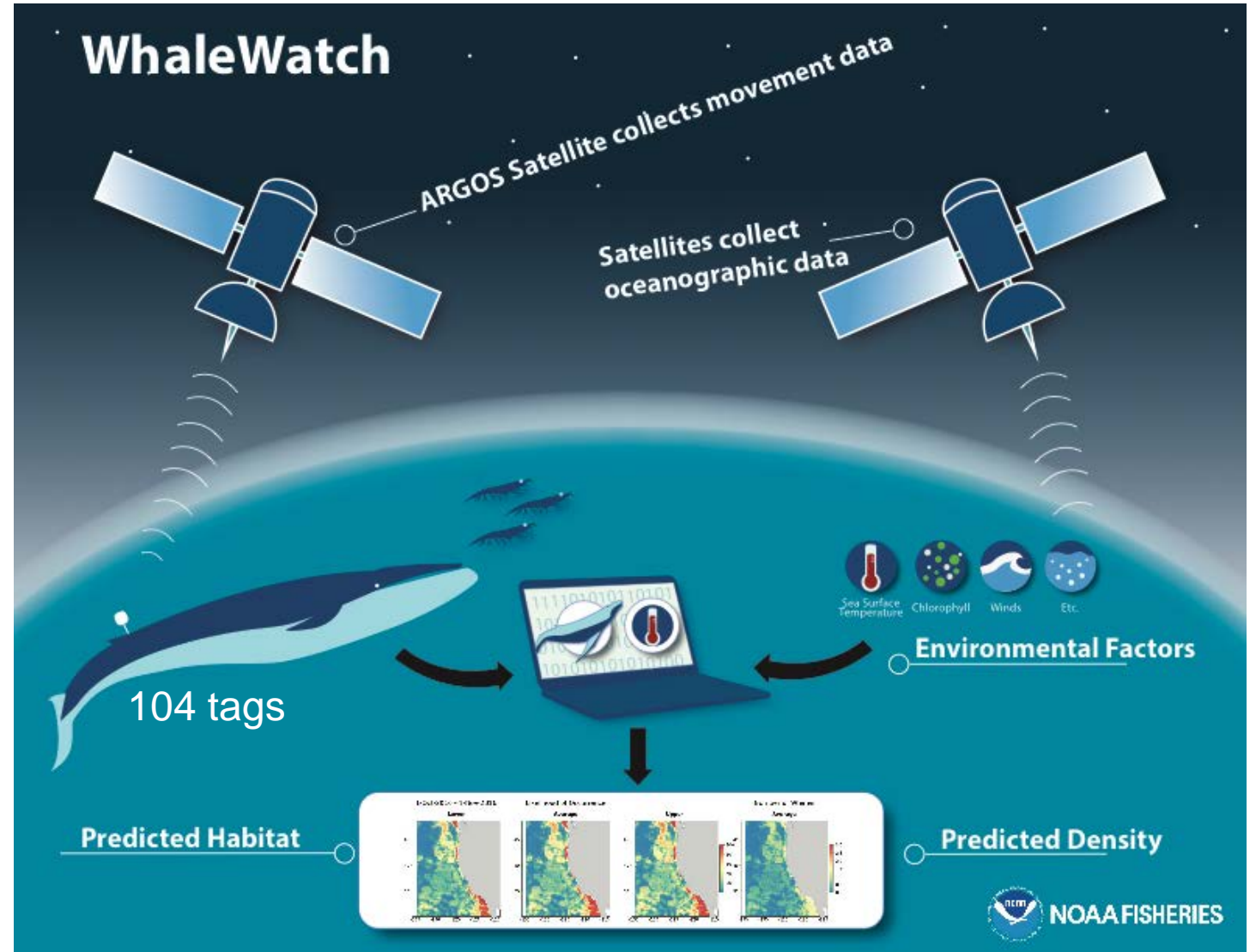


Dynamic ensemble models to predict blue whale distributions and risk exposure in near real-time



Briana Abrahms
February 12th 2019

Protected Species Assessment Working II

Motivation: Ship strikes as a threat to blue whales

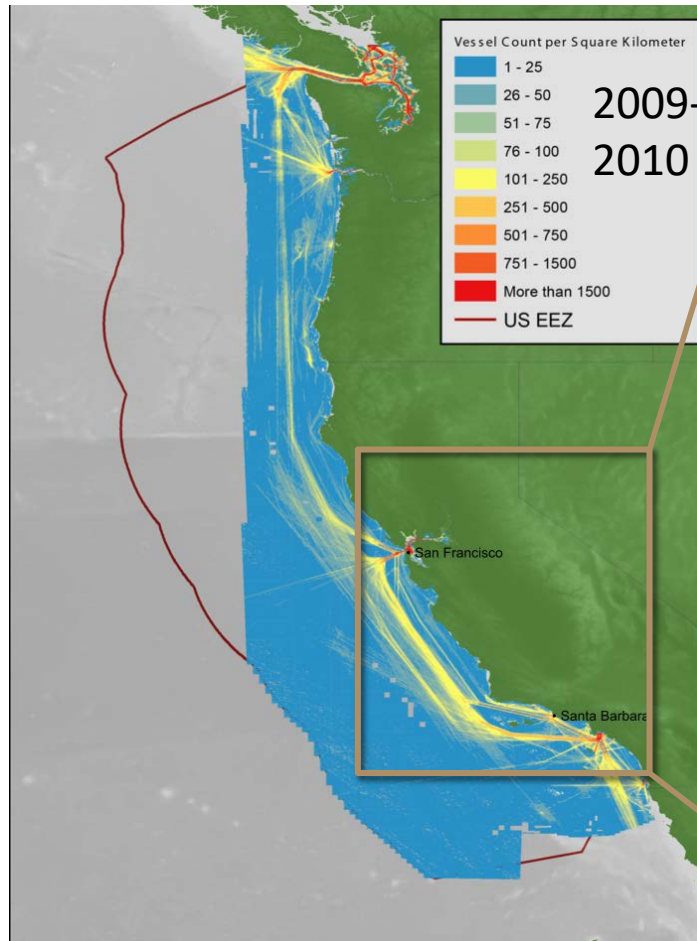


- Blue whale abundance globally is at 3-11% its pre-industrial level
- Ship strikes identified as major threat inhibiting population recovery (Berman-Kowalewski et al. 2010; Redfern et al. 2013, Rockwood et al. 2017)
- Most recent estimate of 20 blue whale ship strikes per year in California Current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

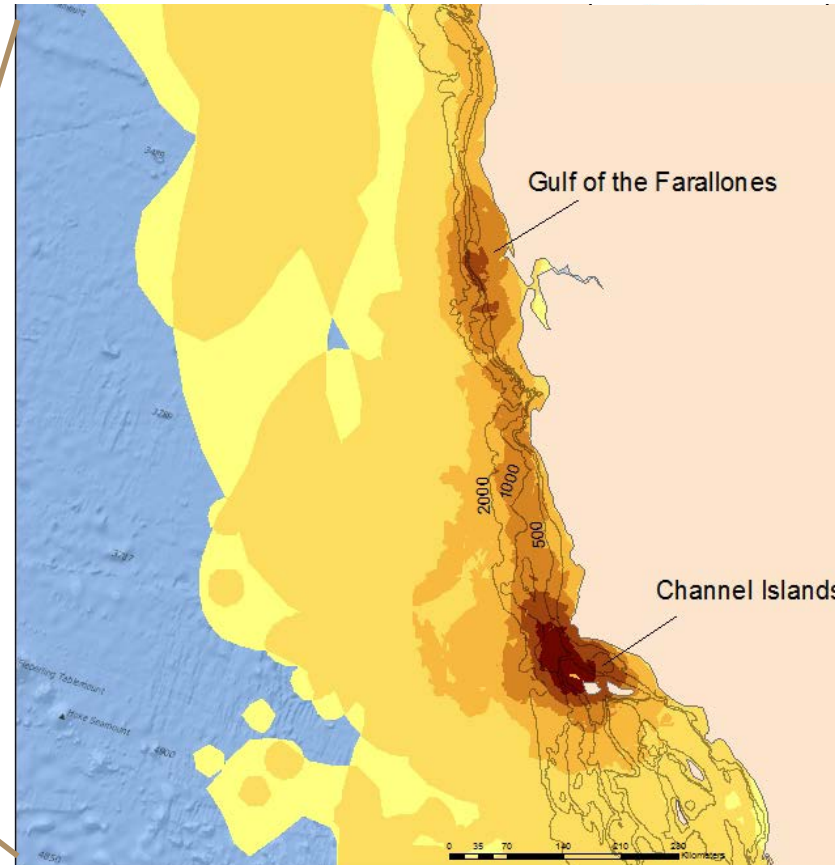


Flip Nicklin, Minden Pictures

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*

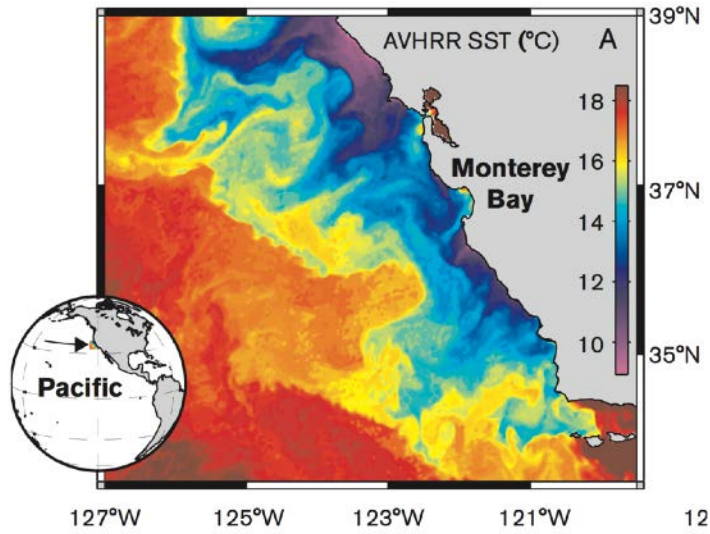
- High spatial overlap between shipping intensity and blue whale hotspots
- Southern CA Bight a hotspot for strikes (Rockwood et al. 2017, Redfern et al. 2013)



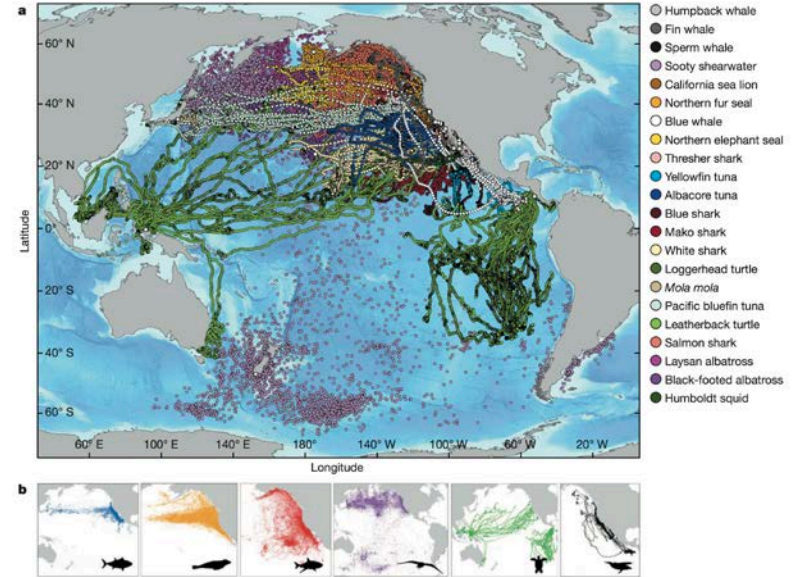
Dynamic Ocean Management

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

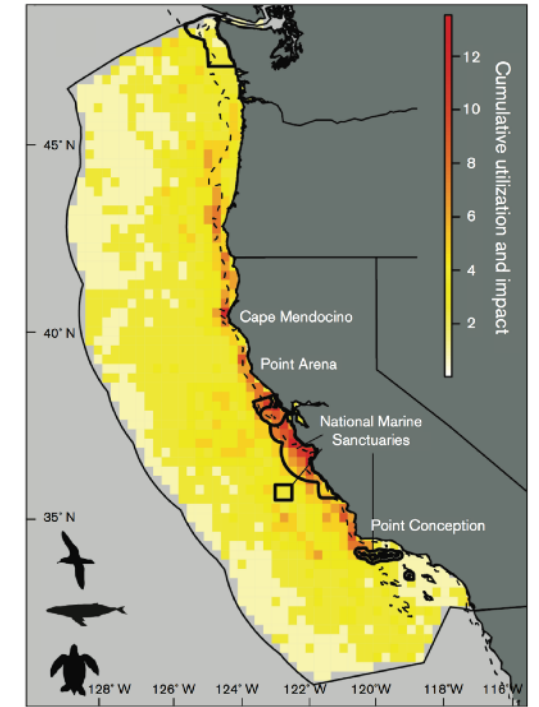
Hobday et al. 2014, Lewison et al. 2015, Maxwell et al. 2015, Hazen et al. 2018



Ryan et al. 2005



Block et al. 2011



Maxwell et al. 2013

E.g.

TURTLEWATCH



WHALEWATCH



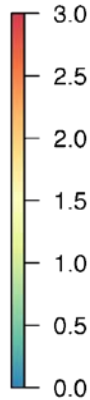
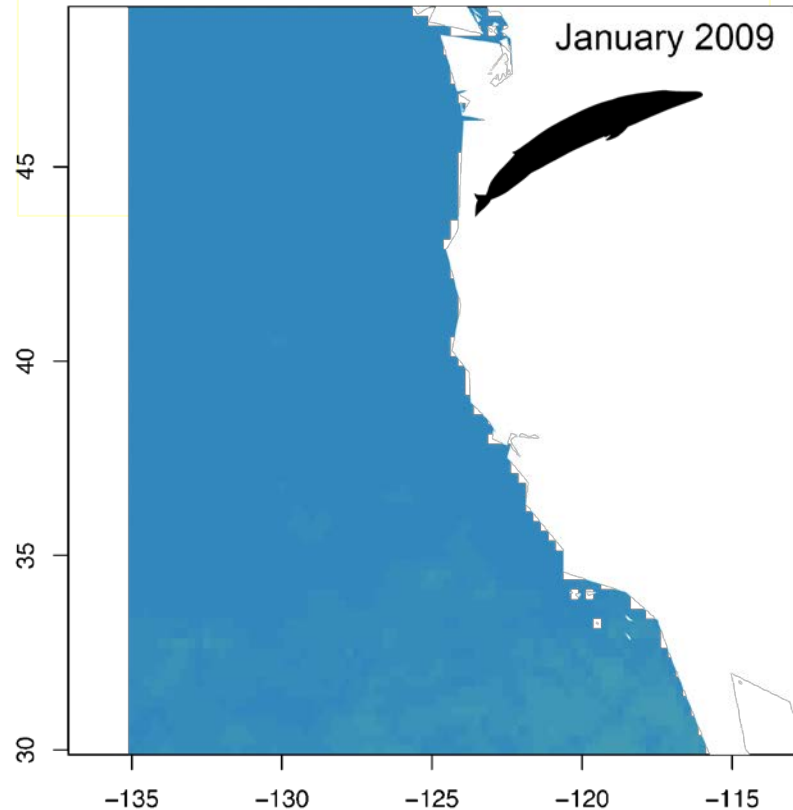
EcoCast

An Eco-informatic Tool for Fisheries Sustainability

Experimental Product



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



NOAA HOME WEATHER OCEANS FISHERIES CHARTING SATELLITES CLIMATE RESEARCH COASTS CAREERS

NOAA FISHERIES | West Coast Region
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Search NMFS Site ... GO!

West Coast Region Home

West Coast Region Home

Home Blue Whale Hot Spots Archive Team Members

WhaleWatch

WhaleWatch is a NASA-funded project to help reduce human impacts on whales by providing near real-time information on where they occur and hence where whales may be most at risk from threats, such as ship strikes, entanglements and loud underwater sounds. These model estimates were developed from habitat-based models of whale occurrence that combine satellite tracking of whales with information on the environment.

[View the WhaleWatch Webinar](#)

This month's model estimates for Blue Whales (*Balaenoptera musculus*) off the U.S. West Coast:

1-Mar-2017 - 1-Apr-2017

Lower Likelihood of Occurrence Average Upper Number of Whales

Lower, Average, and Upper estimates represent the range of relative likelihood of blue whale presence from 0 (low) to 100 (high). Average density (# whales per 25km x 25km grid cell) is included on the far right.

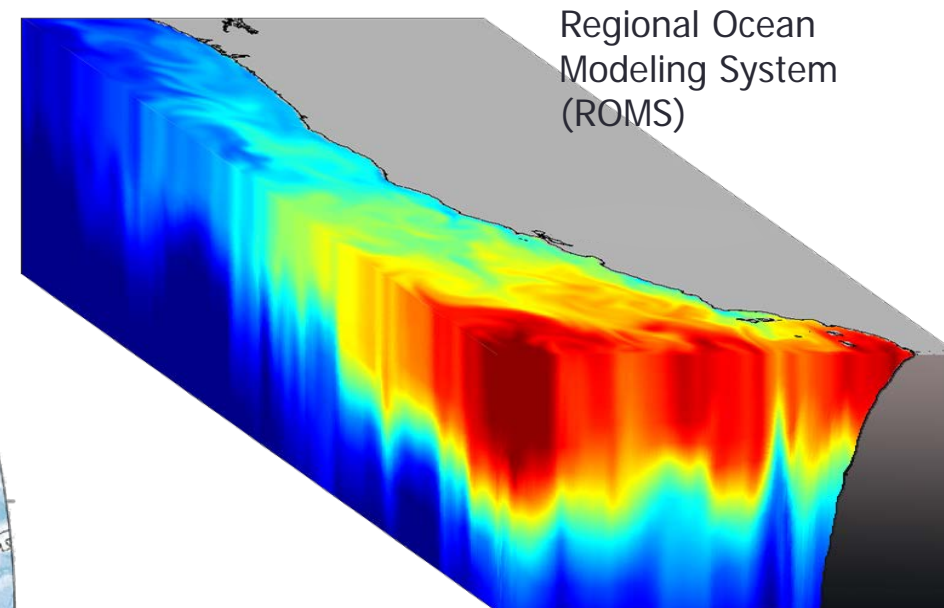
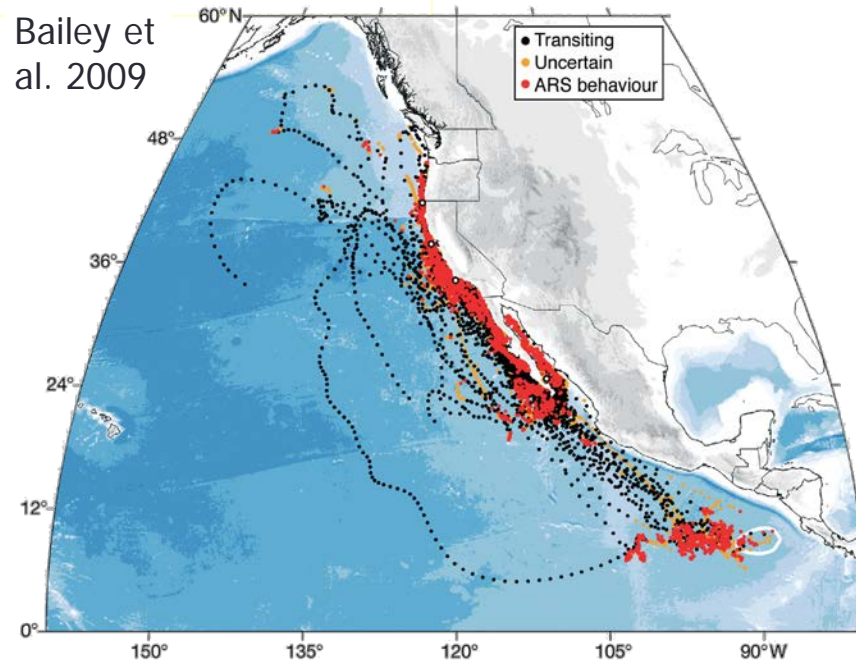
Model developed by [Hazen et al. \(2016\)](#)

Values are per 25 x 25 km (approximately 13 x 13 nmile). Red colors represent higher occurrence and blue lower values. It should be noted that these predictions are only estimates based on the models developed from historical data and do not represent actual recorded sightings or current densities. In this version, the model predictions are based on monthly products of the environmental data.

WhaleWatch 2.0: Objective

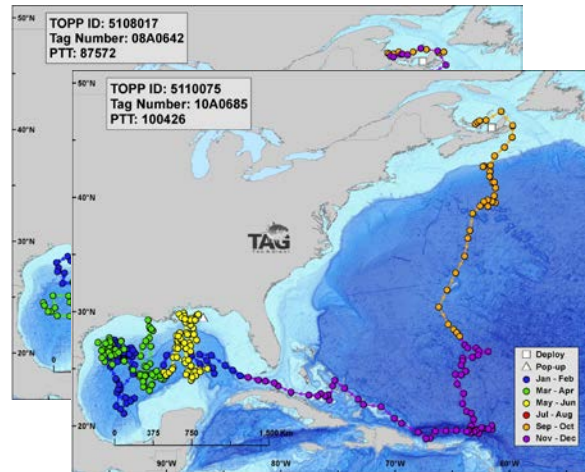


- Use regional ocean modeling (ROMS) data to develop a tool predicting blue whale habitat based on the current environmental conditions in the California Current.
- Models are built and being validated at **daily** and **10km** resolution to offer finer scale approaches towards reducing ship strike risk.

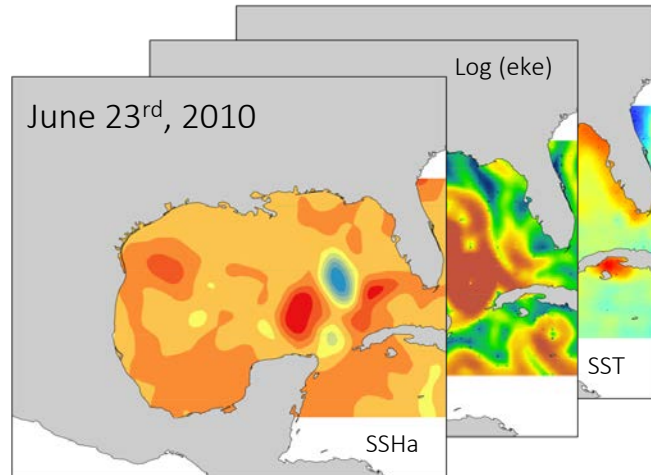


Approach: Species Distributional Modeling

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

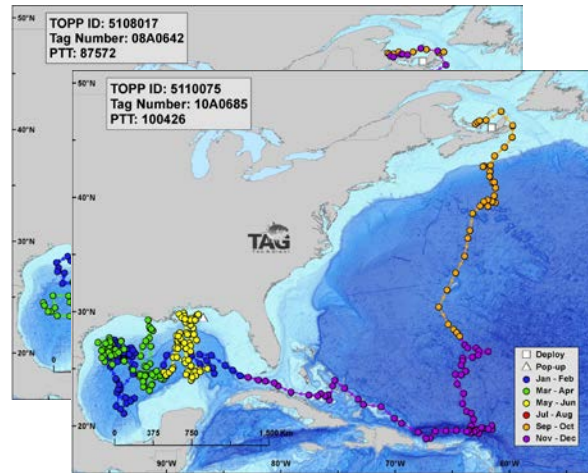


Sampled predictive data

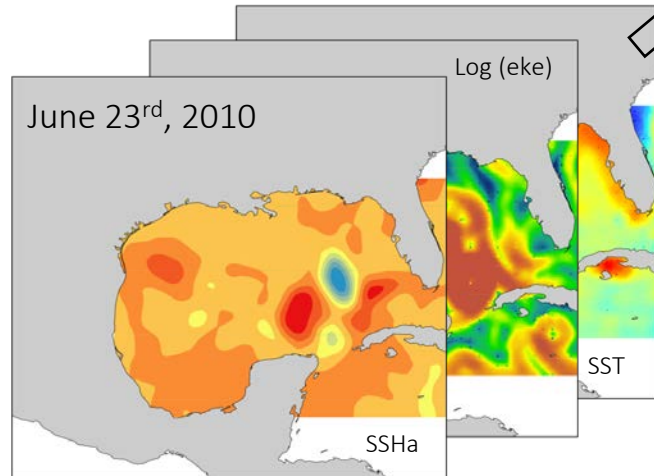


Approach: Species Distributional Modeling

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



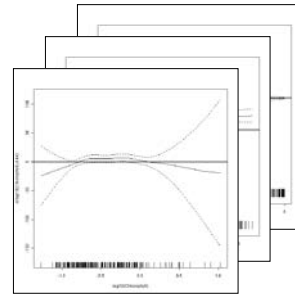
Sampled predictive data



Fit

Statistical models

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

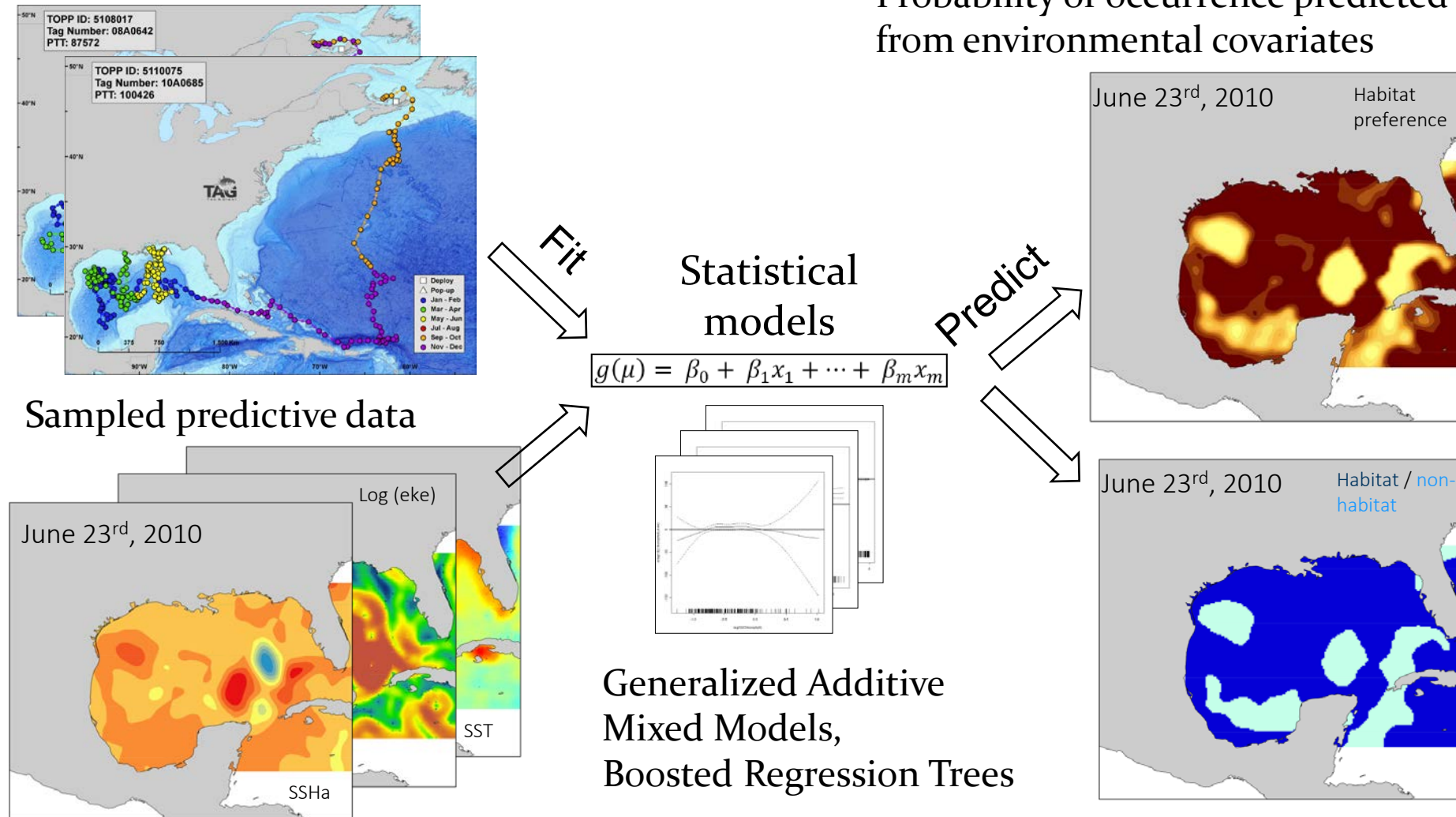


Generalized Additive
Mixed Models,
Boosted Regression Trees

Approach: Species Distributional Modeling

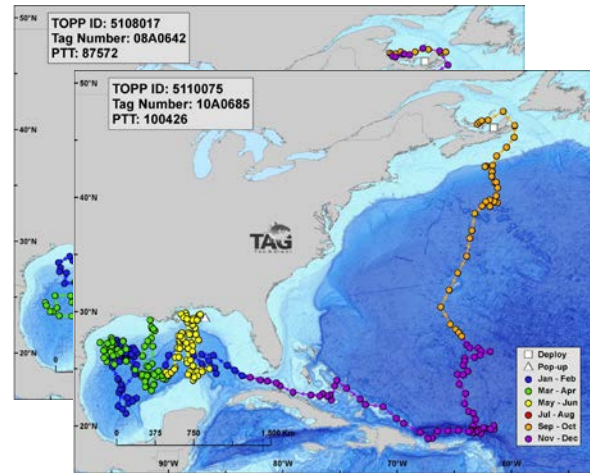
Distribution / behavioral data
e.g. sightings data, tag data, foraging events

Probability of occurrence predicted
from environmental covariates

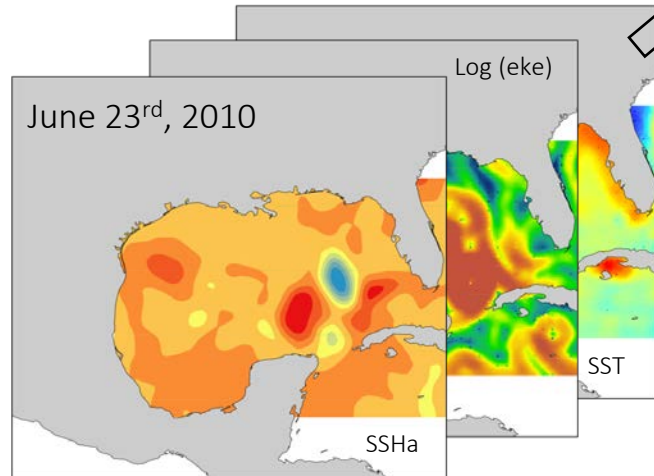


Approach: Species Distributional Modeling

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



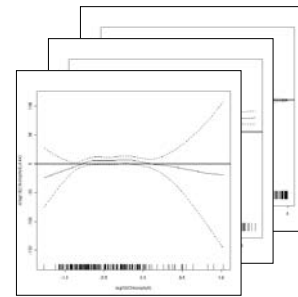
Sampled predictive data



Fit

Statistical models

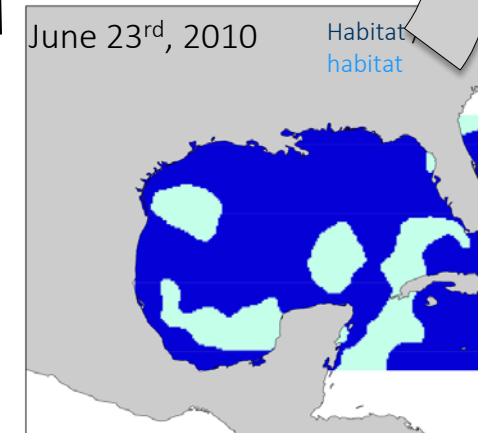
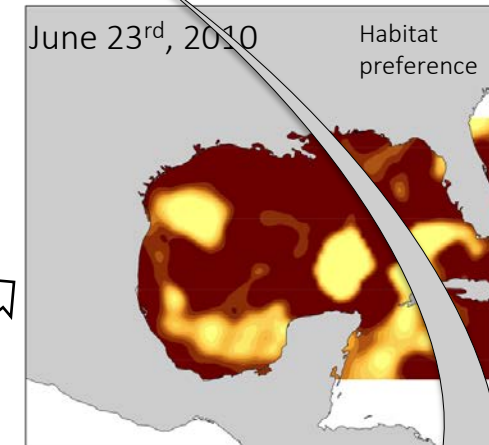
$$g(\mu) = \beta_0 + \beta_1 x_1 + \dots + \beta_m x_m$$



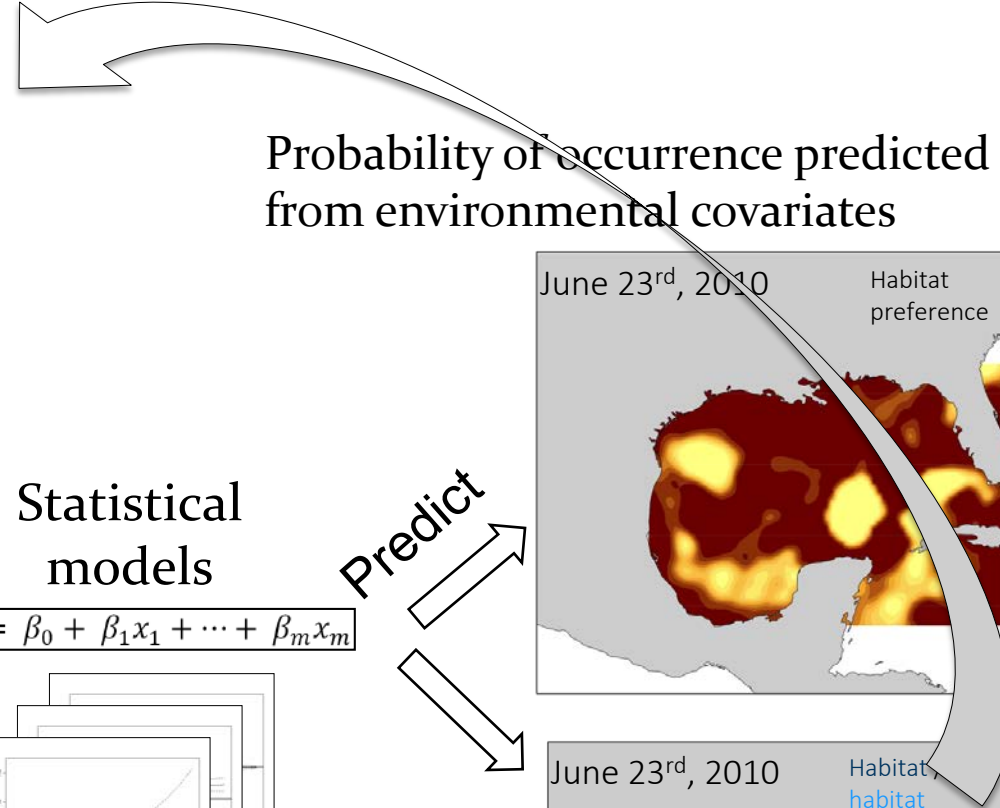
Generalized Additive
Mixed Models,
Boosted Regression Trees

Probability of occurrence predicted
from environmental covariates

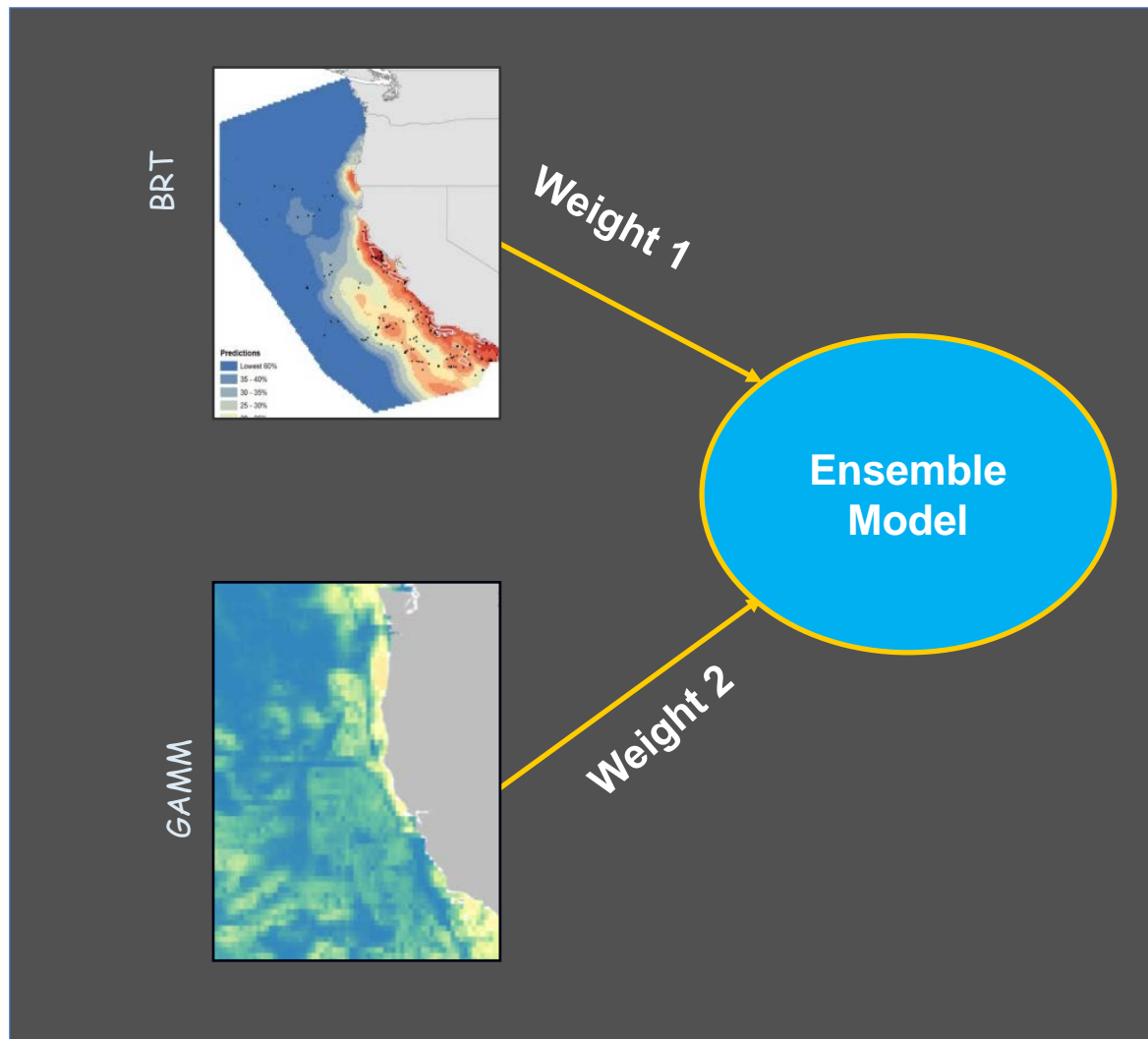
Predict



Validate



Approach: Ensemble Modeling



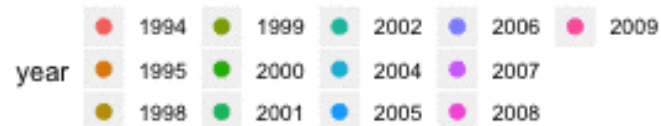
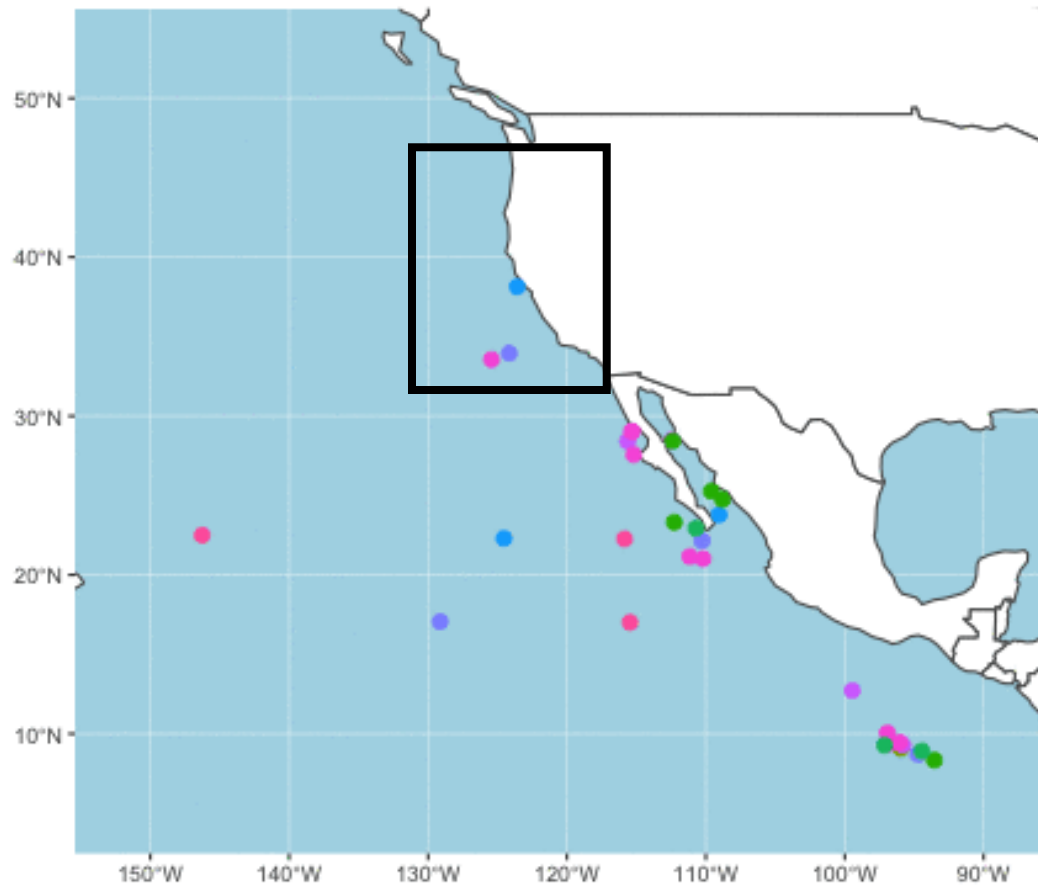
Predictions from a set ('ensemble') of models often yield more robust predictions and allow evaluation of uncertainties.

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

Tracking of blue whales over the year

Date: Jan 1

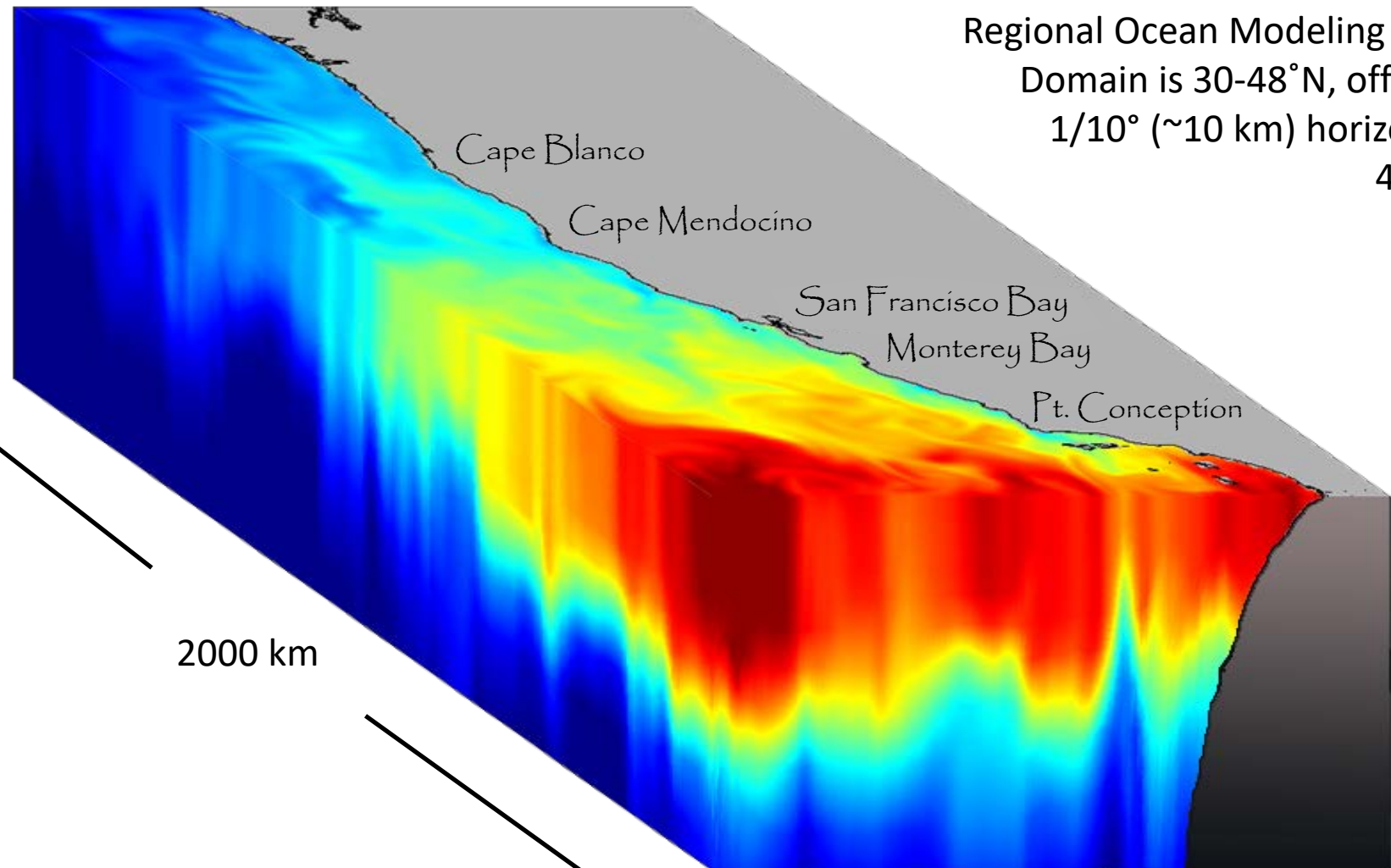


- 104 blue whales tagged 1994-2009
- Daily GPS locations estimated from State-Space Model



Regional Ocean Modeling System (ROMS)

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



Regional Ocean Modeling System (ROMS)

Domain is 30-48°N, offshore to 134°W

1/10° (~10 km) horizontal resolution

42 vertical levels

2000 km

1800 km

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

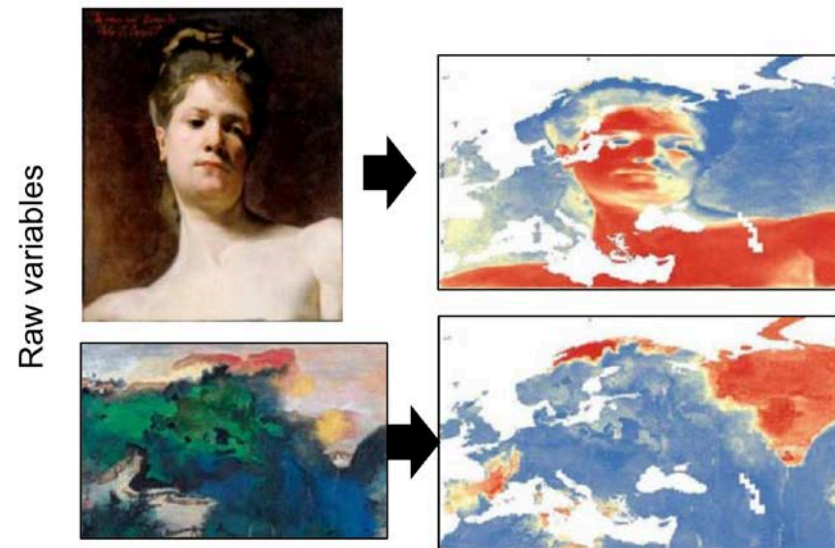
WILEY

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} 

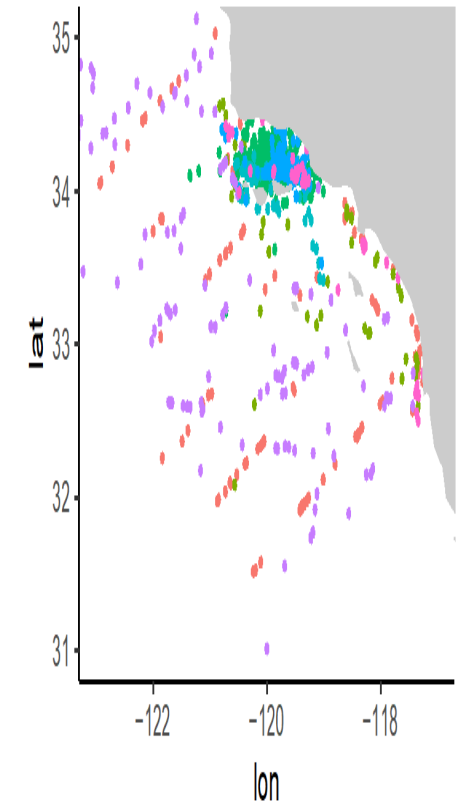
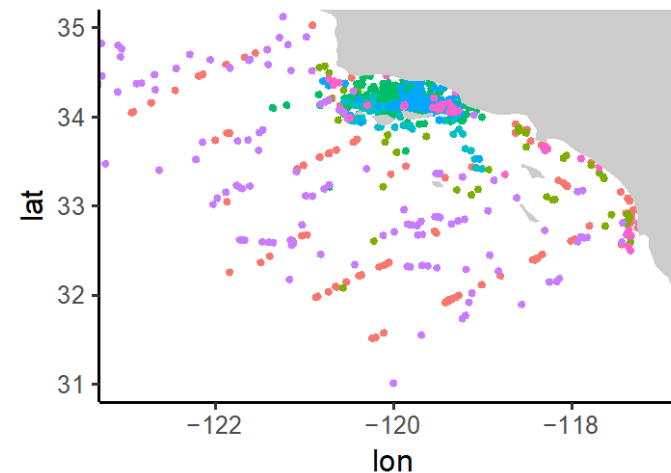
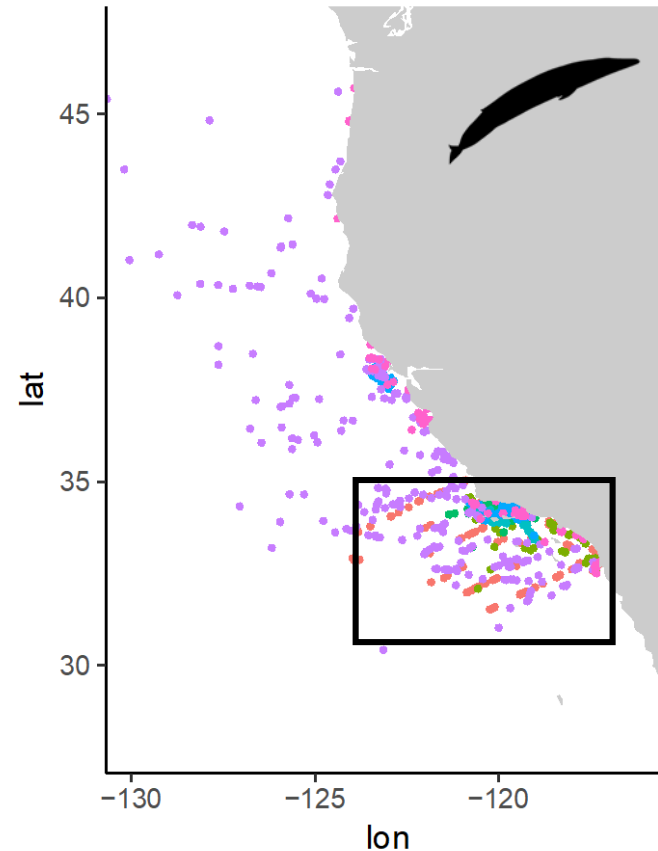


→ *Importance of using independent data for validation and multiple evaluation metrics!*

Model Evaluation

6 Training & Testing Datasets:

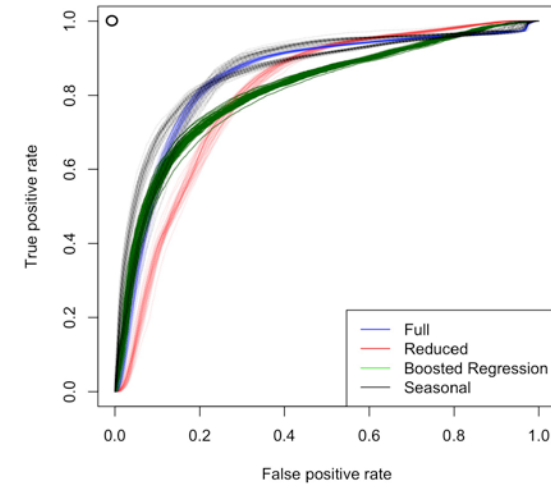
- 100% training vs. 100% testing
- 75% random training vs. 25% random testing
- 100% training vs. testing in the SCB
- K-folds training & testing
- Leave One Year Out training vs. Single Year testing
- **N=3,413 independent sightings**



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

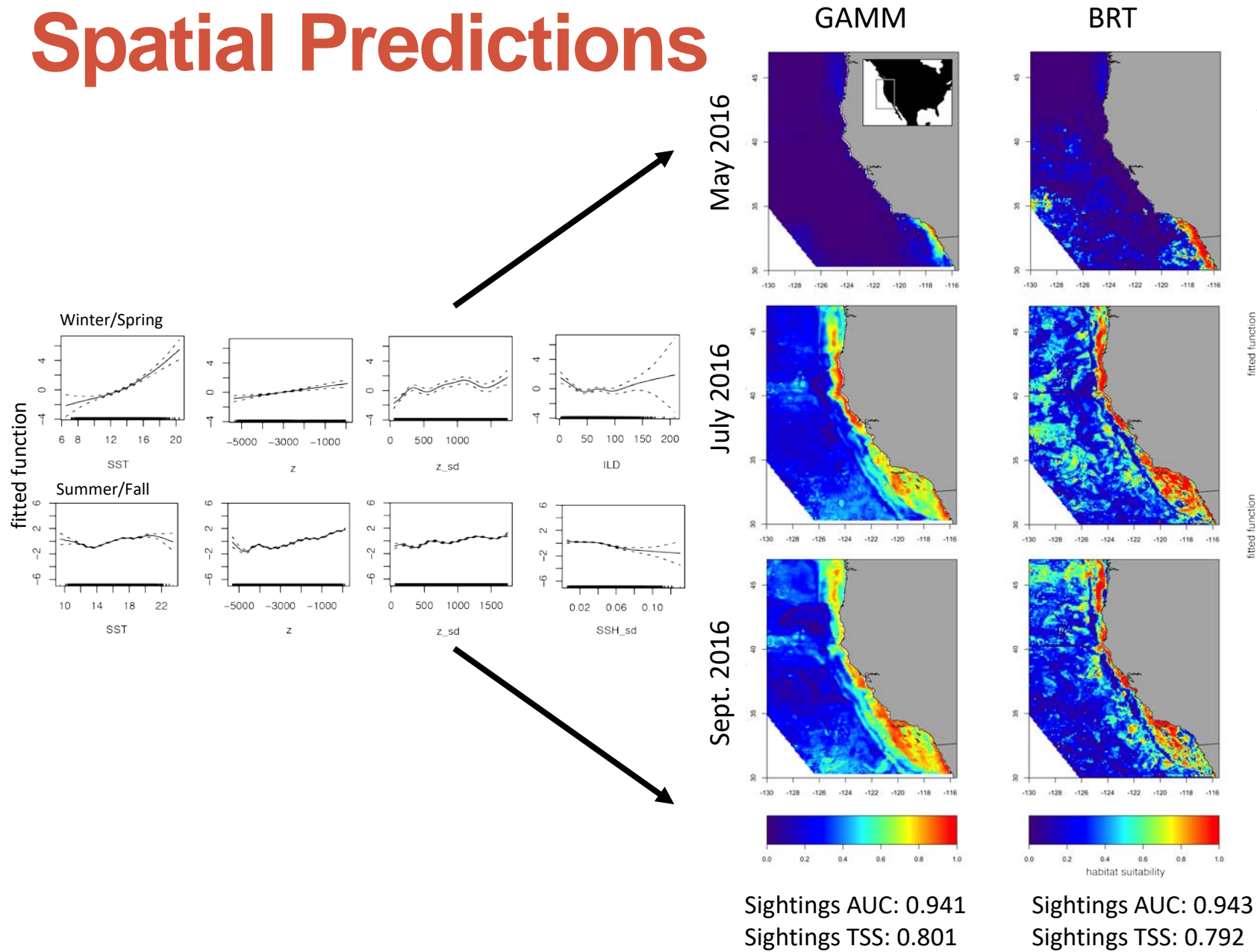
Scores range 0-1

Score ≥ 0.5 = better than random, ≥ 0.75 considered good.

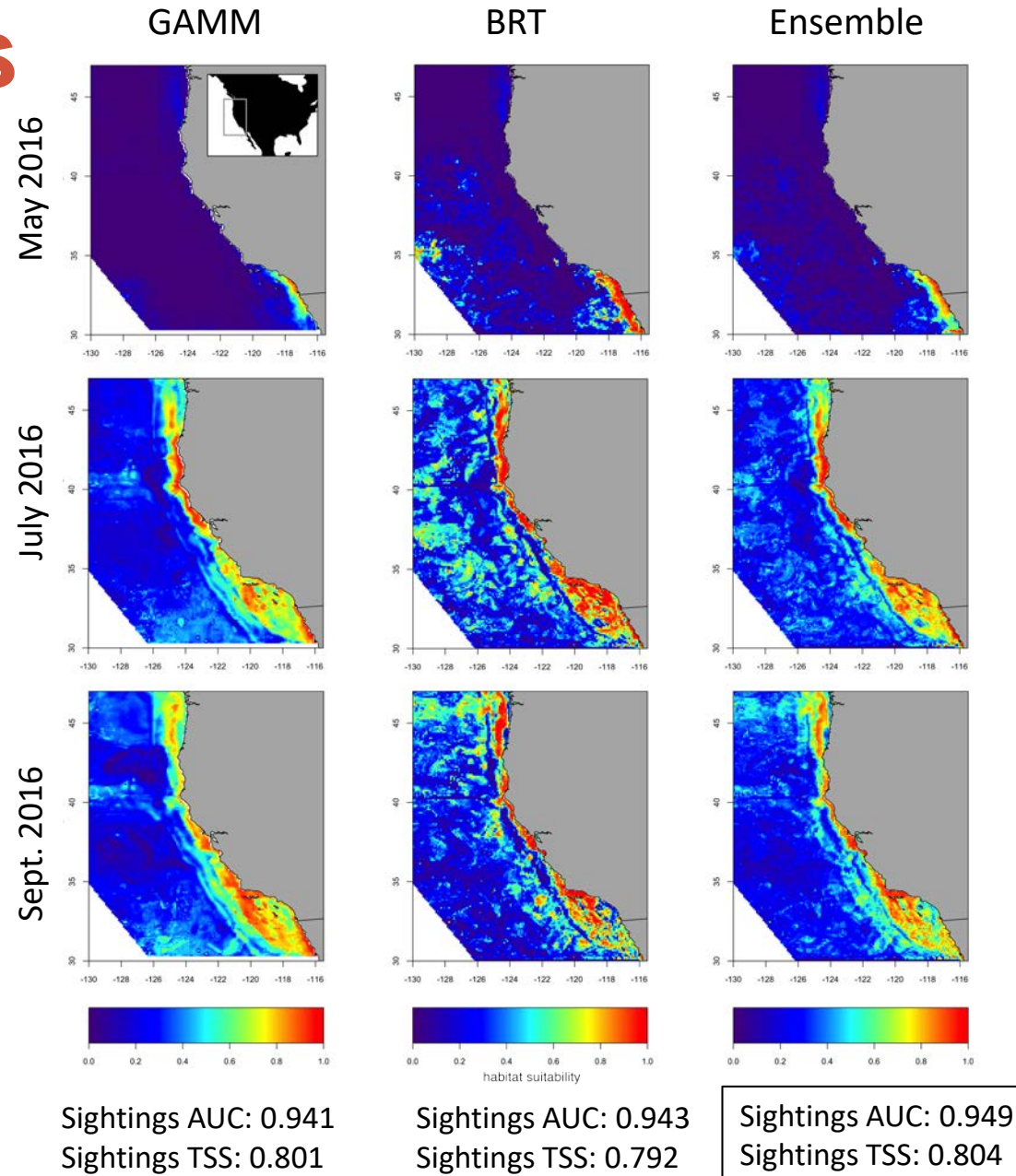
Candidate Models

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

Spatial Predictions



Spatial Predictions

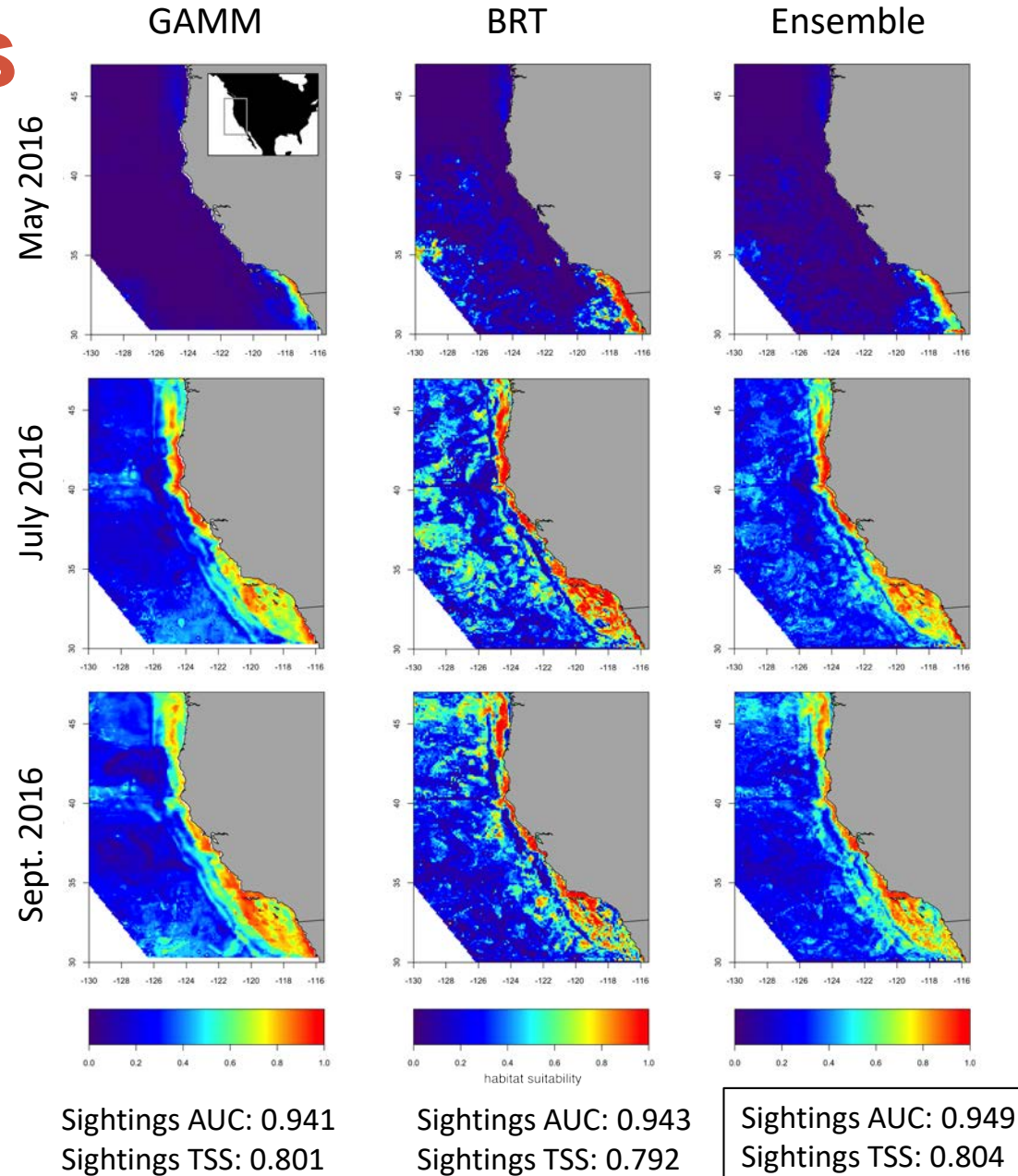


Spatial Predictions

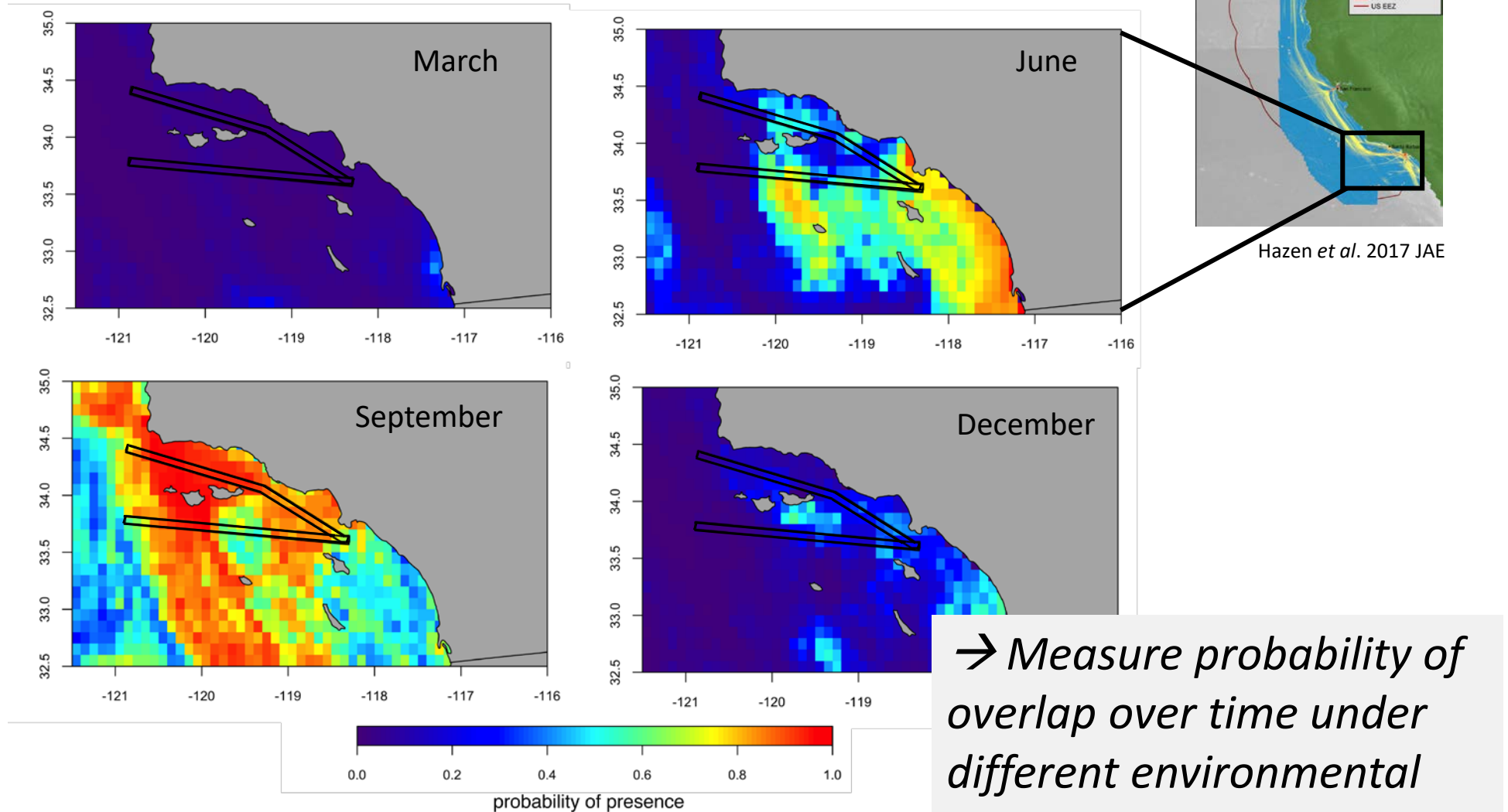
*AUC/TSS scores ≥ 0.5
= better than random,
 ≥ 0.75 considered good.*

100% training / 100% testing
AUC = 0.951

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

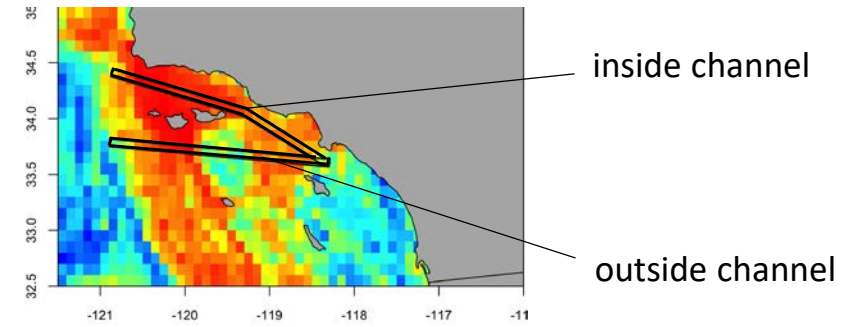
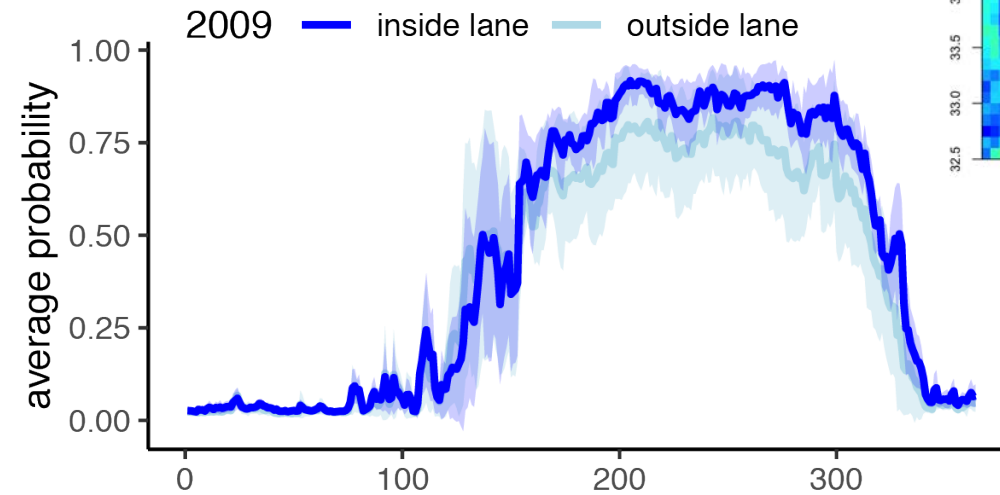


Risk Exposure in Shipping Lanes



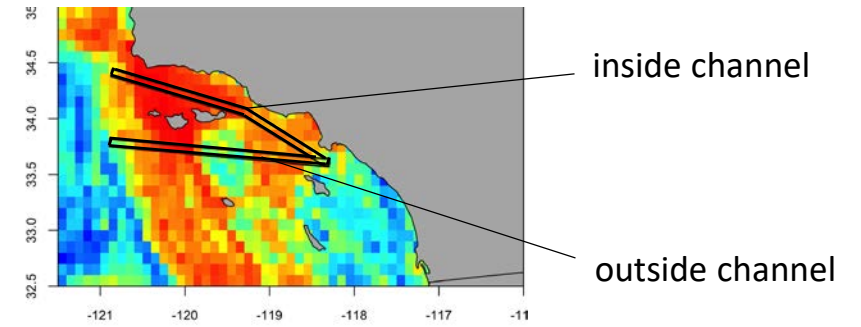
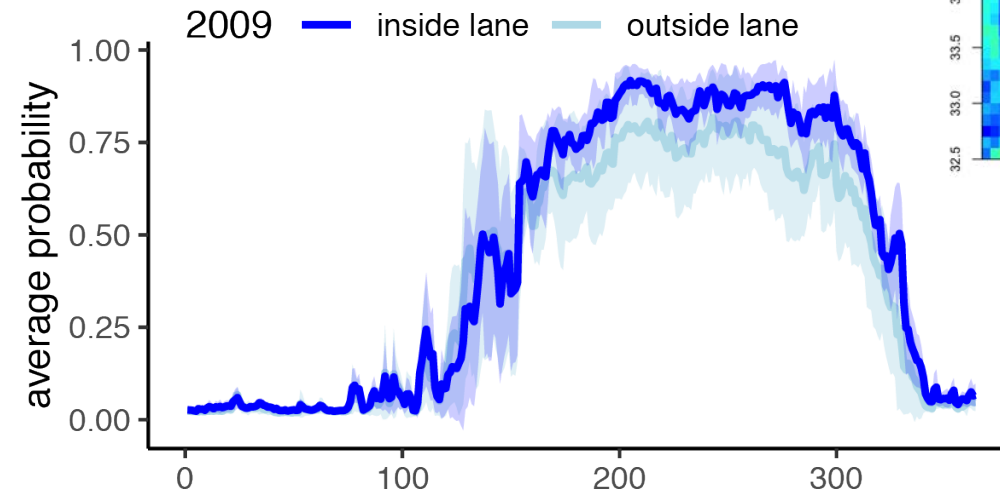
Risk Exposure in Shipping Lanes

2009
"normal"
conditions

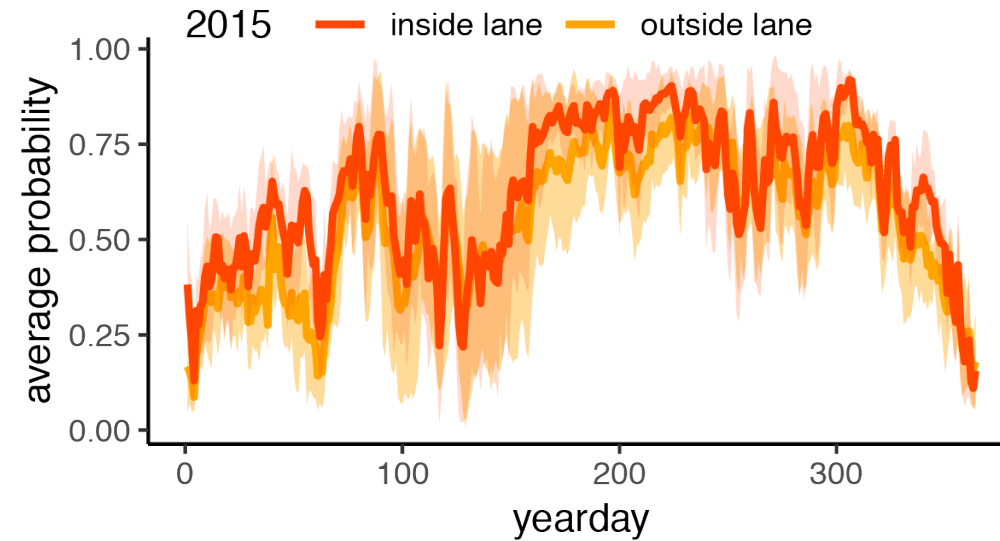


Risk Exposure in Shipping Lanes

2009
"normal"
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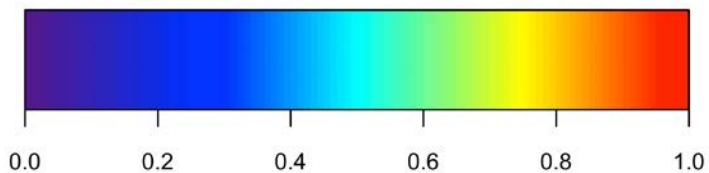
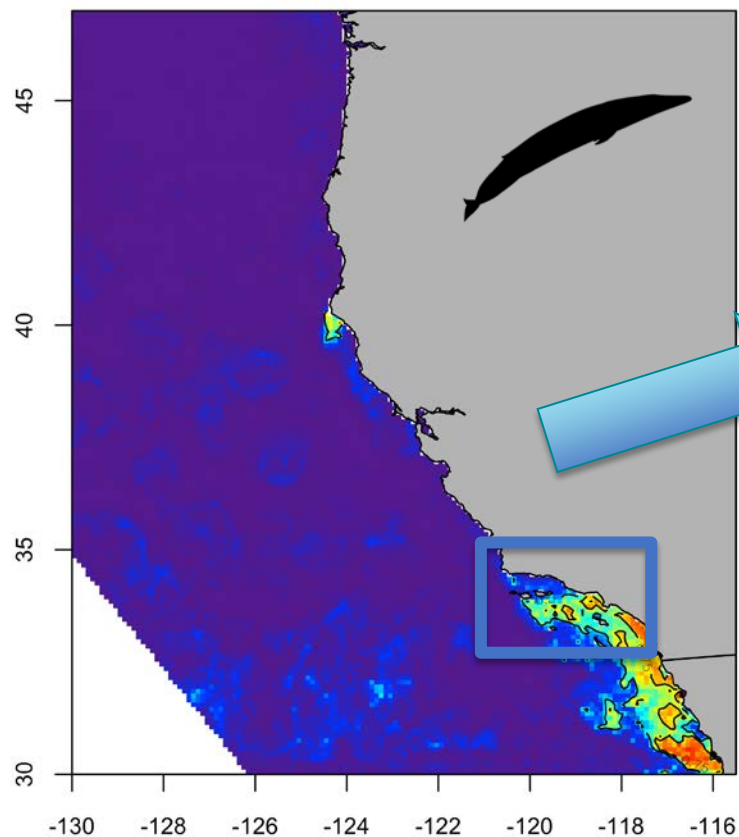


2015 warm
water
anomaly





Decision Support Tool



Probability of blue whale presence 2009-05-15 (mean)

Habitat suitability predictions for blue whales

Select time of year

Julian days

1 78 365

Change extent

Zoom to full extent

Zoom to West Coast

Zoom to Bight

Add map elements

Download selected rasters

Display date is March 20

2009 2015 2016

Suitability

0.0 0.2 0.4 0.6 0.8 1.0

Leaflet | © OpenStreetMap © CartoDB

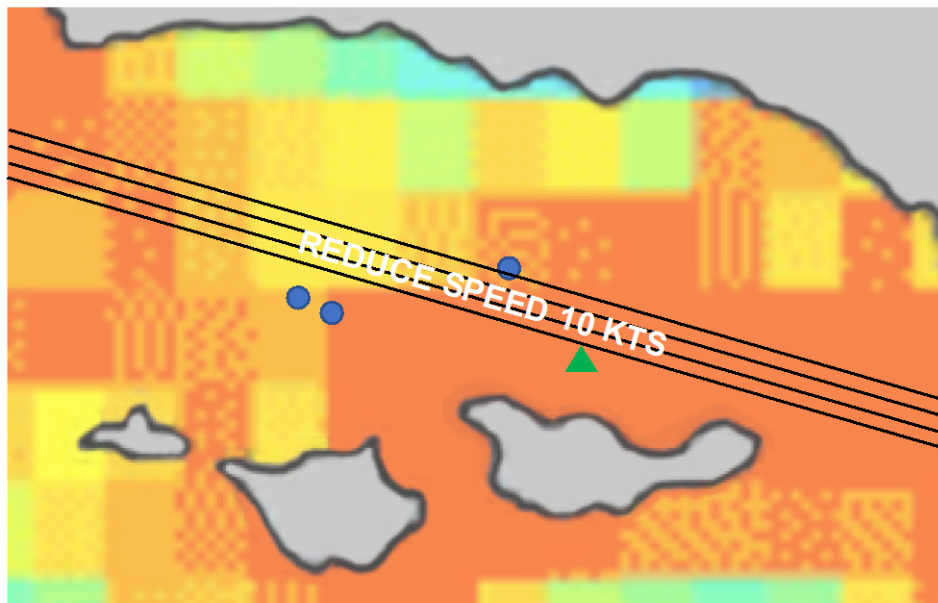
https://heatherwelch.shinyapps.io/benioff_app/



Decision Support Tool

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

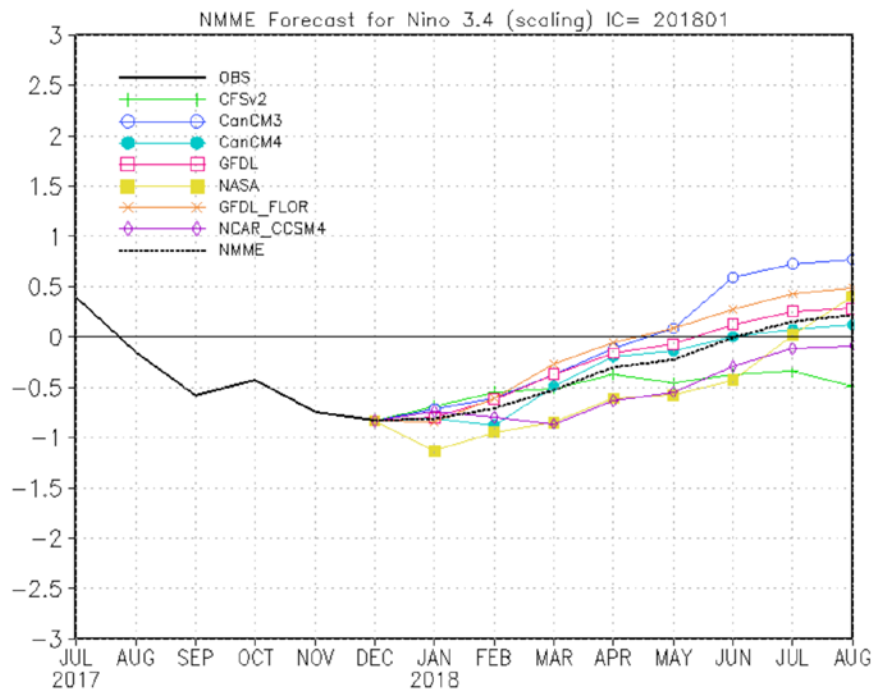
- Opportunistic sightings
 - Blue whale
 - Humpback whale
 - Fin whale
 - Gray whale
 - Other whale
- Blue whale likelihood of occurrence
 - 0 1
- Acoustic detections
 - Online buoy
 - Offline buoy
 - Whale detected
 - Listening radius
- Thermal detections
- NOAA VSR zone (10 knots)
- NOAA whale advisory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





Future opportunities

January Forecasts of ENSO Conditions



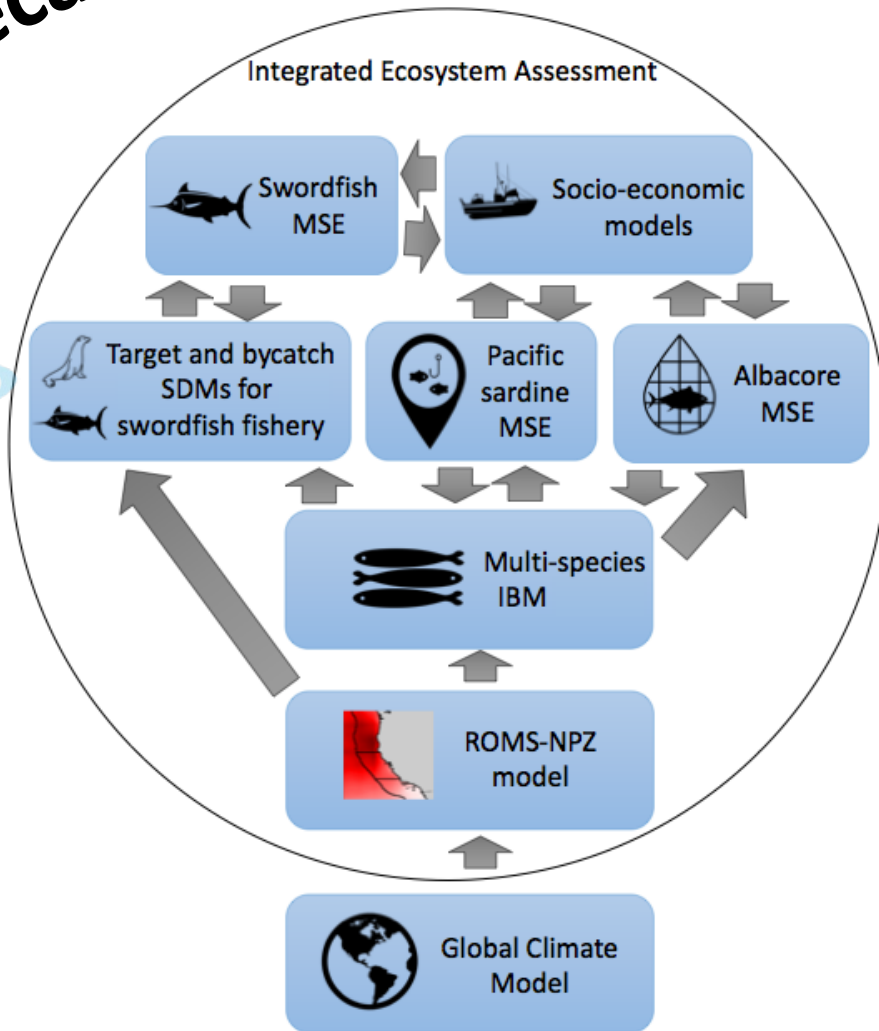
NOAA - MAPP

Seasonal



Decadal

NOAA - COCA





Conclusions

- Dynamic species distribution models can offer a better match with ecological processes **AND** human activities in space and time.



OSU



BBC



NOAA NMML



NOAA SWFSC



Southwest Fisheries Science Center, NOAA Fisheries Service



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.



OSU



BBC



NOAA NMML



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Southwest Fisheries Science Center, NOAA Fisheries Service



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.



OSU



BBC



NOAA NMML



NOAA SWFSC



Southwest Fisheries Science Center, NOAA Fisheries Service

Thank you!

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Elizabeth Becker, Steven J. Bograd, Ladd Irvine,
Daniel Palacios, Bruce Mate, Elliott L. Hazen

Thanks to: CINMS staff, Benioff Ocean Initiative



WWF

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