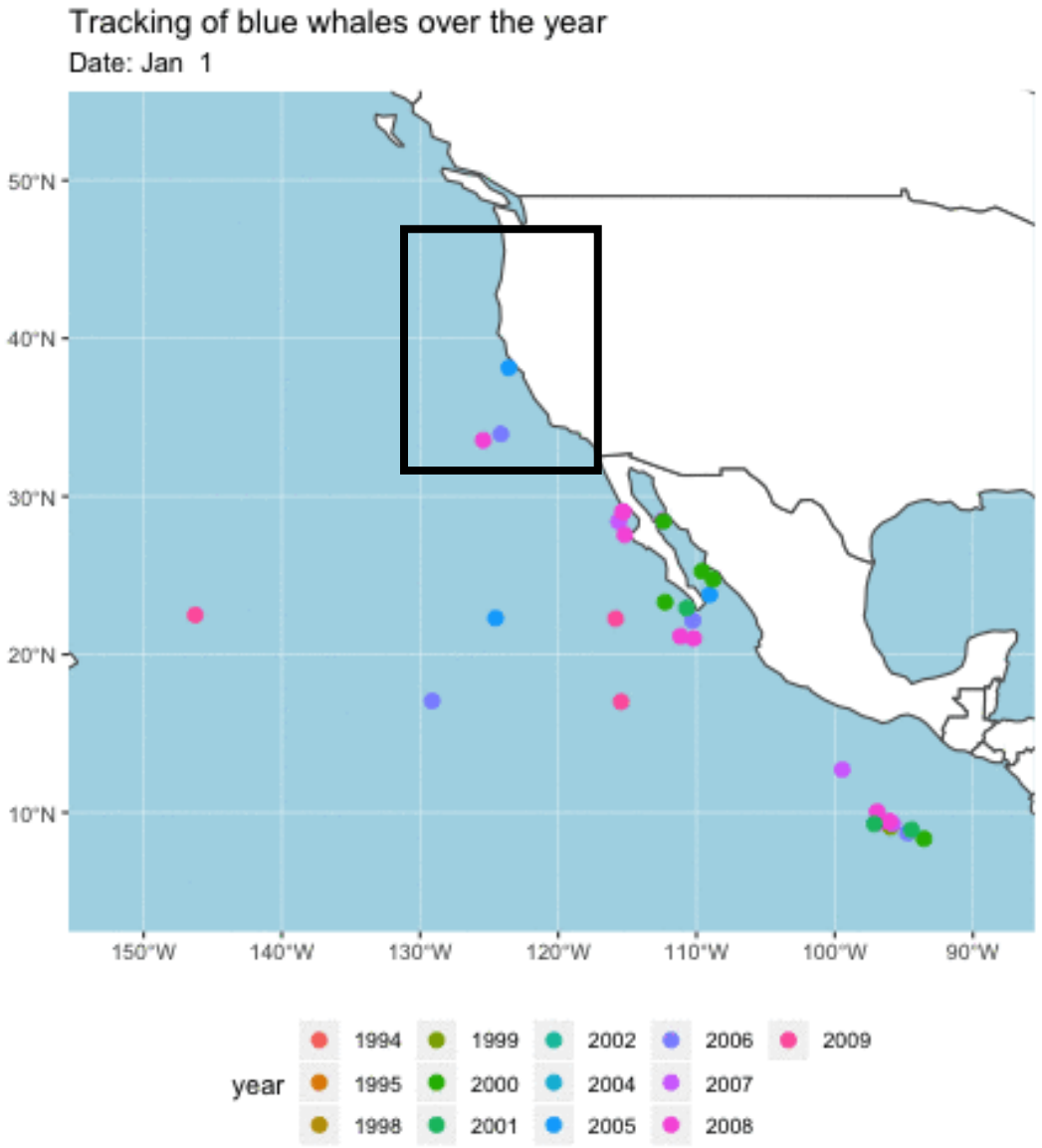
Approach: Ensemble Modeling



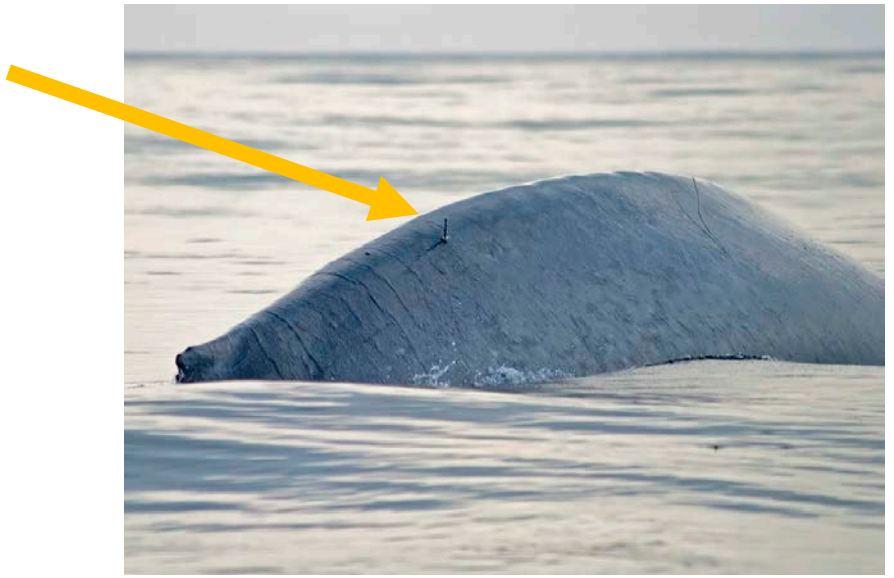
Predictions from a set ('ensemble') of models often yield more robust predictions and allow evaluation of uncertainties.

Wintle et al. 2003, Johnson and Omland 2004, Araújo and New 2007, Thuiller et al. 2008, Gritti et al. 2013, Scales et al. 2015

Blue Whale Tag Data



- 104 blue whales tagged 1994-2009
- Daily GPS locations estimated from State-Space Model

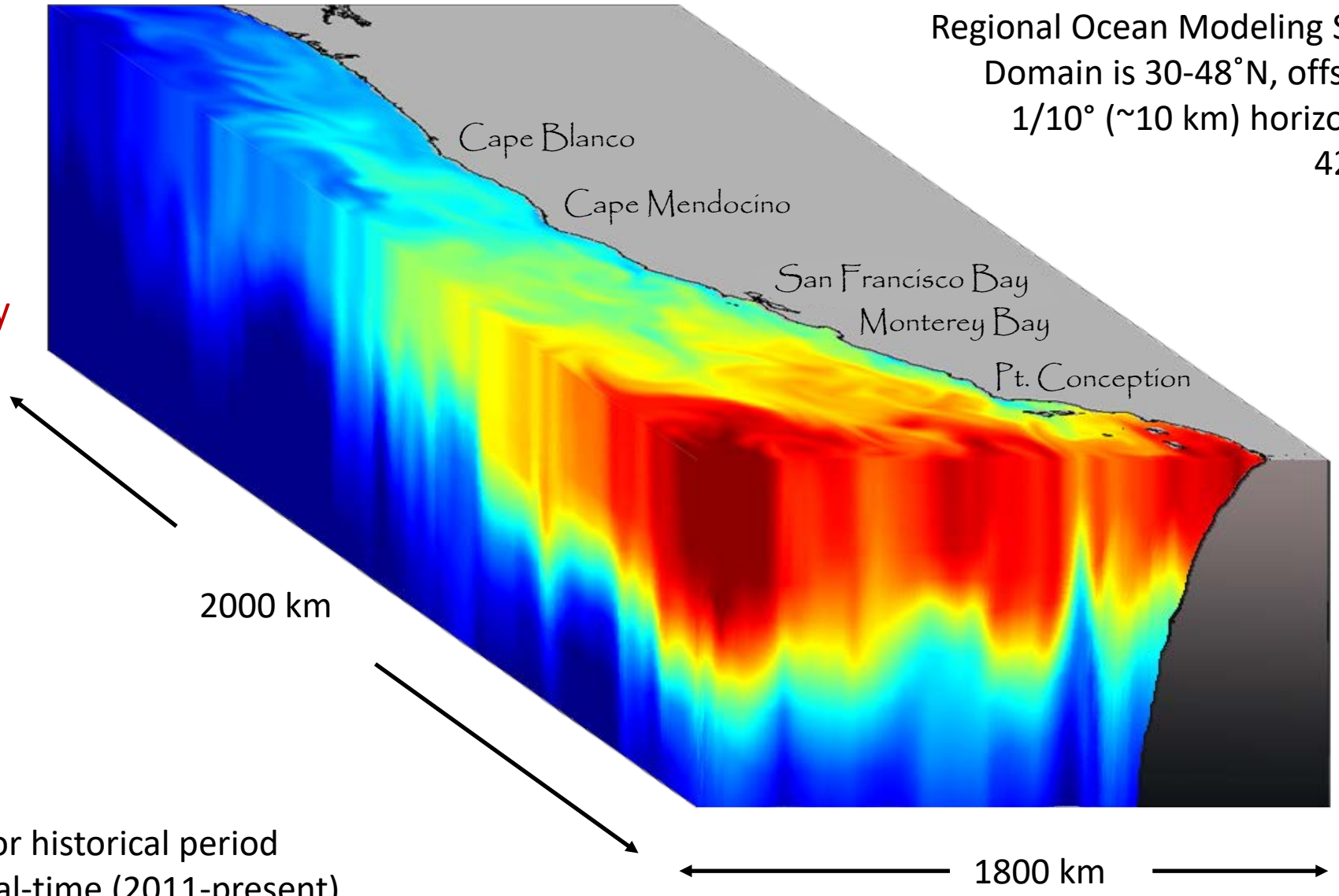


Regional Ocean Modeling System (ROMS)

Regional Ocean Modeling System (ROMS)
Domain is 30-48˚N, offshore to 134˚W
1/10° (~10 km) horizontal resolution
42 vertical levels

- Bathymetry
- Sea surface height
- Eddy kinetic energy
- Sea surface temp.
- Isothermal layer depth
- Water column stratification
- Wind stress

… and more



Model output is available for historical period (1980-2010) and in near-real-time (2011-present)
All output archived and served on UC Santa Cruz OPeNDAP THREDDS server (oceanmodeling.ucsc.edu)

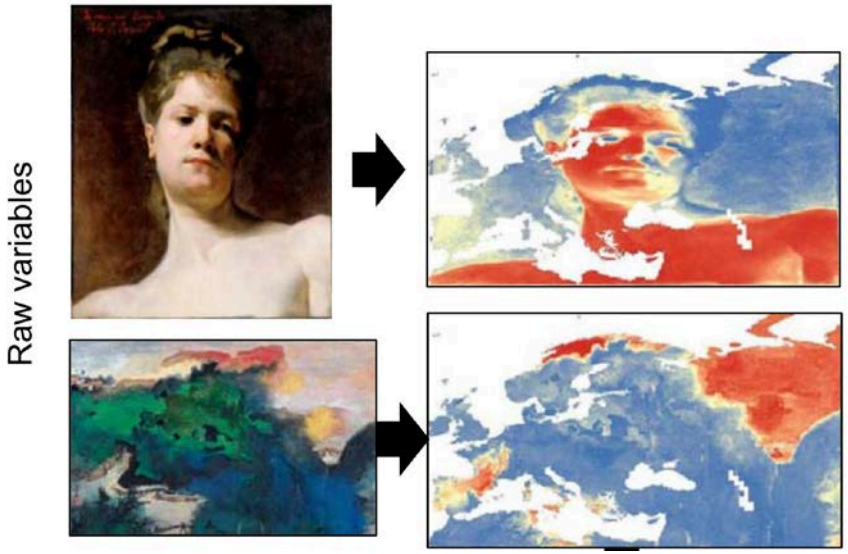
Model Evaluation

MACROECOLOGICAL METHOD 2017

WILEY Global Ecology and Biogeography A Journal of Macroecology

Paintings predict the distribution of species, or the challenge of selecting environmental predictors and evaluation statistics

Yoan Fourcade[1,2] | Aurélien G. Besnard[1,3] | Jean Secondi[1,4,5]

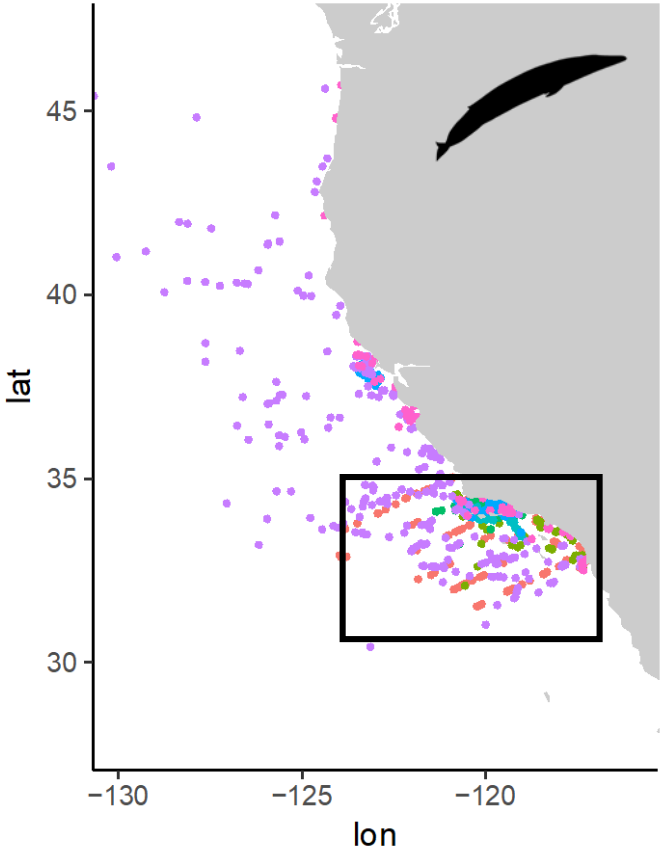


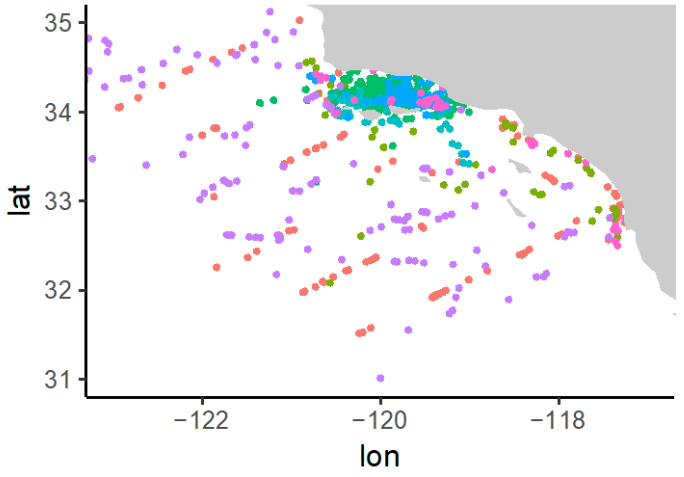
→ *Importance of using independent data for validation and multiple evaluation metrics!*

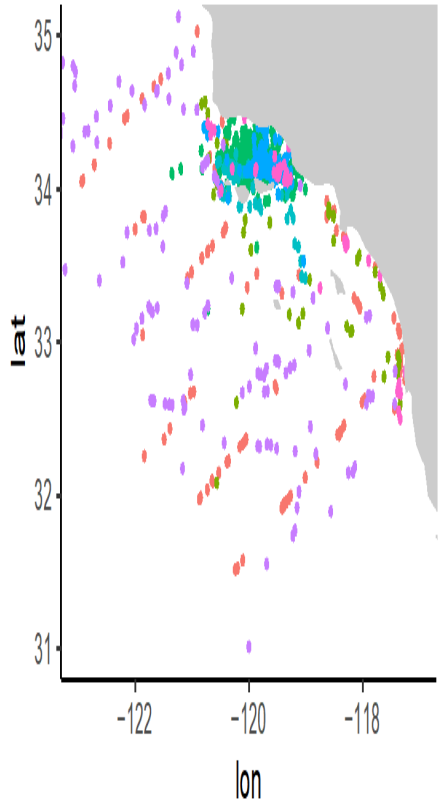
Model Evaluation

6 Training & Testing Datasets:

- 100% training vs. 100% testing
- 75% random training vs. 25% random testing
- 100% training vs. testing in the SCB
- K-folds training & testing
- Leave One Year Out training vs. Single Year testing
- **N=3,413 independent sightings**



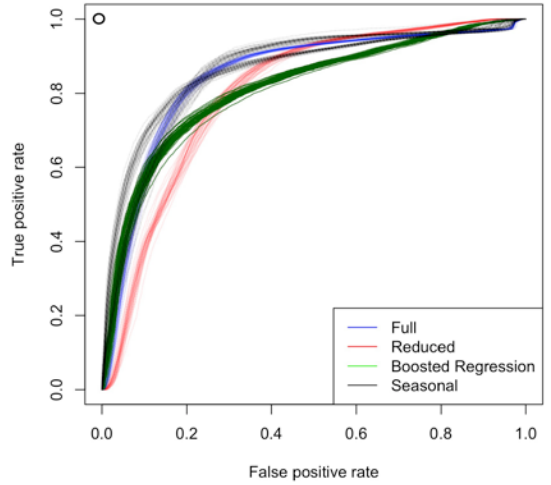




Model Evaluation

6 Training & Testing Datasets x 2 metrics:

- 100% training vs. 100% testing
- 75% random training vs. 25% random testing
- 100% training vs. testing in the SCB
- K-folds training & testing
- Leave One Year Out training vs. Single Year testing
- N=3,413 independent sightings



AUC = true positive rate vs. false positive rate

TSS = true positive rate + true absence rate - 1

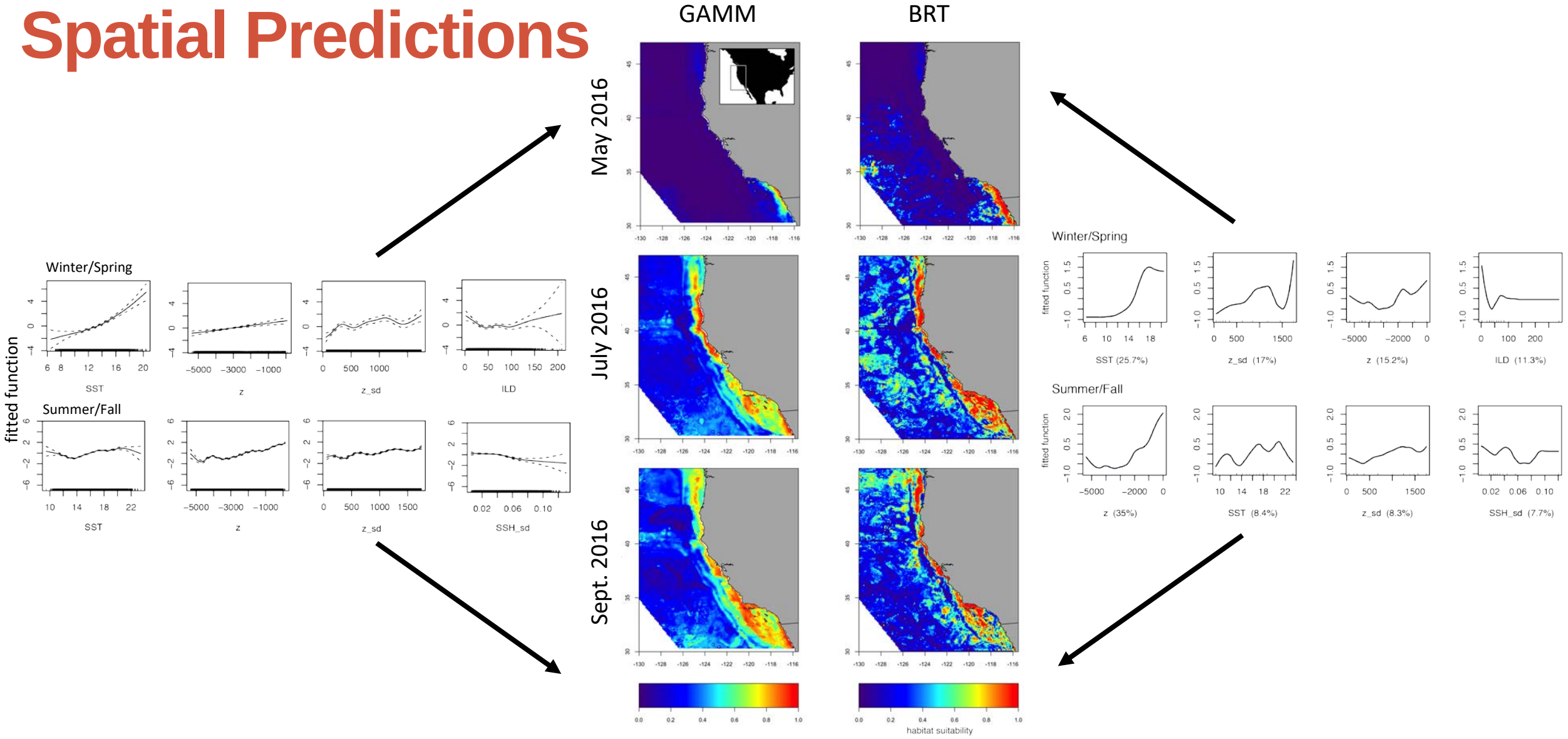
Scores range 0-1
Score ≥ 0.5 = better than random, ≥ 0.75 considered good.

Candidate Models

Model name	Model description	100%/100% AUC / TSS	K-fold AUC / TSS	Sightings AUC / TSS
GAMM 1	SST + SSH_sd + z + z_sd + ILD + EKE	0.912 / 0.701	0.839 / 0.569	0.941 / 0.801
GAMM 2	SST + SSH_sd + z + z_sd + ILD + EKE + lat*lon	0.931 / 0.745	0.862 / 0.598	0.903 / 0.706
GAMM 3	SST*lat + SSH_sd + z + z_sd + ILD + EKE	0.923 / 0.722	0.916 / 0.713	0.921 / 0.750
BRT	SST + SST_sd + SSH_sd + z + z_sd + ILD + EKE + curl + BV_frequency + slope + aspect	0.944 / 0.760	0.873 / 0.607	0.943 / 0.792
Ensemble 1	GAMM 1 + BRT	0.951 / 0.764	0.862 / 0.594	**0.949** / **0.804**
Ensemble 2	GAMM 2 + BRT	0.959 / 0.798	0.873 / 0.623	0.941 / 0.787
Ensemble 3	GAMM 3 + BRT	0.956 / 0.782	0.871 / 0.618	0.941 / 0.790

Abrahms et al. *in review*

Spatial Predictions

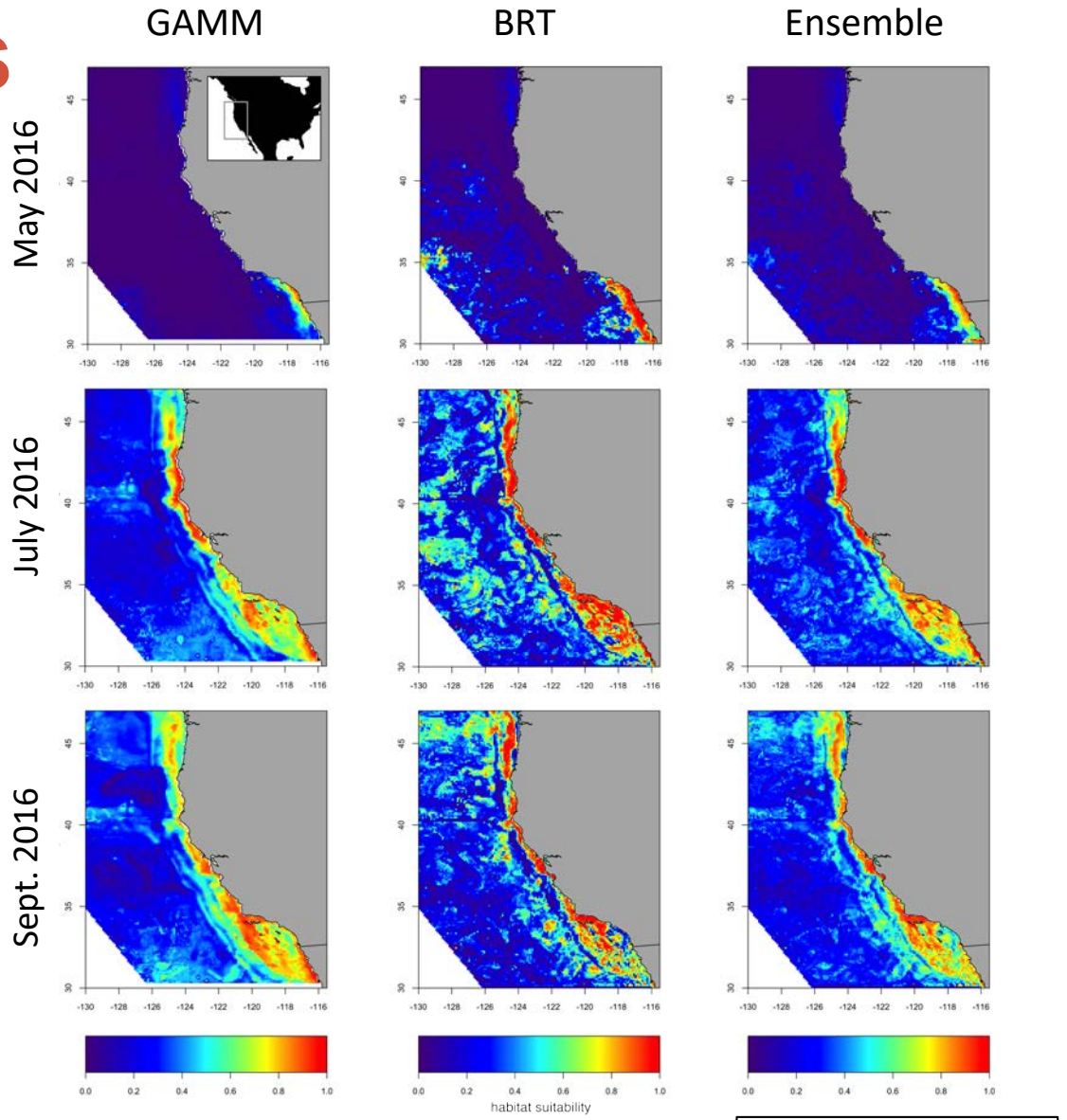


Sightings AUC: 0.941
Sightings TSS: 0.801

Sightings AUC: 0.943
Sightings TSS: 0.792

Abrahms et al. *in review*

Spatial Predictions



GAMM	BRT	Ensemble
Sightings AUC: 0.941 Sightings TSS: 0.801	Sightings AUC: 0.943 Sightings TSS: 0.792	Sightings AUC: 0.949 Sightings TSS: 0.804

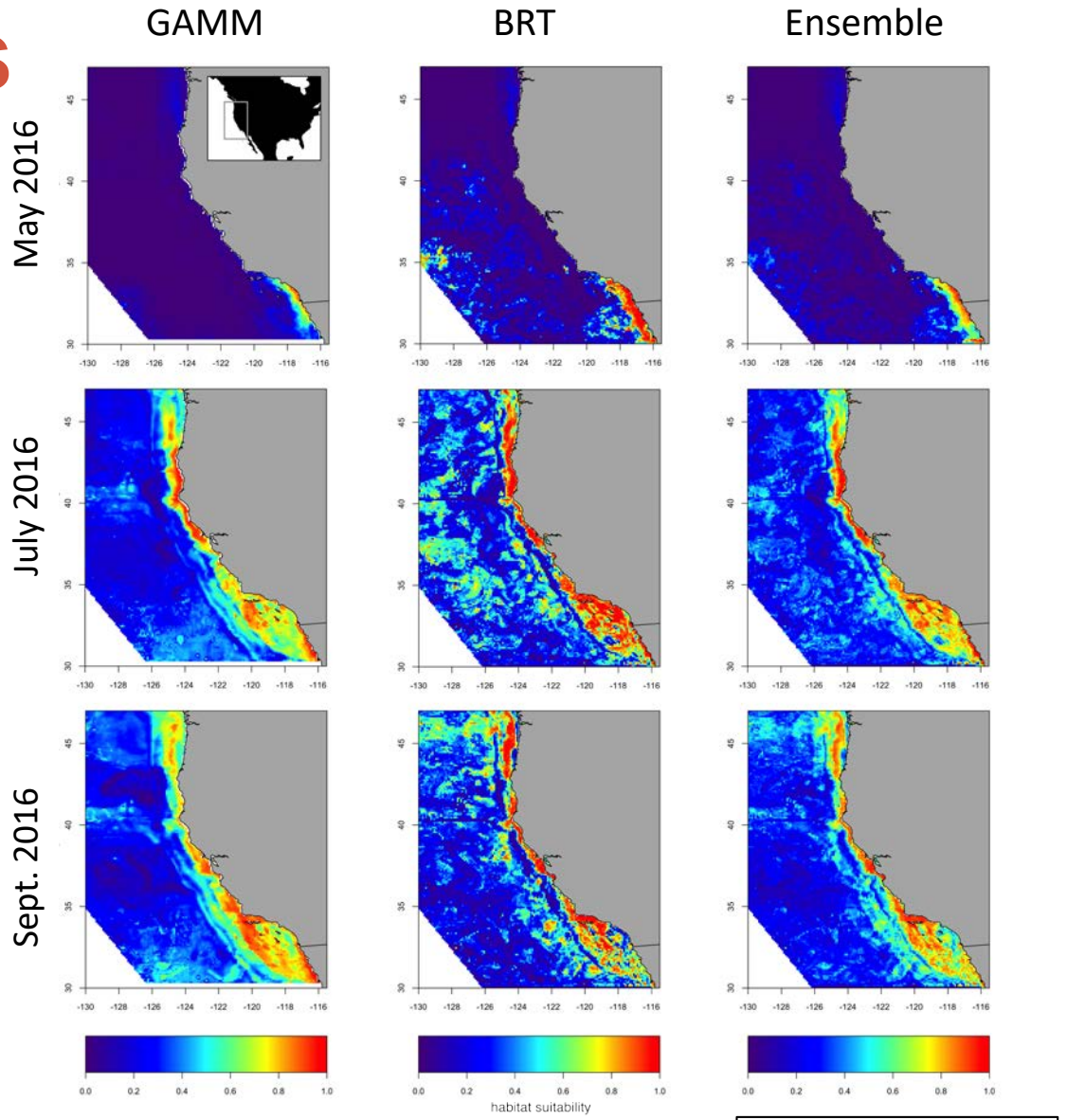
Abrahms et al. *in review*

Spatial Predictions

AUC/TSS scores ≥ 0.5
= better than random,
≥ 0.75 considered good.

100% training / 100% testing
AUC = 0.951

Previous WhaleWatch model
100% training / 100% testing
AUC = 0.845



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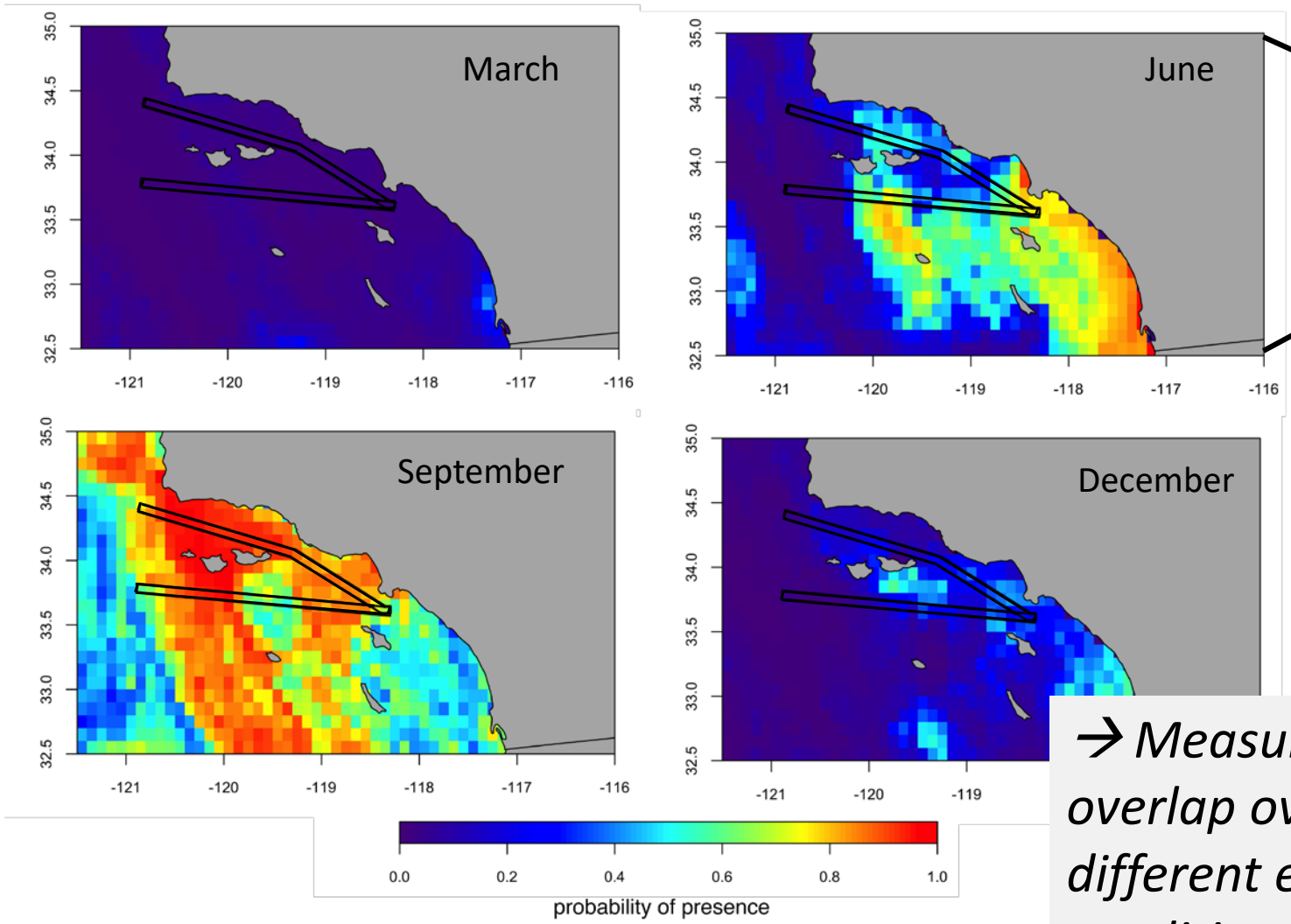
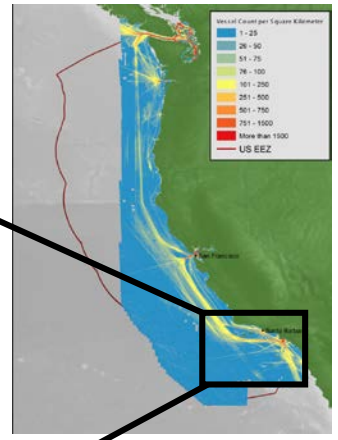
Abrahms et al. *in review*

Risk Exposure in Shipping Lanes





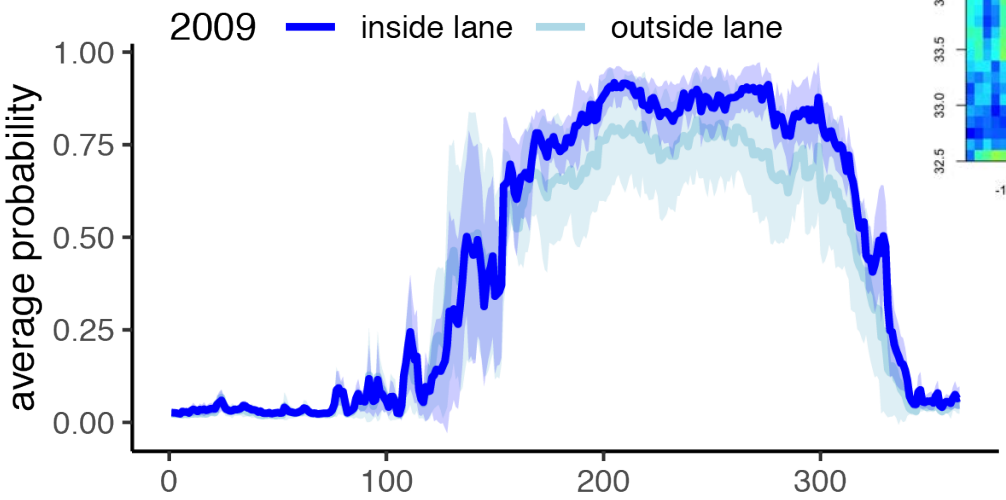
Hazen *et al*. 2017 JAE

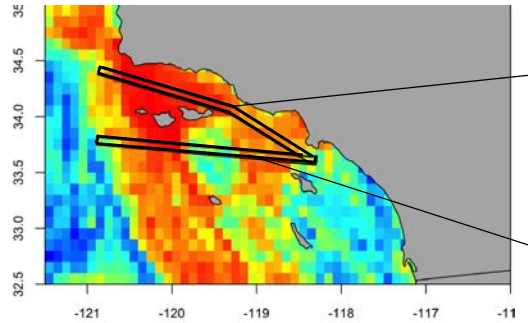
→ *Measure probability of overlap over time under different environmental conditions*

Abrahms et al. *in review*

Risk Exposure in Shipping Lanes

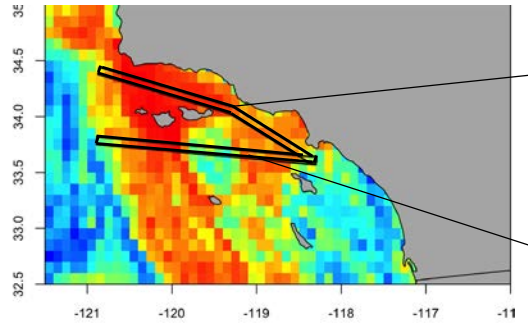
2009
”normal”
conditions



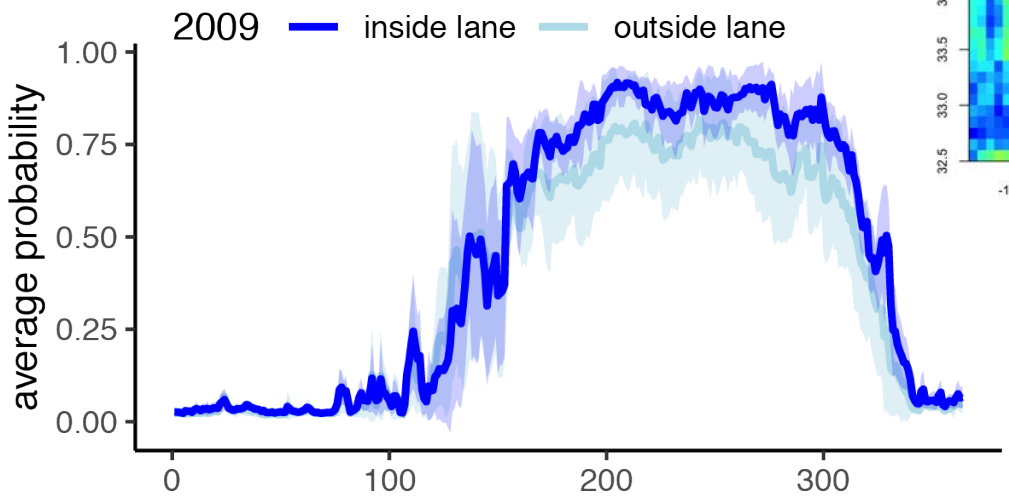


Abrahms et al. *in review*

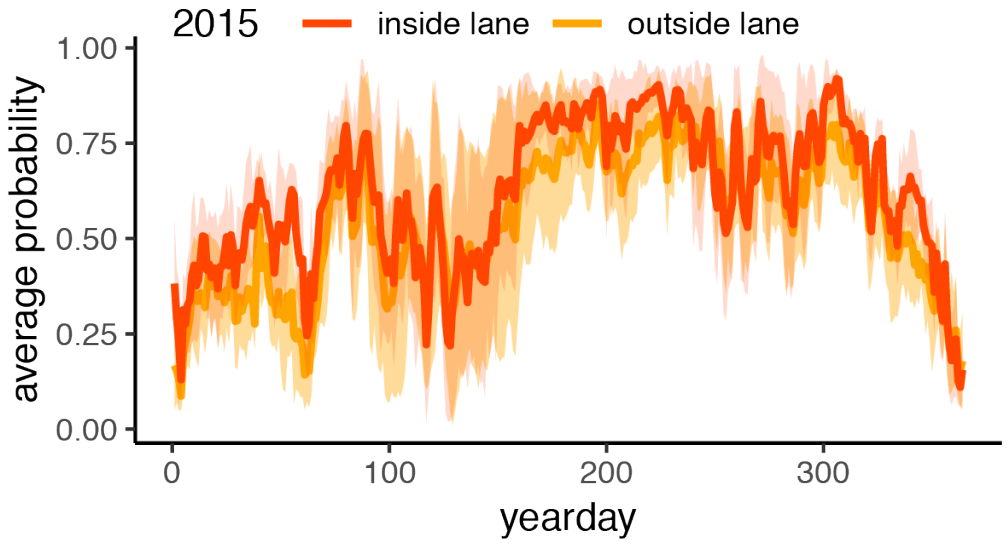
Risk Exposure in Shipping Lanes



2009 "normal" conditions

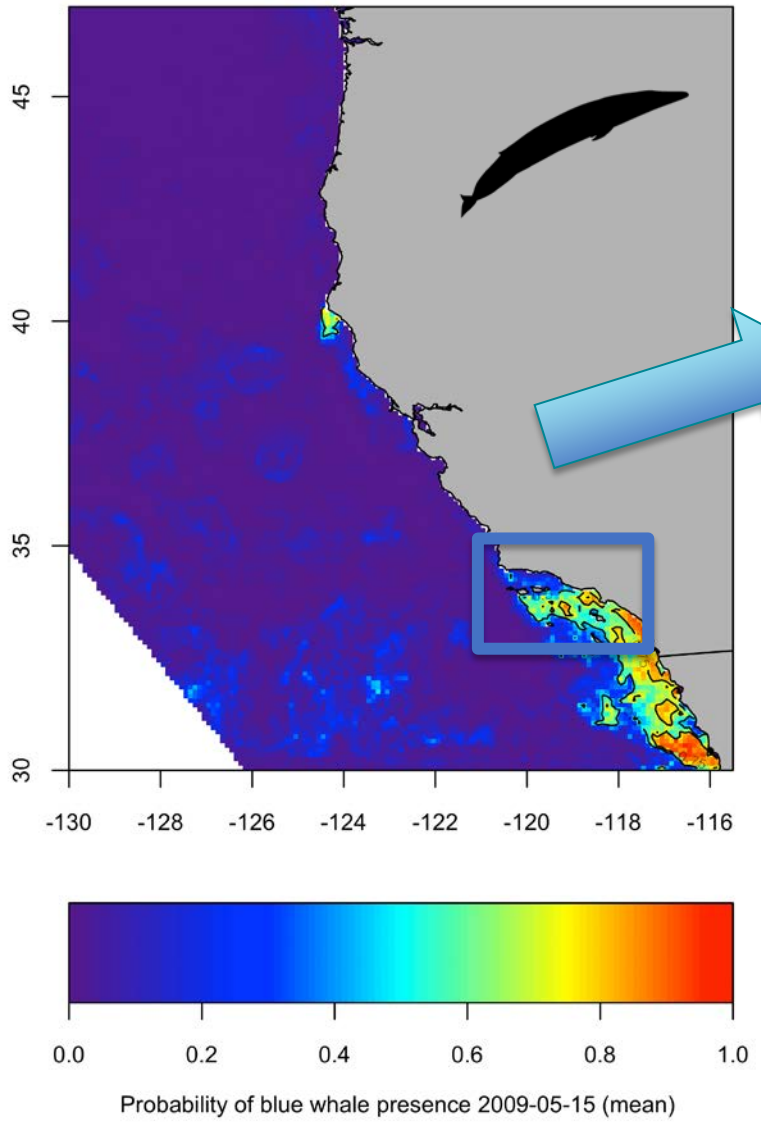


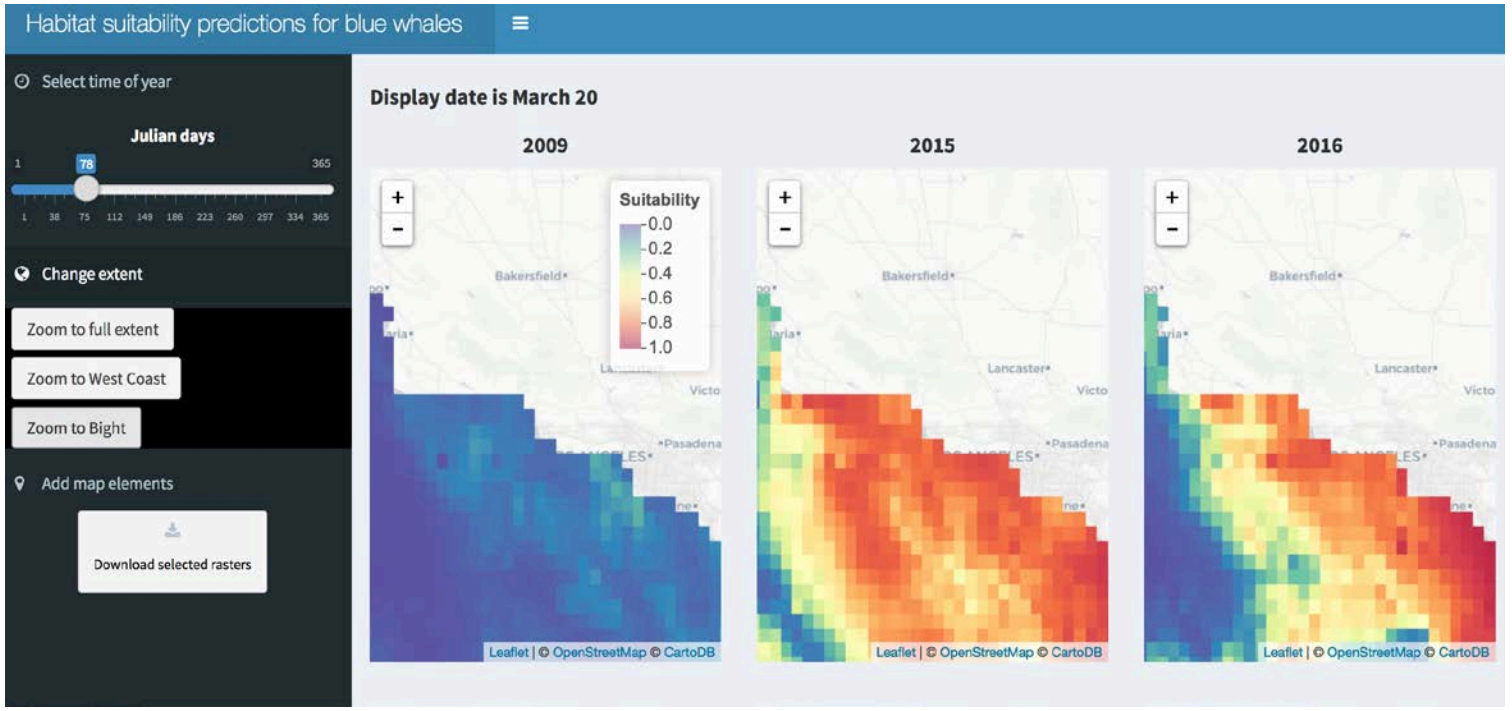
2015 warm water anomaly



Abrahms et al. *in review*

Decision Support Tool





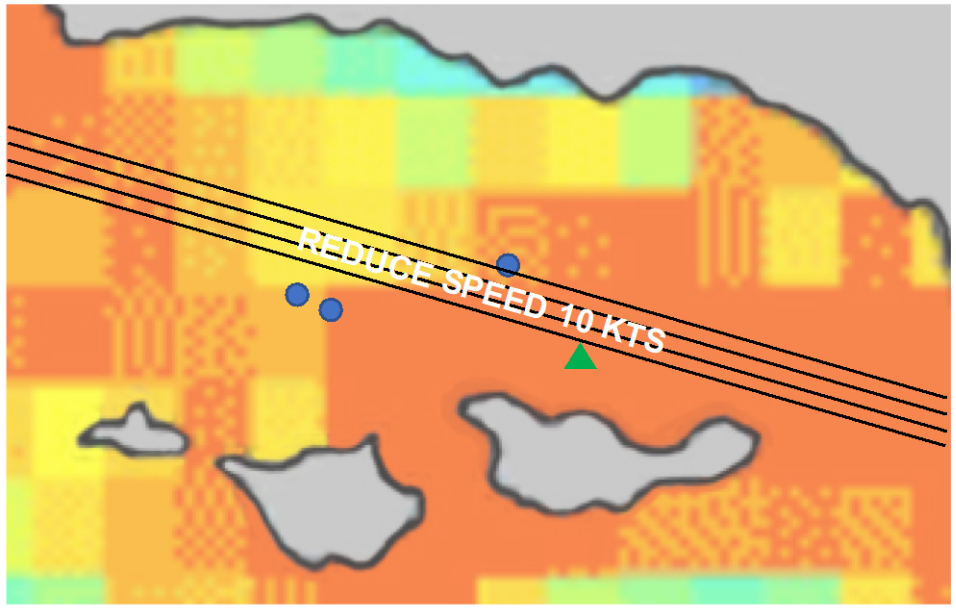
https://heatherwelch.shinyapps.io/benioff_app/

Decision Support Tool

BENIOFF OCEAN INITIATIVE

Whale Map

Last Updated 25 January 2019 10:00



Whale Presence

How was this calculated?

NOAA Whale Advisory

IN EFFECT

Vessels 300 gross registered tons or larger reduce speed to 10 kts in Santa Barbara Channel TSS

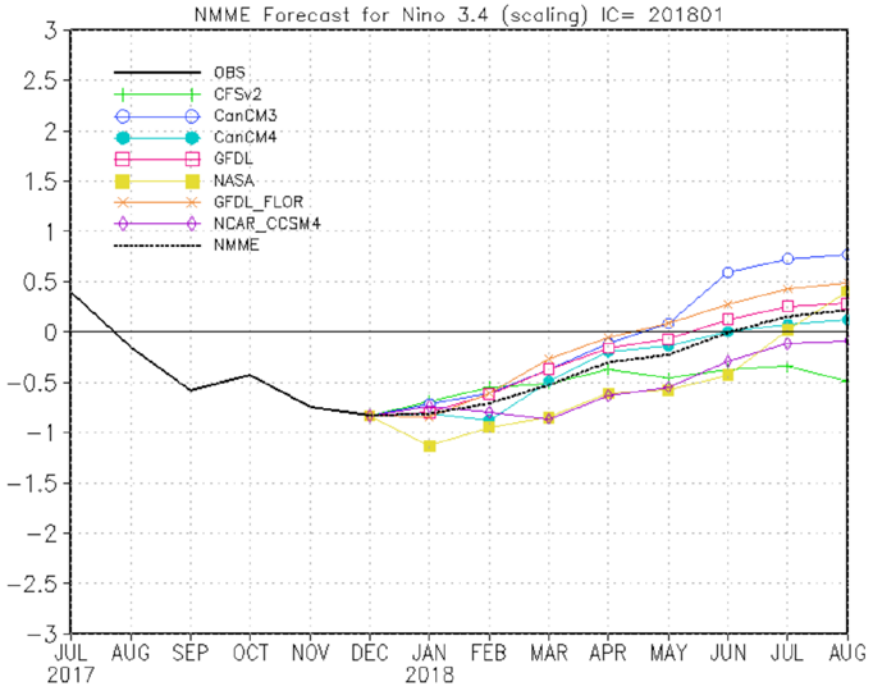
See Local Notice to Mariners

Data Layers

- ☑ Opportunistic sightings
  - ☑ Blue whale
  - ☐ Humpback whale
  - ☐ Fin whale
  - ☐ Gray whale
  - ☐ Other whale
- ☑ Blue whale likelihood of occurrence
  - 0 — 1
- ☑ Acoustic detections
  - Online buoy
  - Offline buoy
  - Whale detected
  - Listening radius
- ☐ Thermal detections
- ☑ NOAA VSR zone (10 knots)
- ☐ NOAA whale advisory zone
- ☑ Shipping Lanes

Future opportunities

January Forecasts of ENSO Conditions

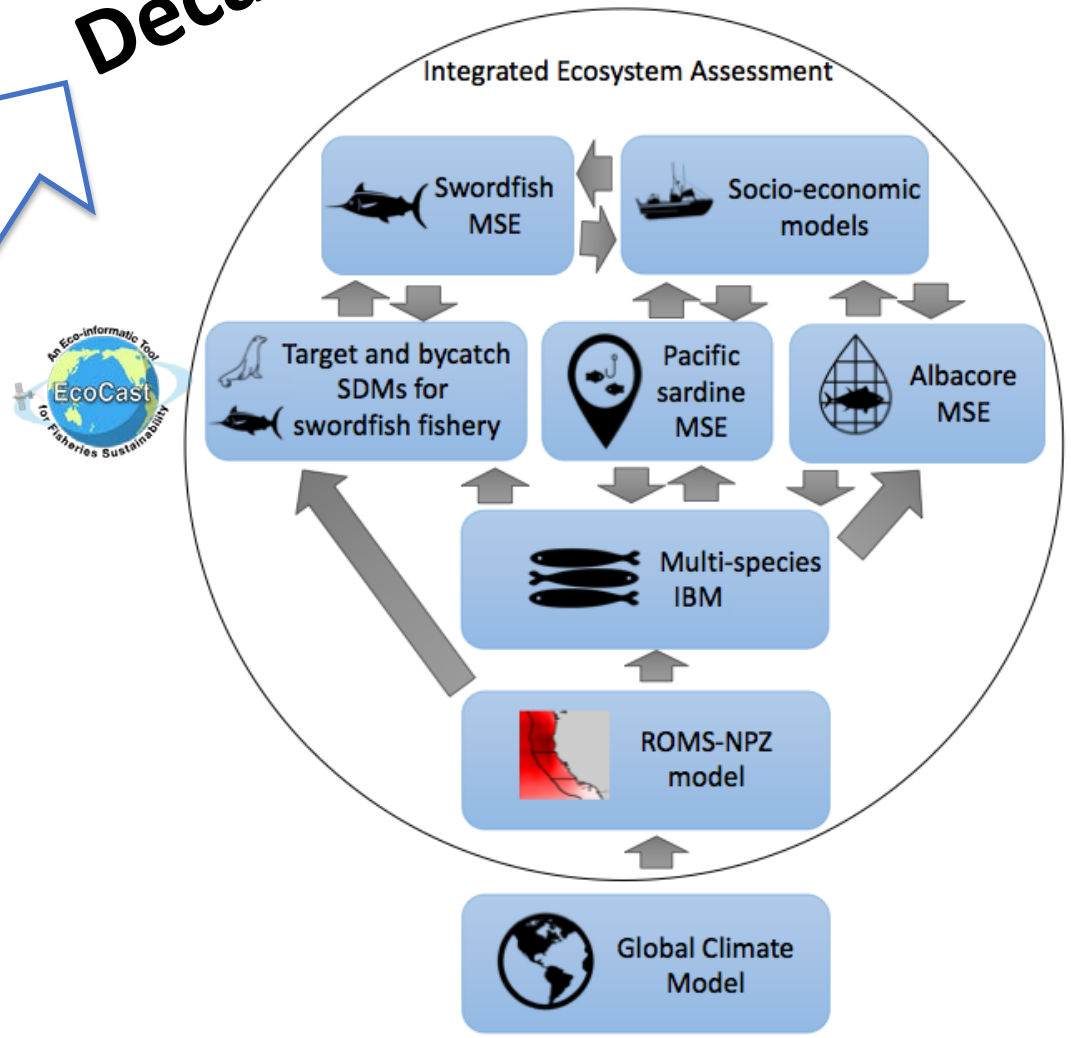


NOAA - MAPP

Seasonal

Decadal

NOAA - COCA



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Conclusions

- Dynamic species distribution models can offer a better match with ecological processes **AND** human activities in space and time.
- ROMS-based models offer the ability to improve our spatial (25 to 10 km) and temporal (monthly to daily) scales, and predictive performance, for estimating the dynamic distribution of blue whales.
- These models are valuable for integrating into decision support tools.

Thank you!

Heather Welch, Stephanie Brodie, Michael Jacox, Elizabeth Becker, Steven J. Bograd, Ladd Irvine, Daniel Palacios, Bruce Mate, Elliott L. Hazen

Thanks to: CINMS staff, Benioff Ocean Initiative

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