

Movements of striped bass in response to extreme weather events



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Background

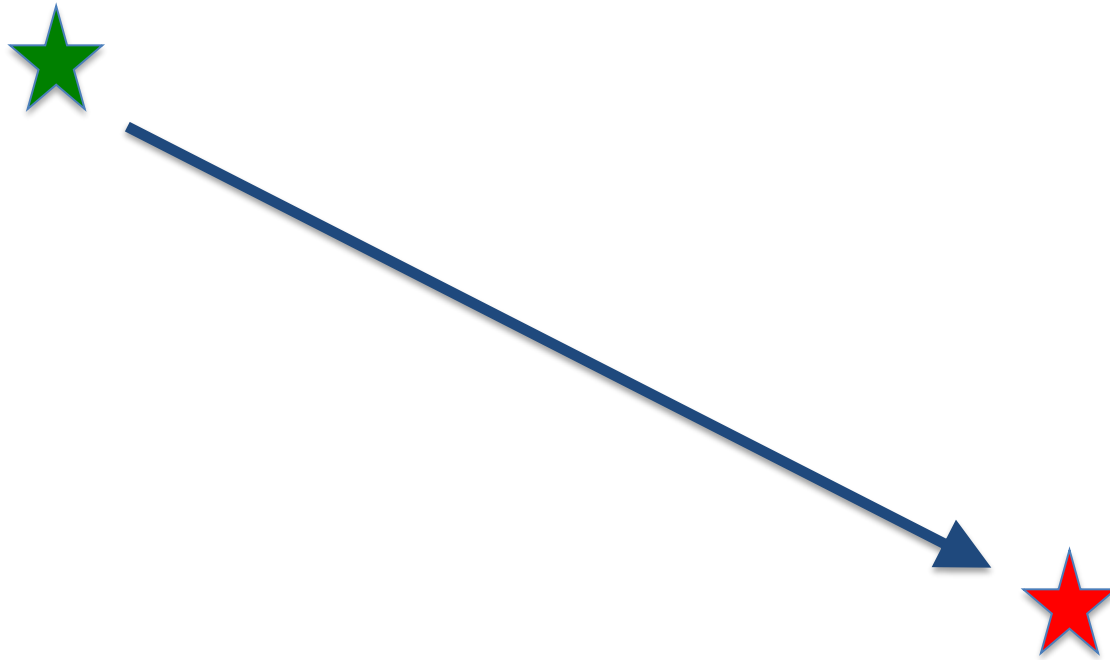


Outline

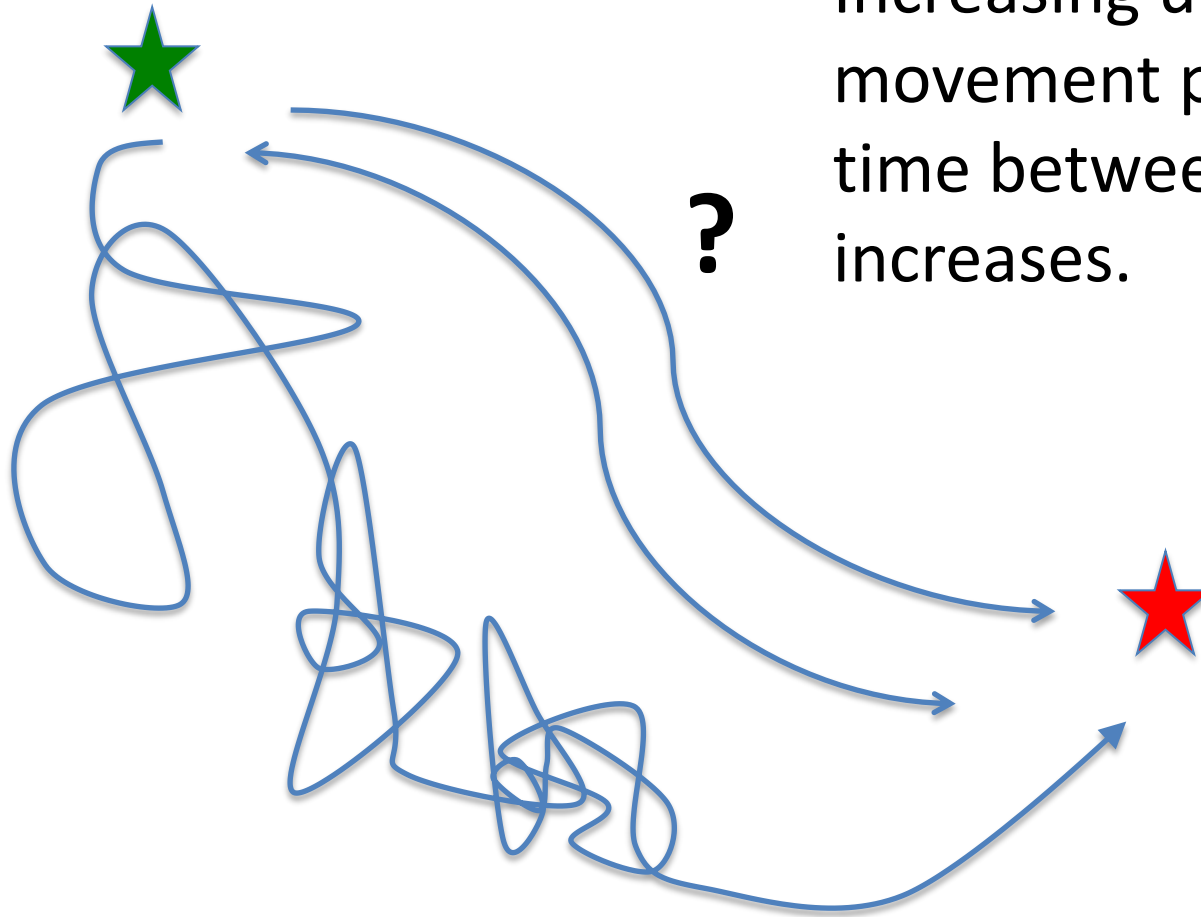
- What is movement ecology?
- Methods for analyzing animal tracks
- Application to acoustic telemetry
- Determining response of striped bass to extreme weather events



Animal Movements

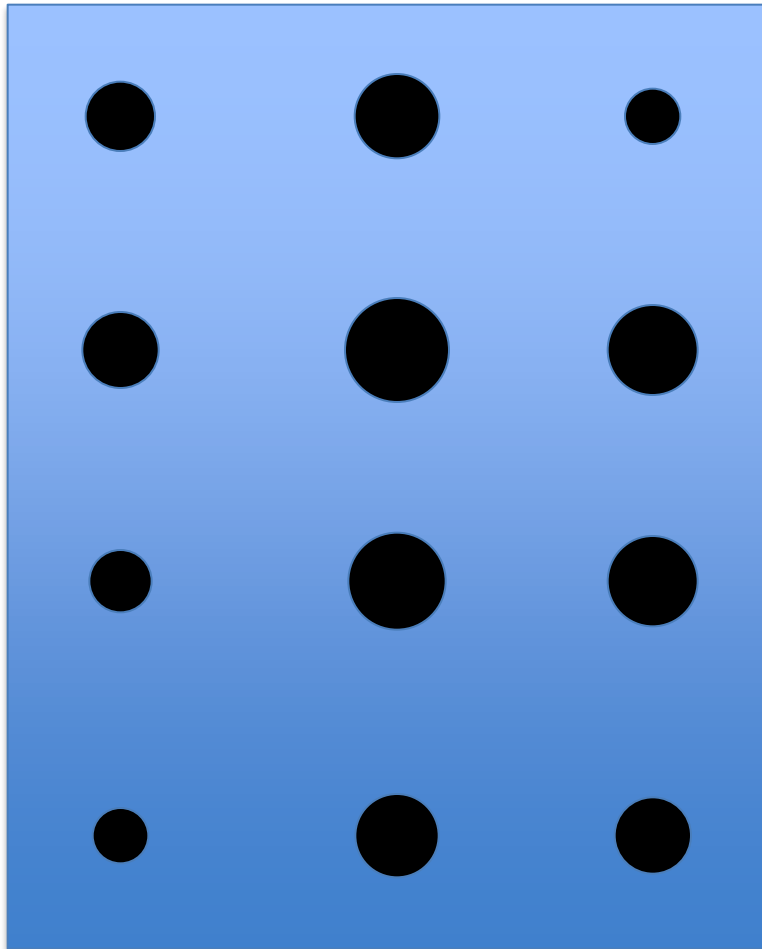


Animal Movements

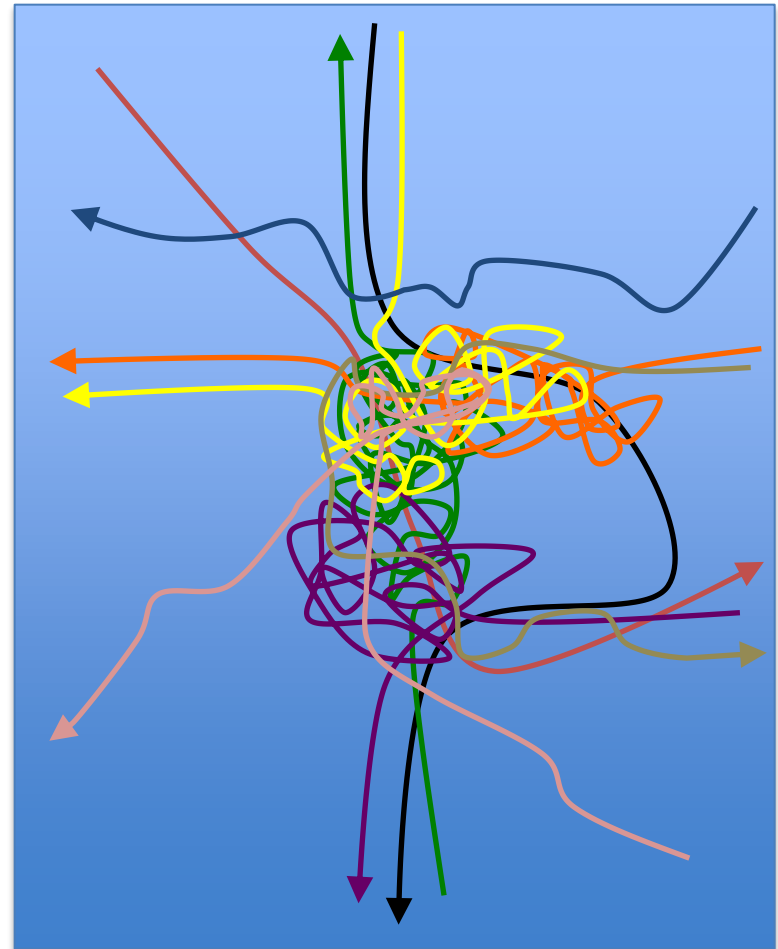


Increasing uncertainty in movement pathway as time between locations increases.

Survey limitations

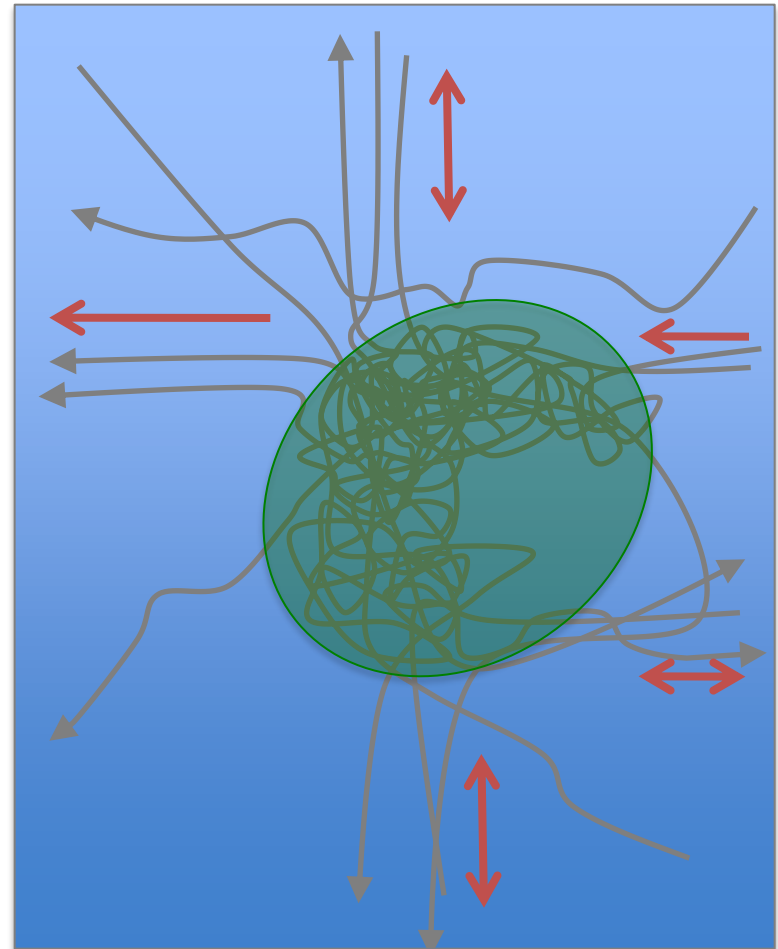
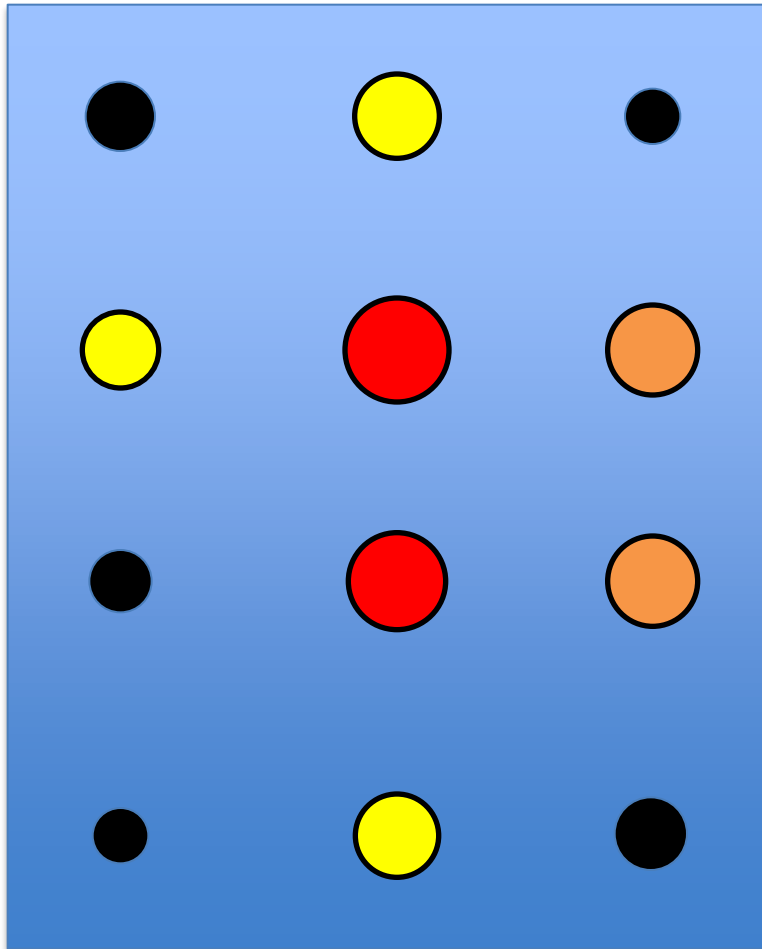


Survey abundance

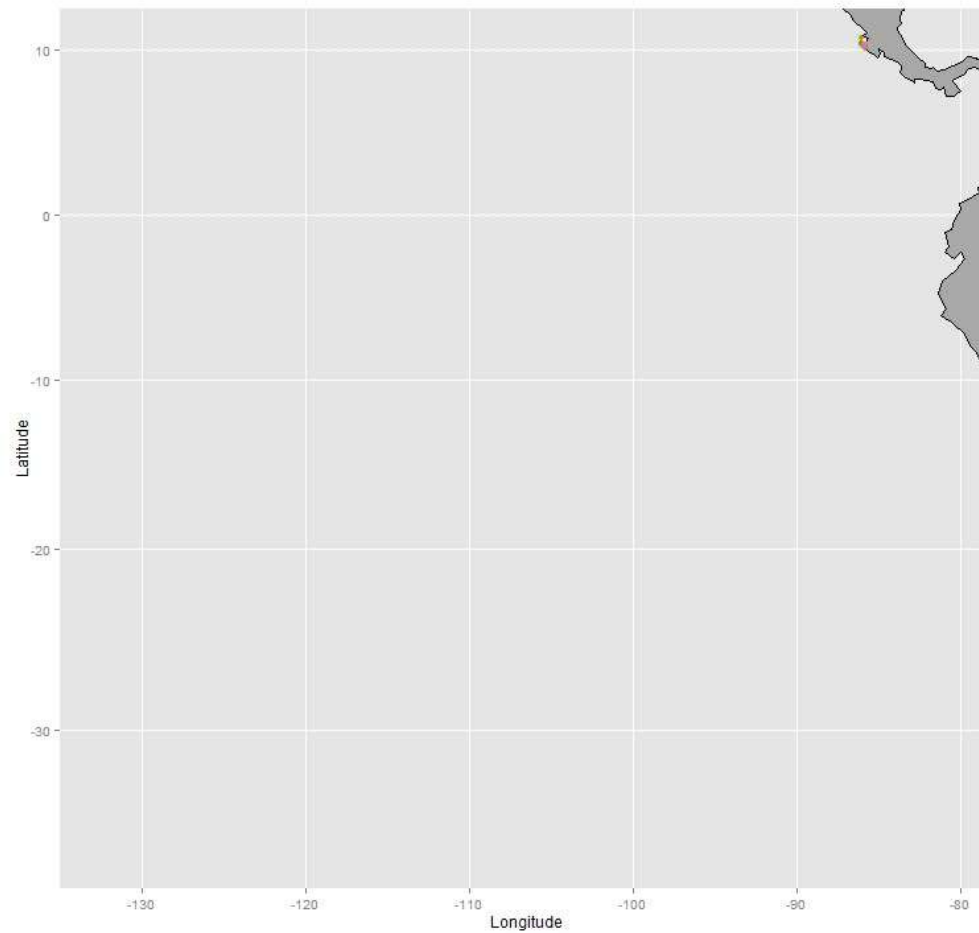


Movement pathways

Survey limitations

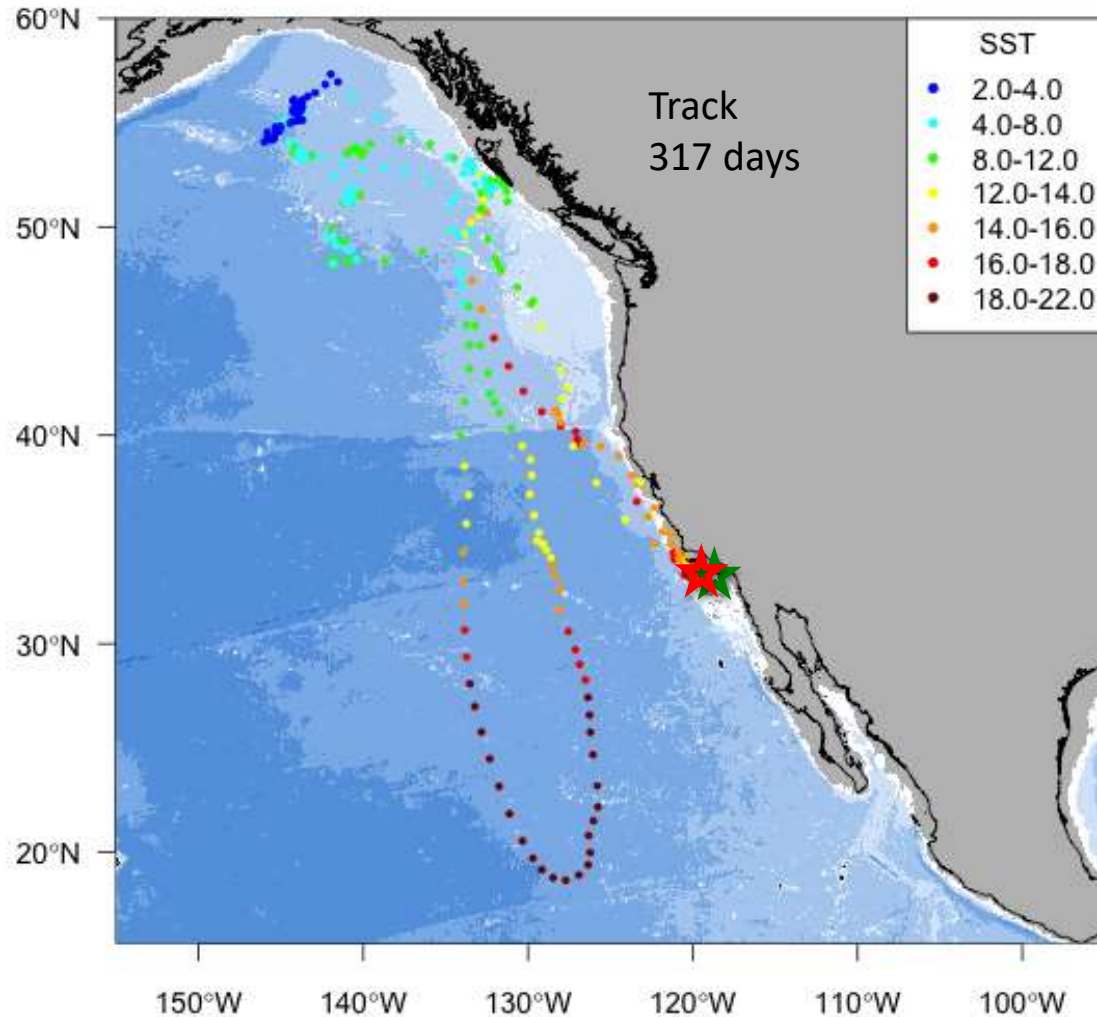


Migratory pathways



Track data: George Shillinger. Animation by Mike O'Brien

Fin whale: Breaking the paradigm

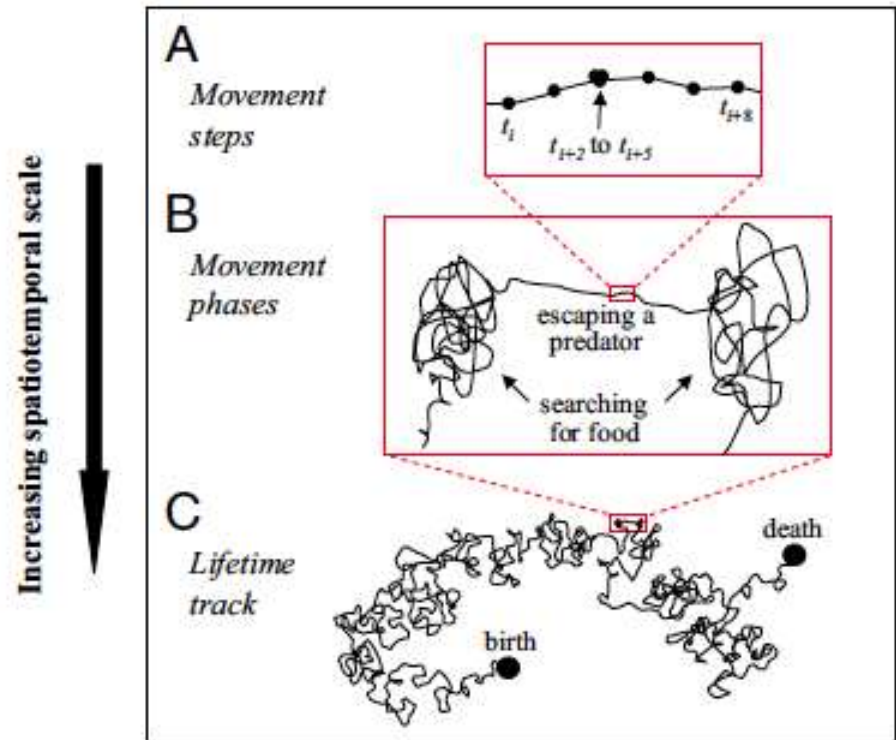


Track data: Bruce Mate, OSU.



Movement Ecology

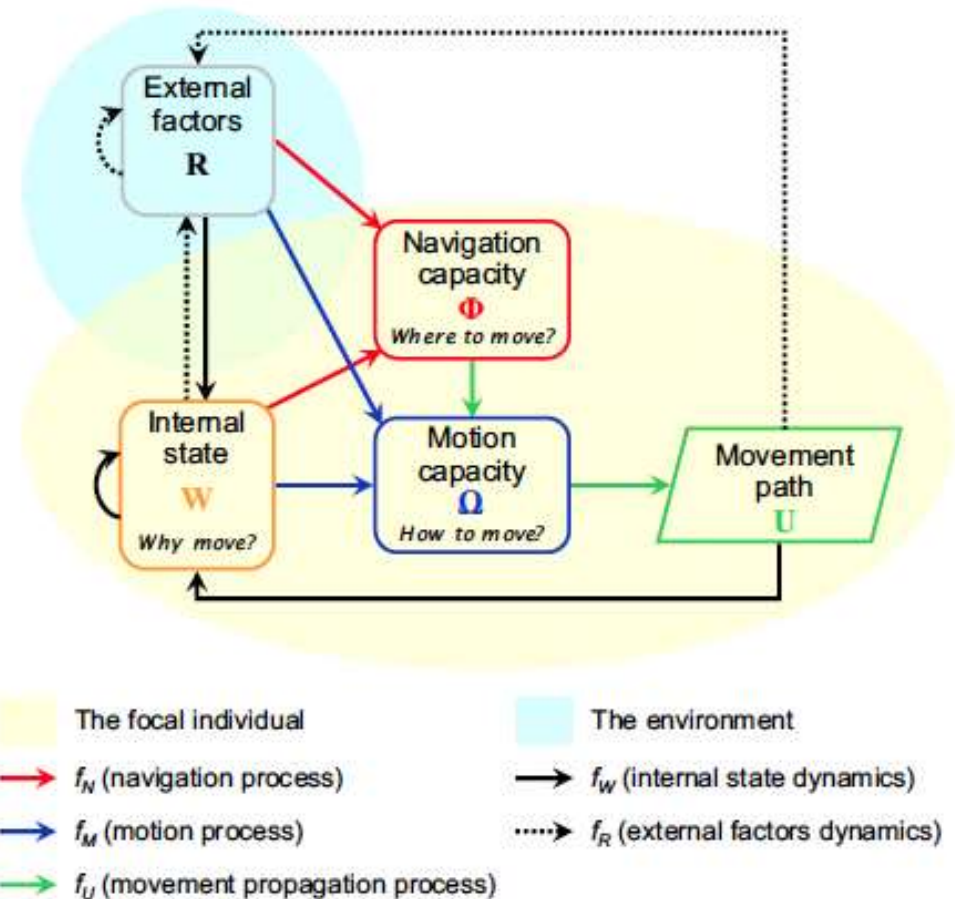
- Understanding the causes, mechanisms, patterns, and consequences of movement phenomena
- Linking movements to specific functional behaviours



From Nathan et al. 2008

Movement Ecology

- Focus on individual animals and bridge the gap with population dispersals
- Movement incorporates BOTH spatial and temporal dynamics
- Inferences can be made about behavior and functional habitat use
- Can assess fine-scale responses to events

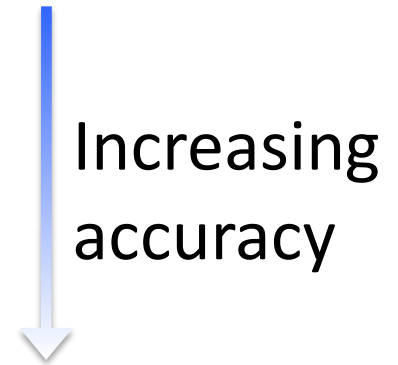


From Nathan et al. 2008

Tracking technologies

Global tracking

- Geolocation (~50-100 km error)
- Argos satellite (~1-10 km error)
- GPS (~20-100 m error)

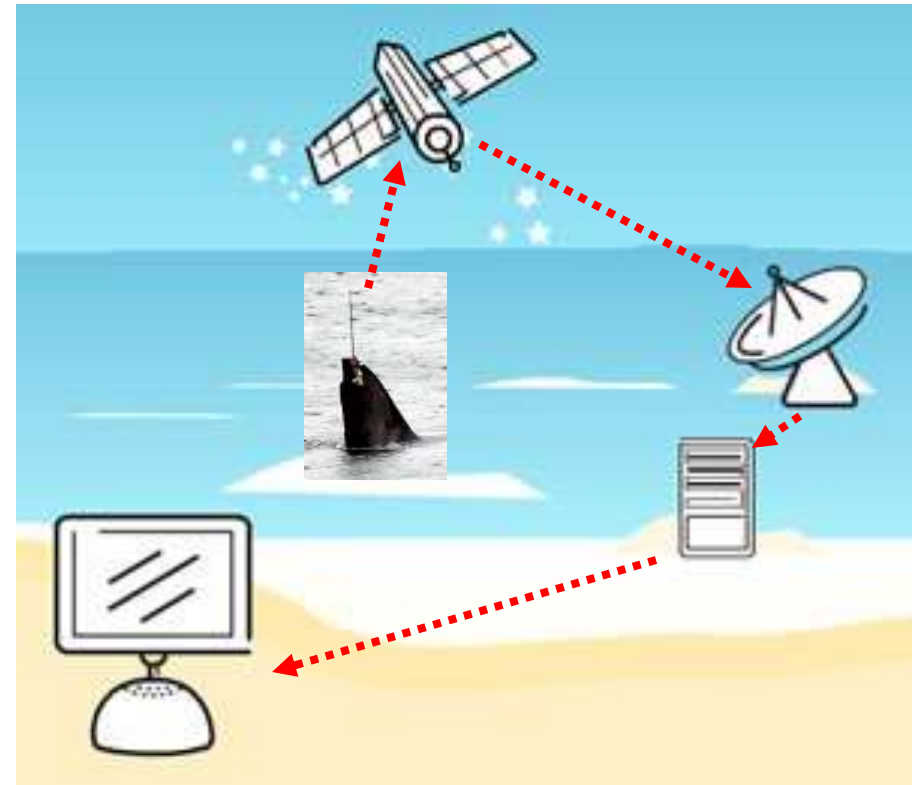


Mobile tracking or fixed receivers

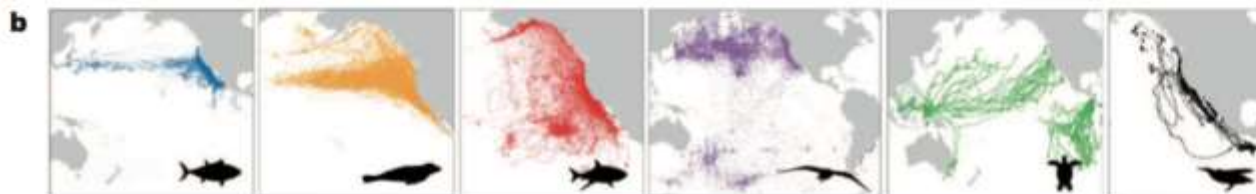
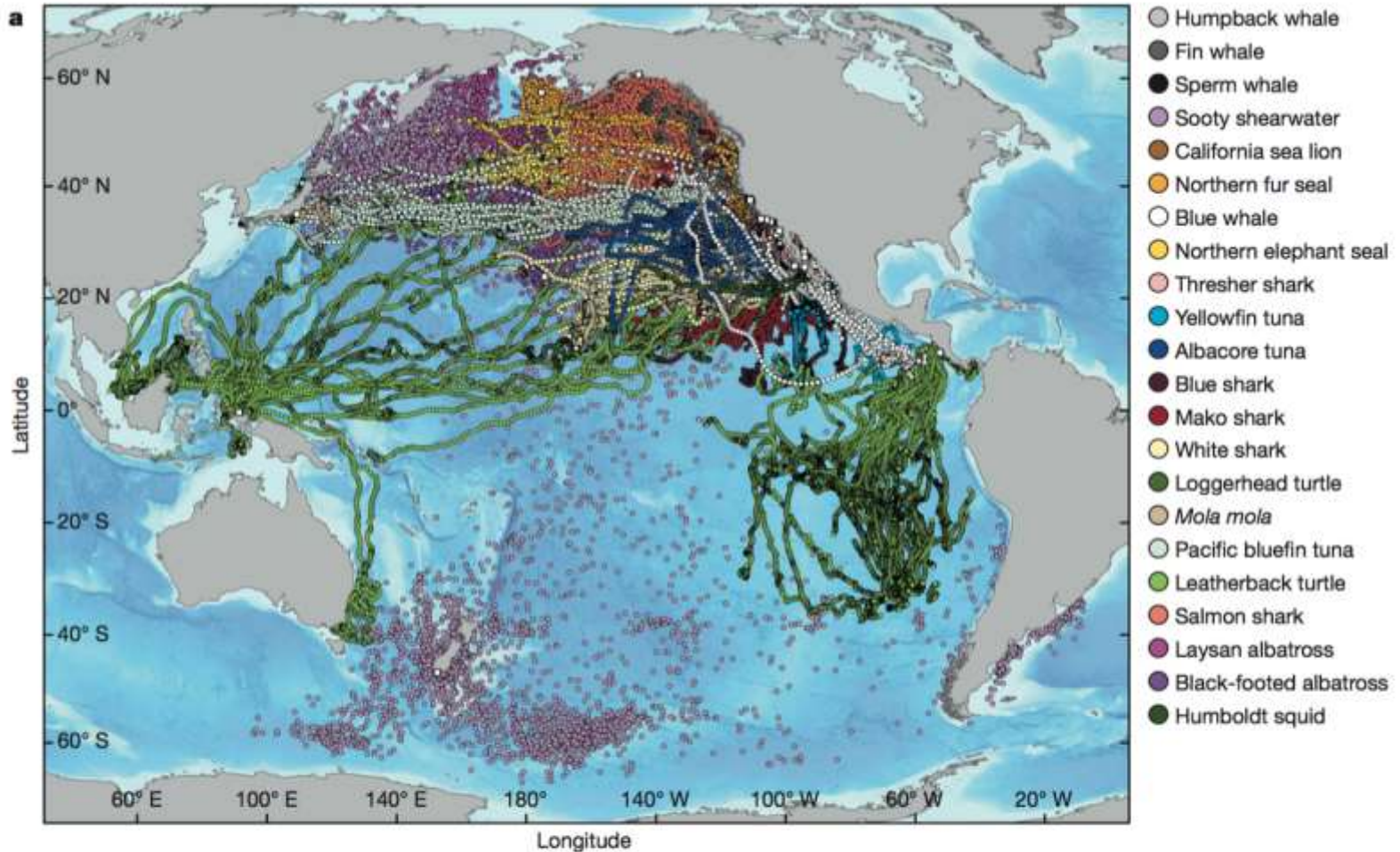
- Acoustic telemetry (receiver range ~1 km)

Satellite tracking

1. Tagged animal comes to the surface
2. Satellite-tag switches on and transmits radio signals to satellite
3. Satellite locates tag position and relays to Argos center on land.
4. Information is processed and then sent to tag owner.



Tagging of Pacific Predators



From Block et al.
2011

Blue Whales

- Largest animal on the planet at up to 30 m (100 ft) long.
- Baleen whale that specializes on feeding on krill



Threats to whales

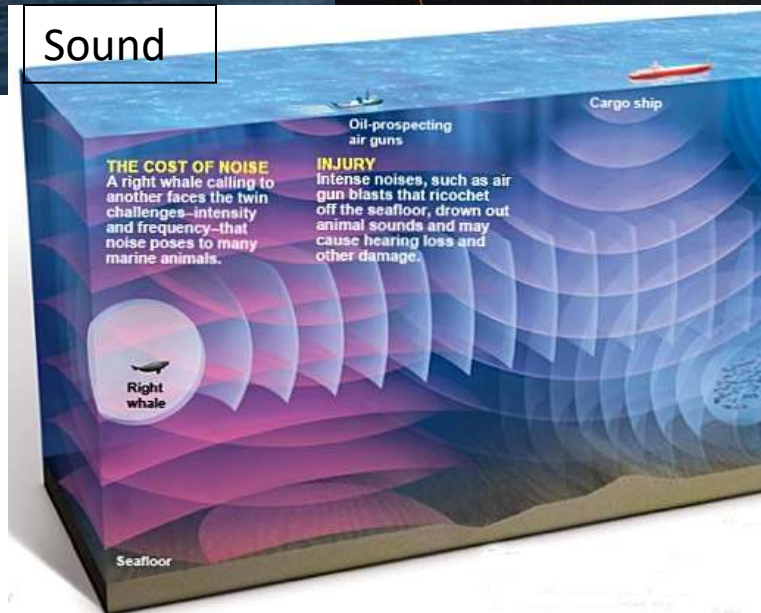
Entanglements



Ship strikes



Sound

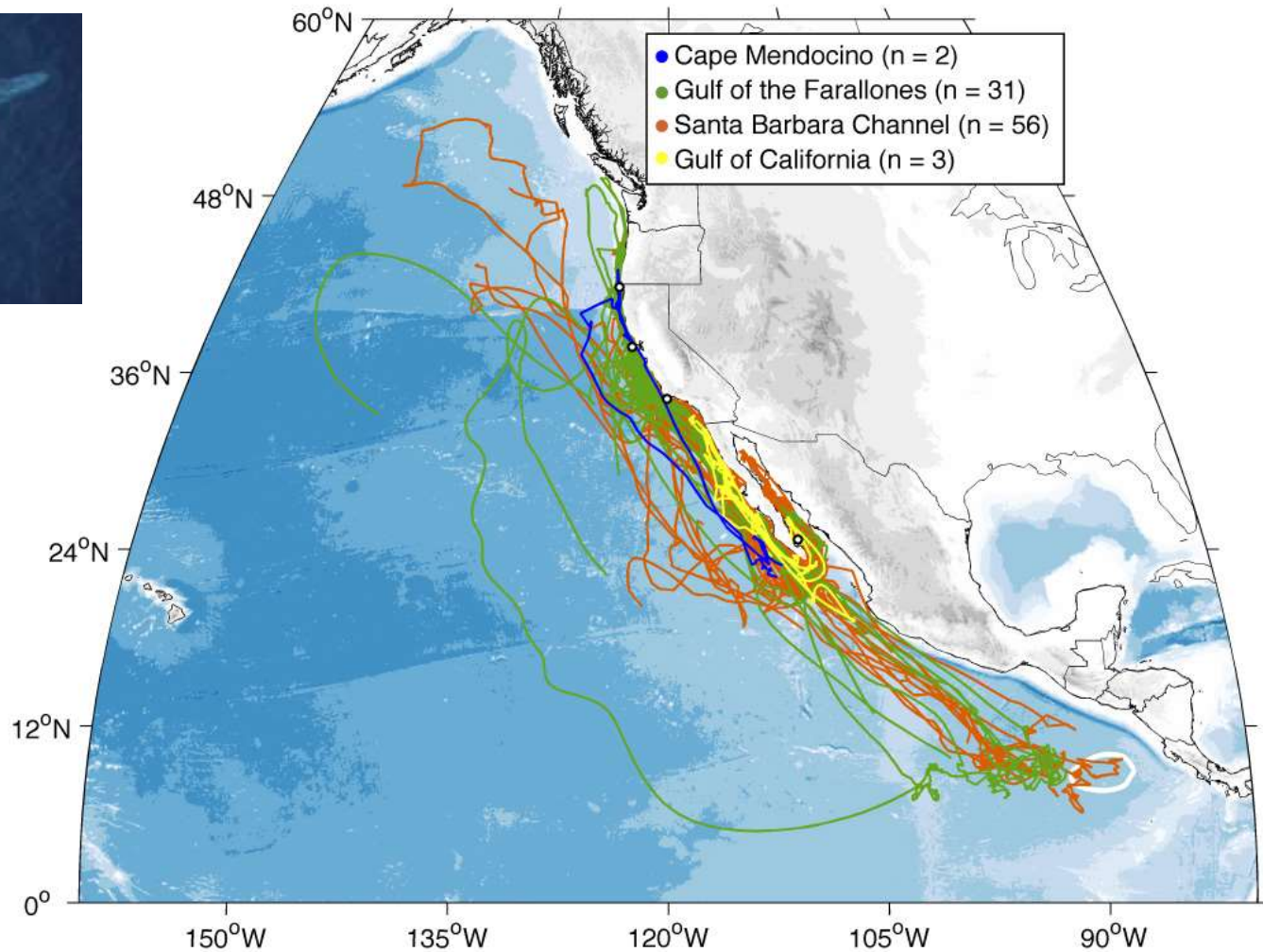


Blue whale tracks

- 171 tags deployed during 1993-2008 by Bruce Mate and his team at OSU
- Most of the whales tagged off California in July-October
- Tracking duration ranged from <1 day to 504 days

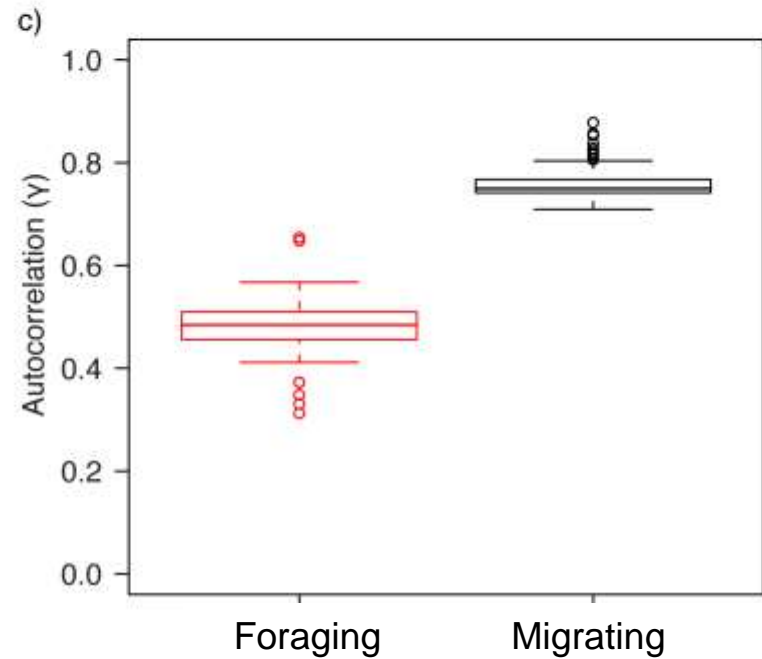
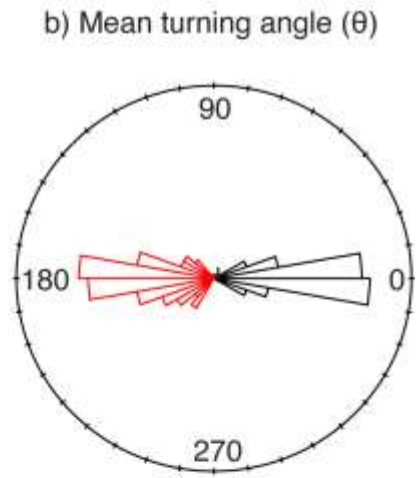
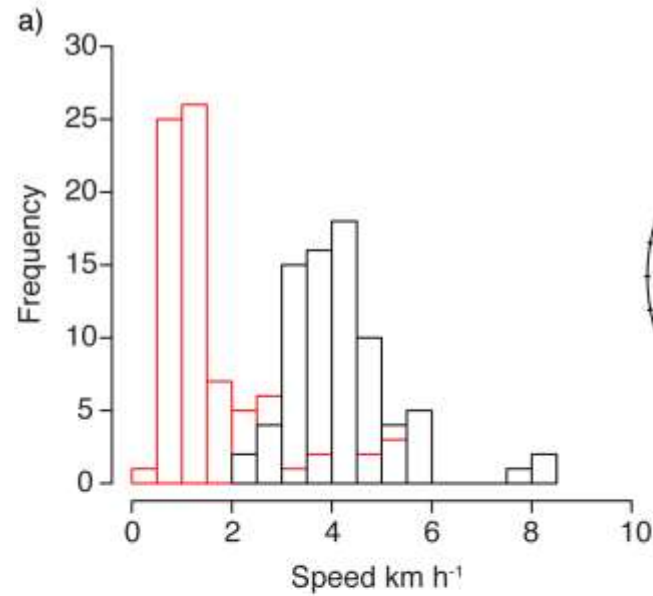
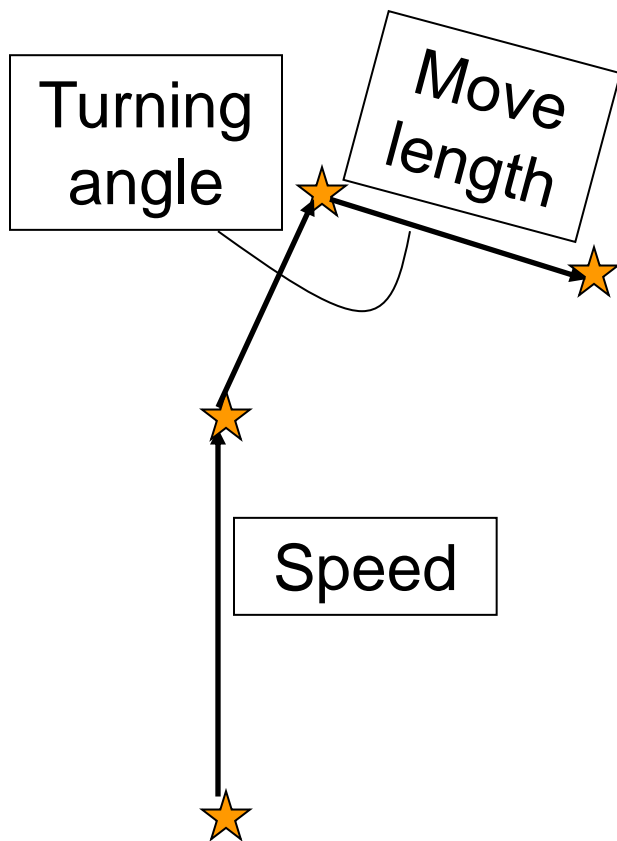


Northeast Pacific Blue Whales



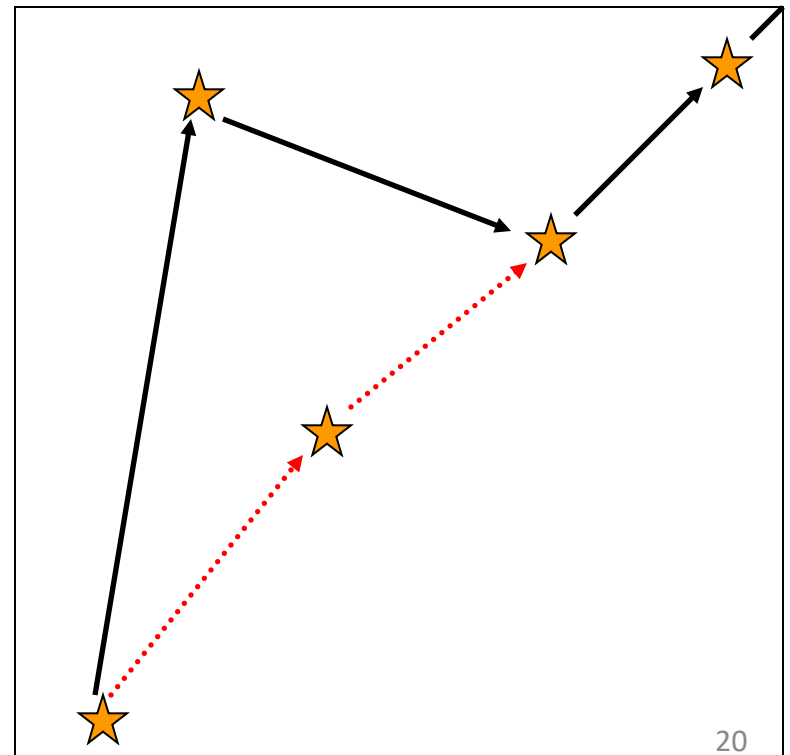
Analysis Process

1. Reduce
2. Reconstitute
3. Predict



State-space modeling

- “A time series model that predicts the future state of a system from its previous states probabilistically” (Patterson et al. 2008 TREE)



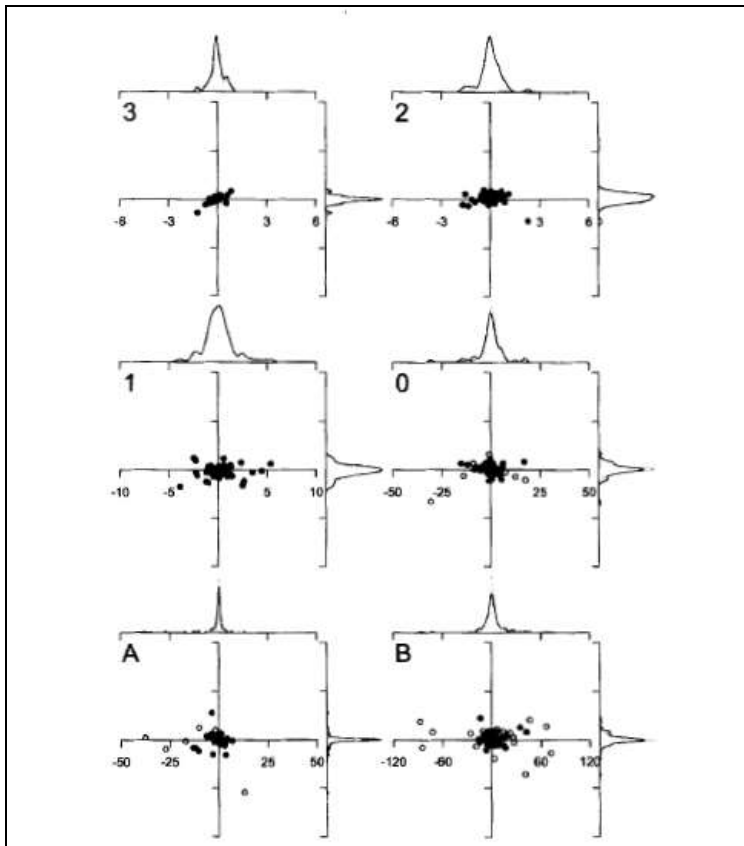
State-space movement model

- Measurement equation

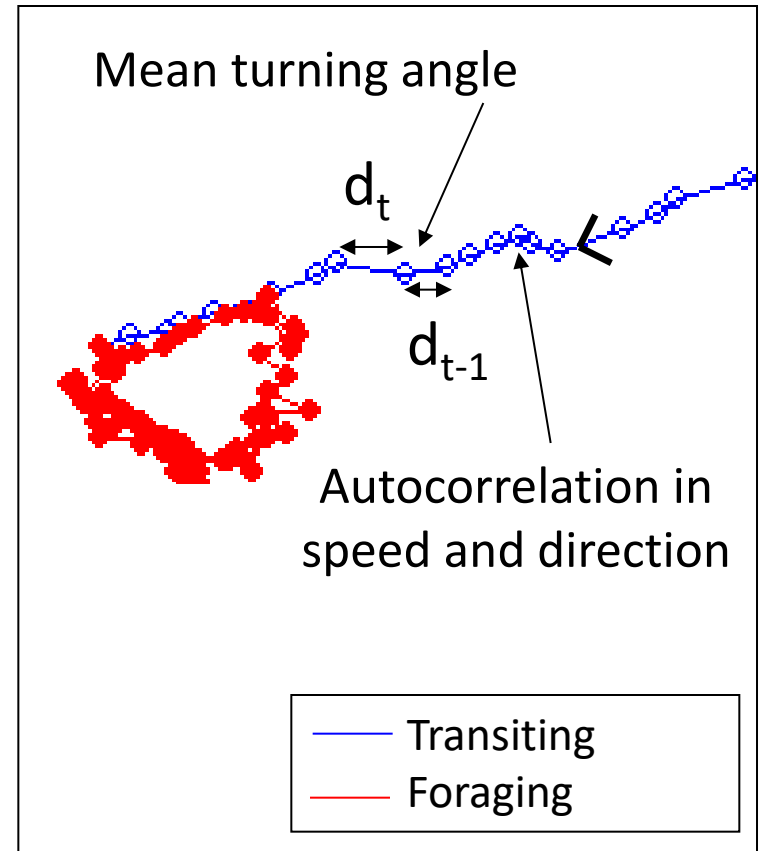
Probability of obtaining observation, conditional on animal's true location.

- Transition equation

Predicts the future location, given its current location.

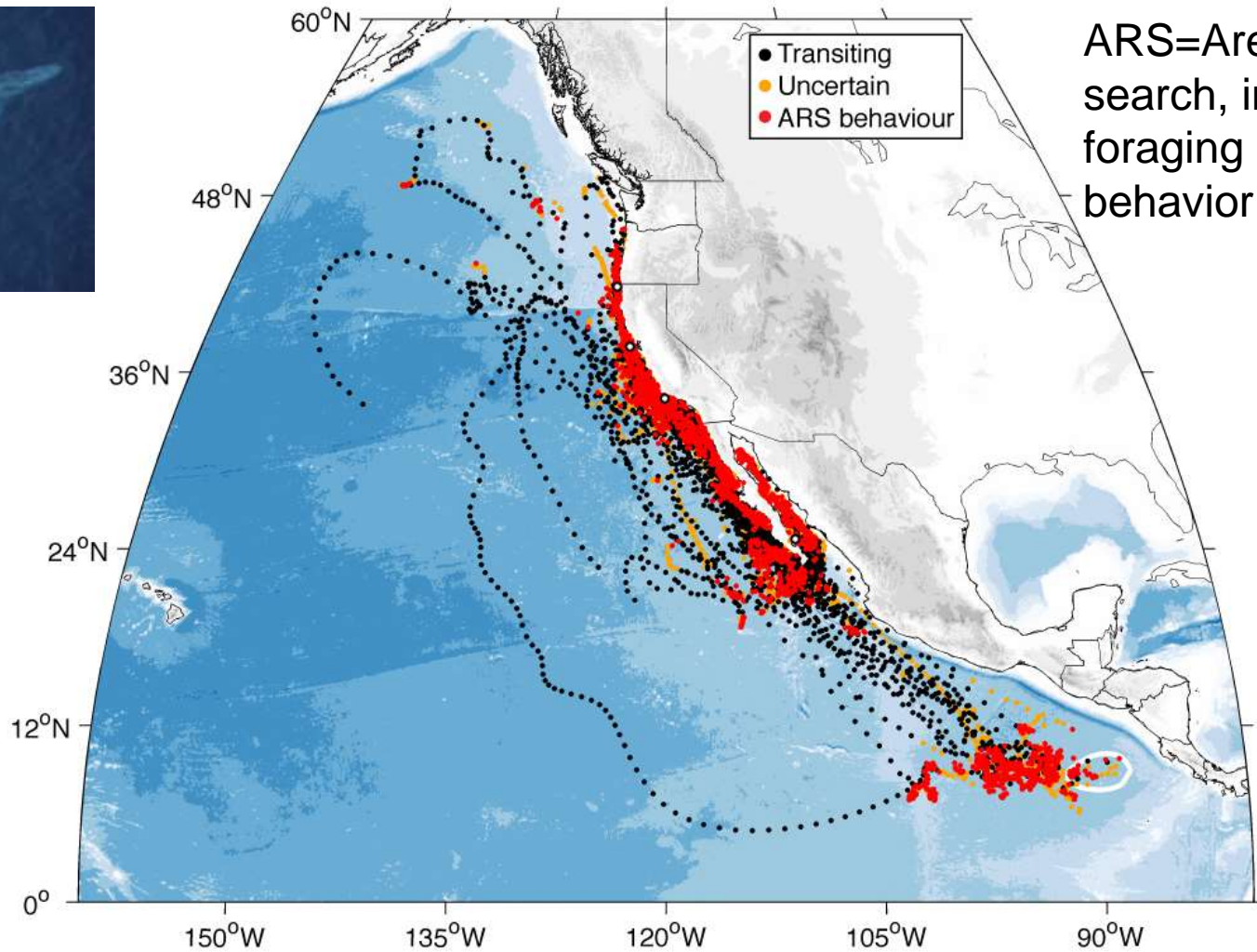


From Vincent et al. (2002)

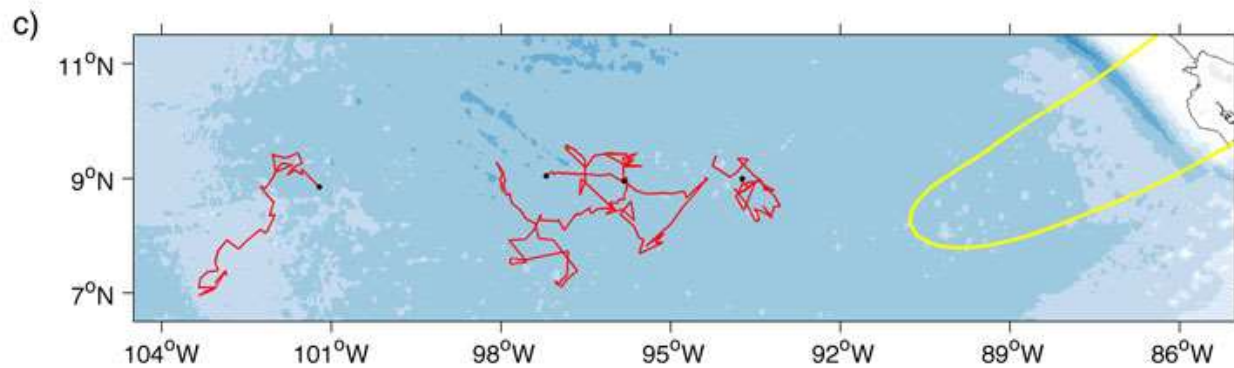
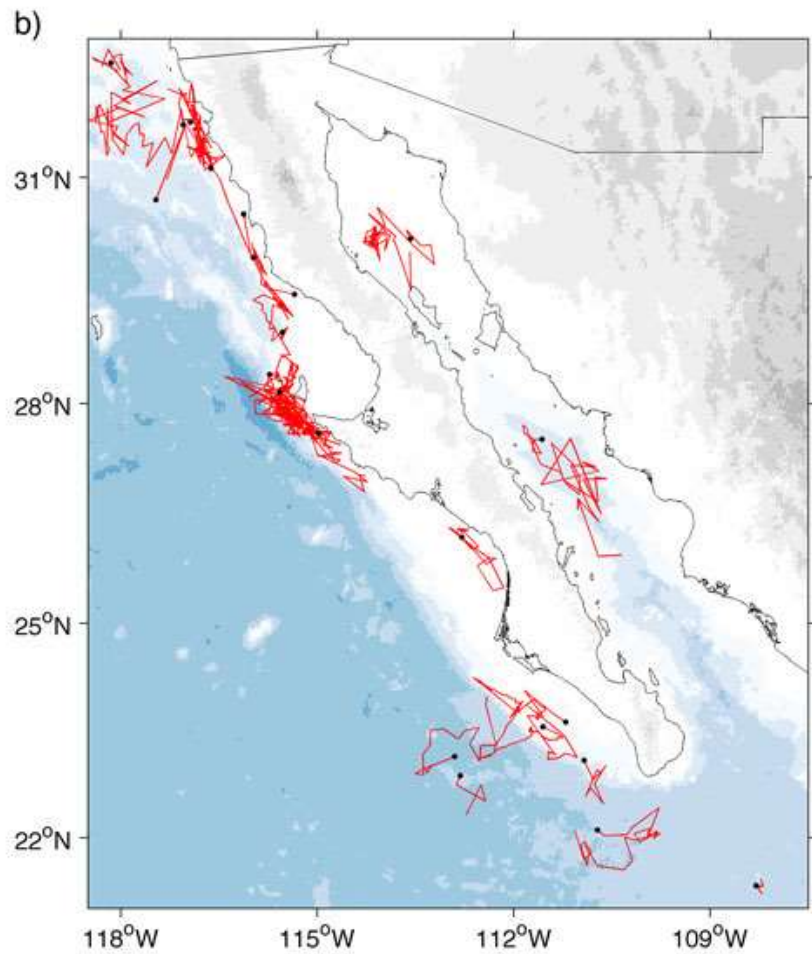
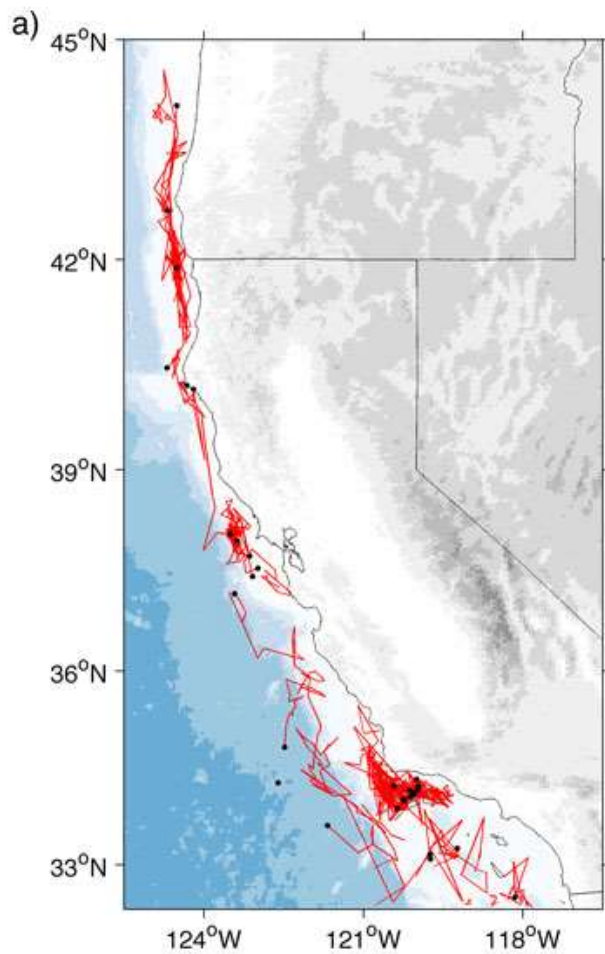


From Jonsen et al. (2007)

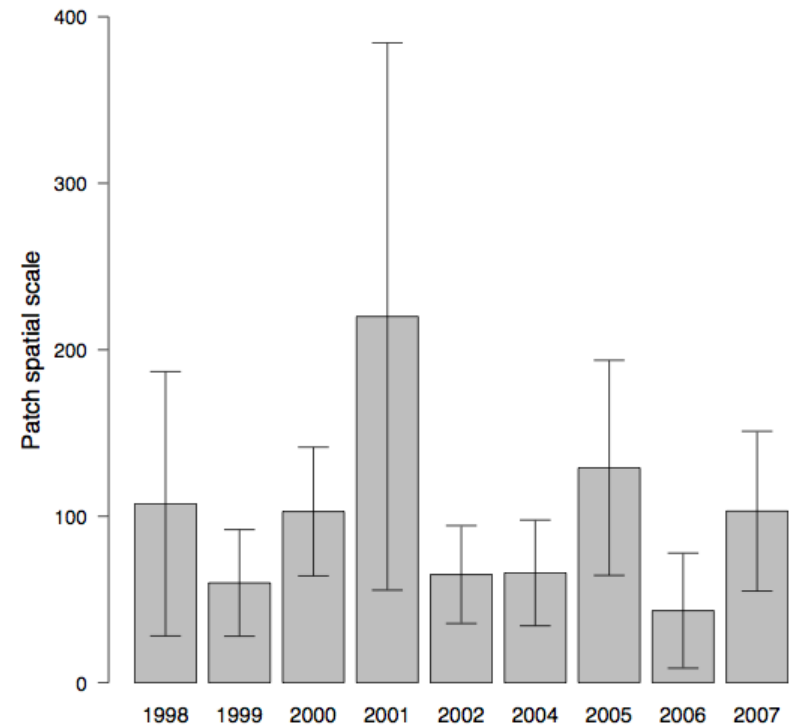
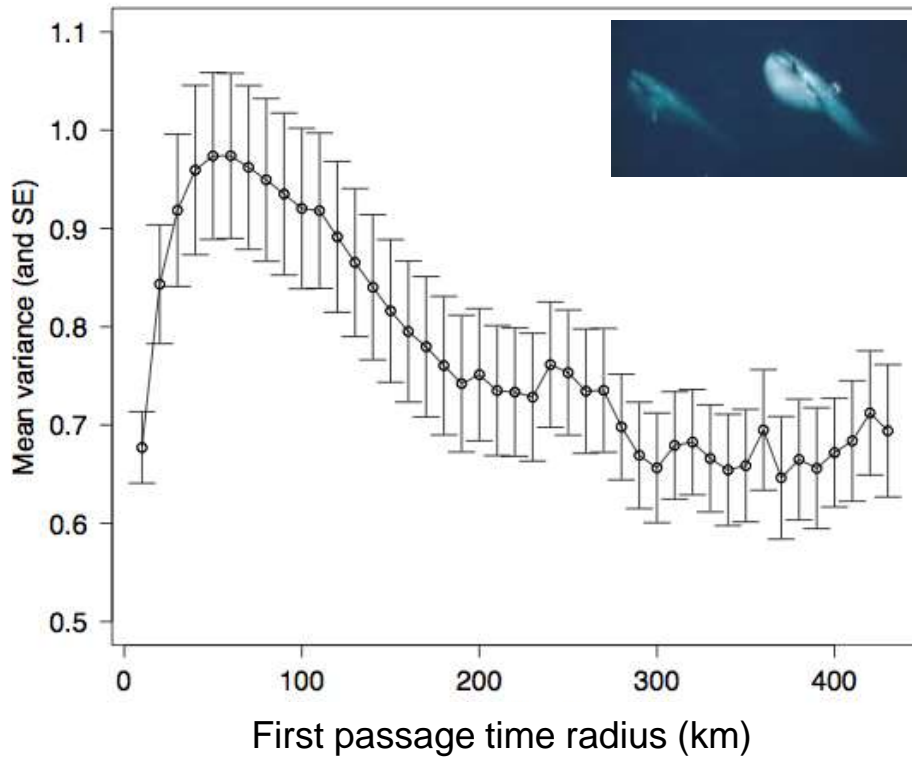
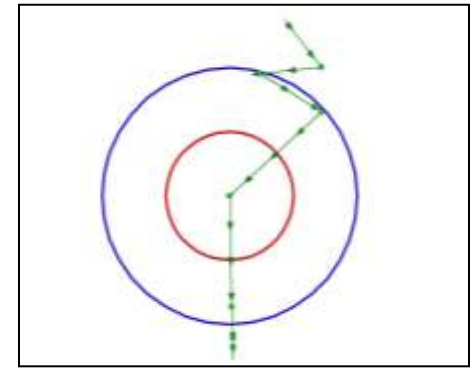
High-use areas



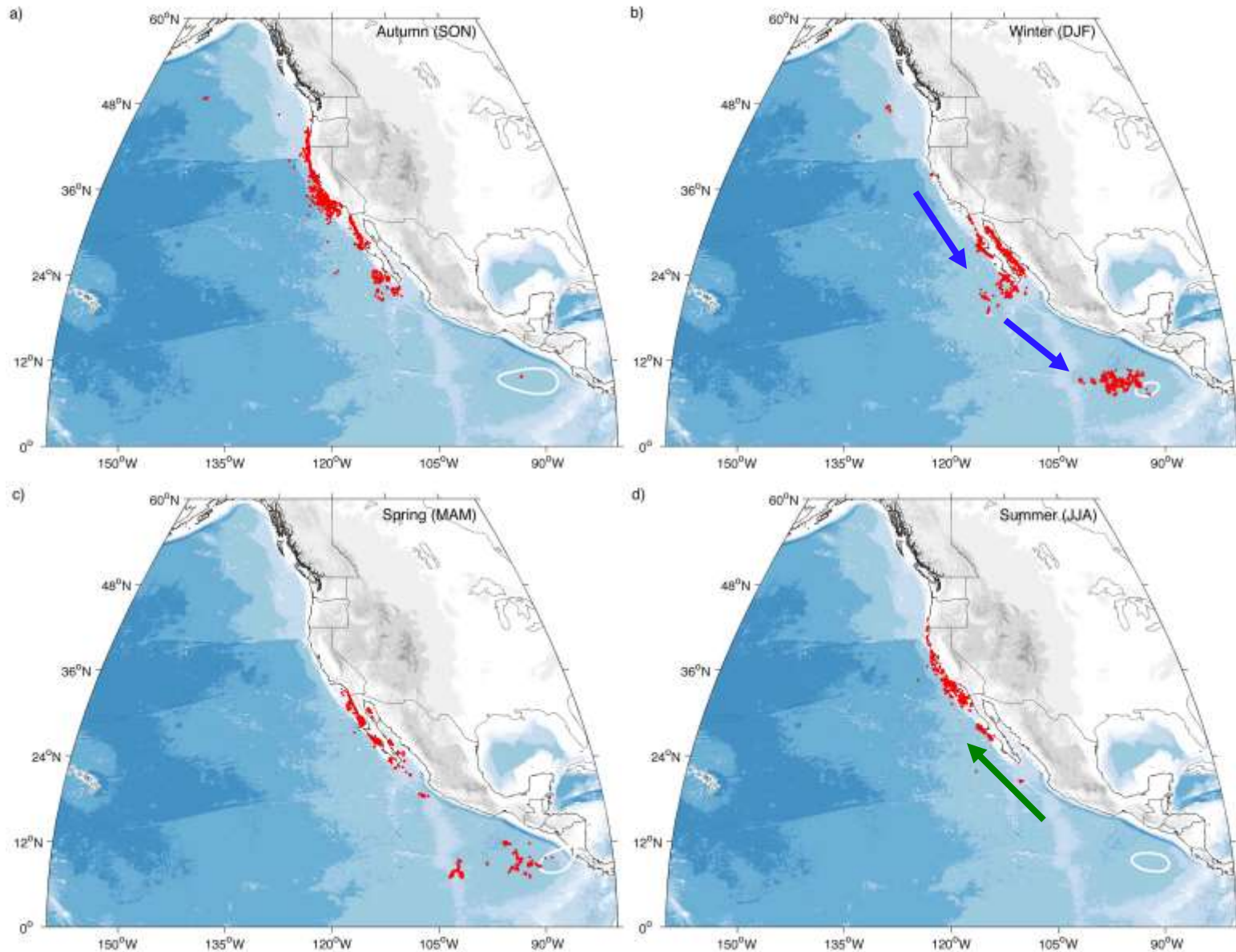
ARS=Area-restricted search, indicates foraging or breeding behavior



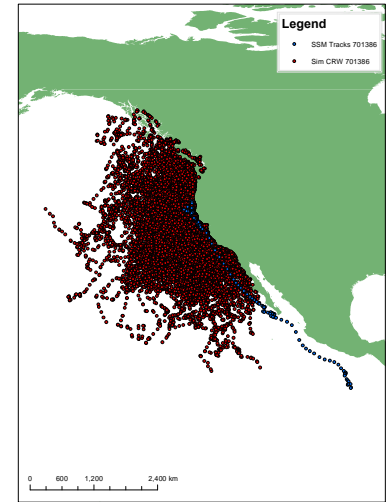
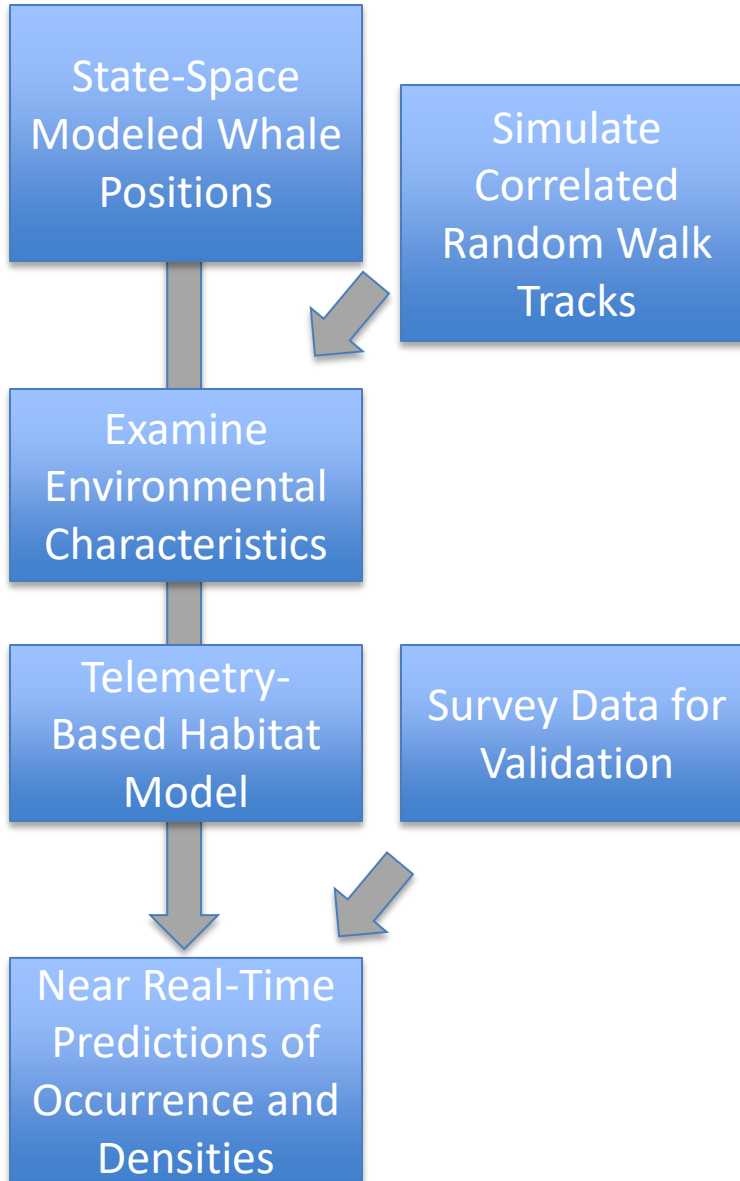
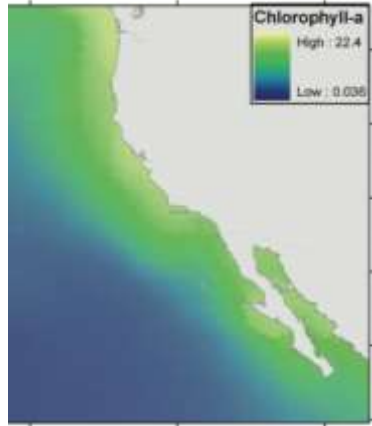
Patch spatial scale



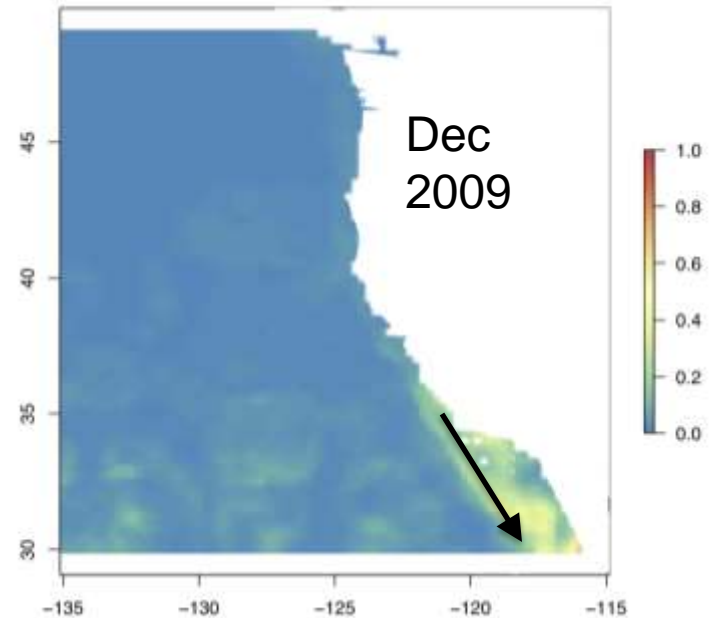
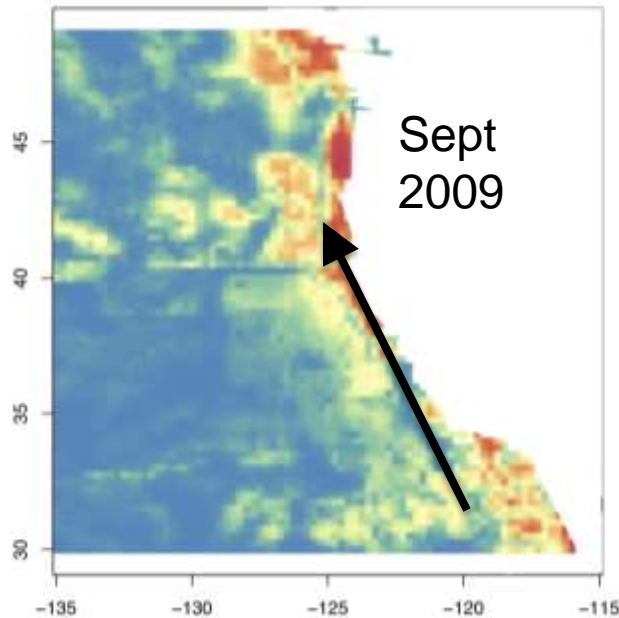
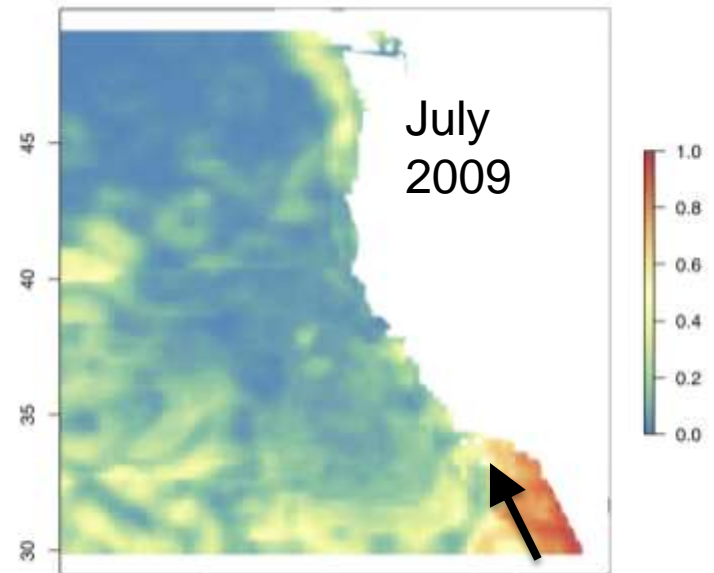
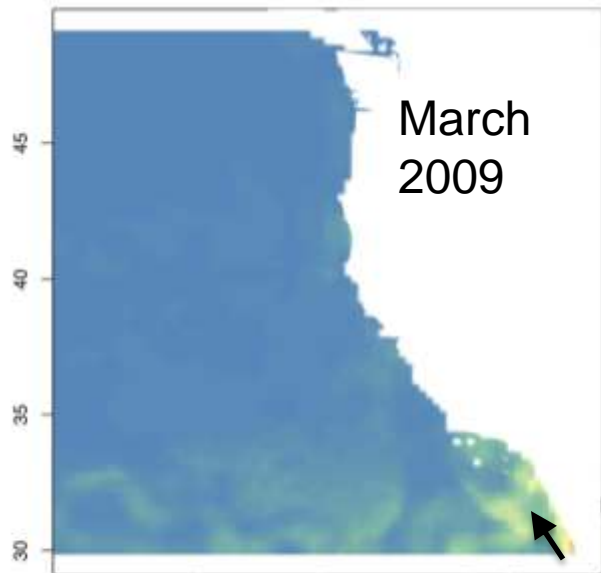
Seasonal pattern



Blue whale habitat-based model

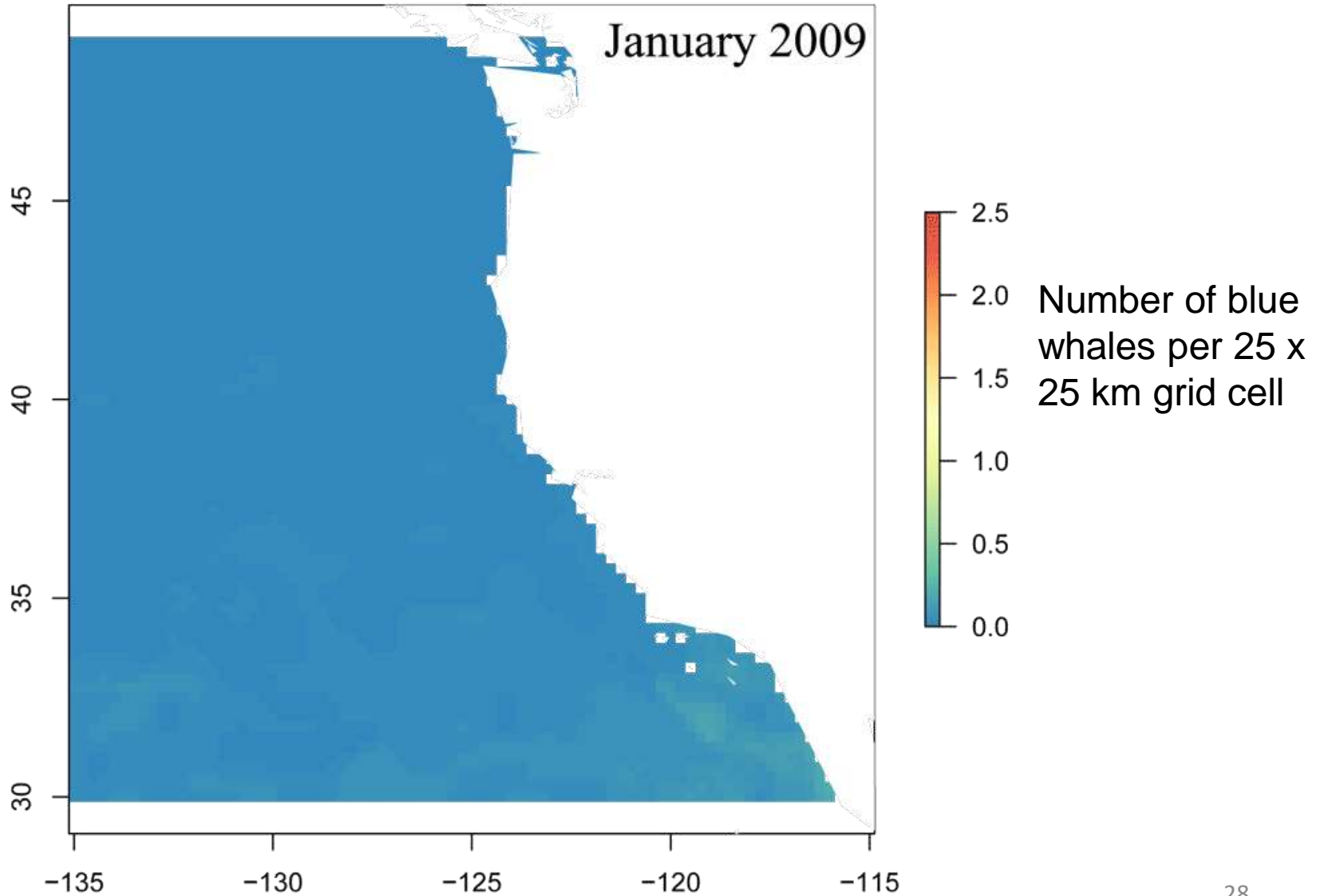


Predictions of occurrence



Hazen et al.
In press
J. App. Ecol.

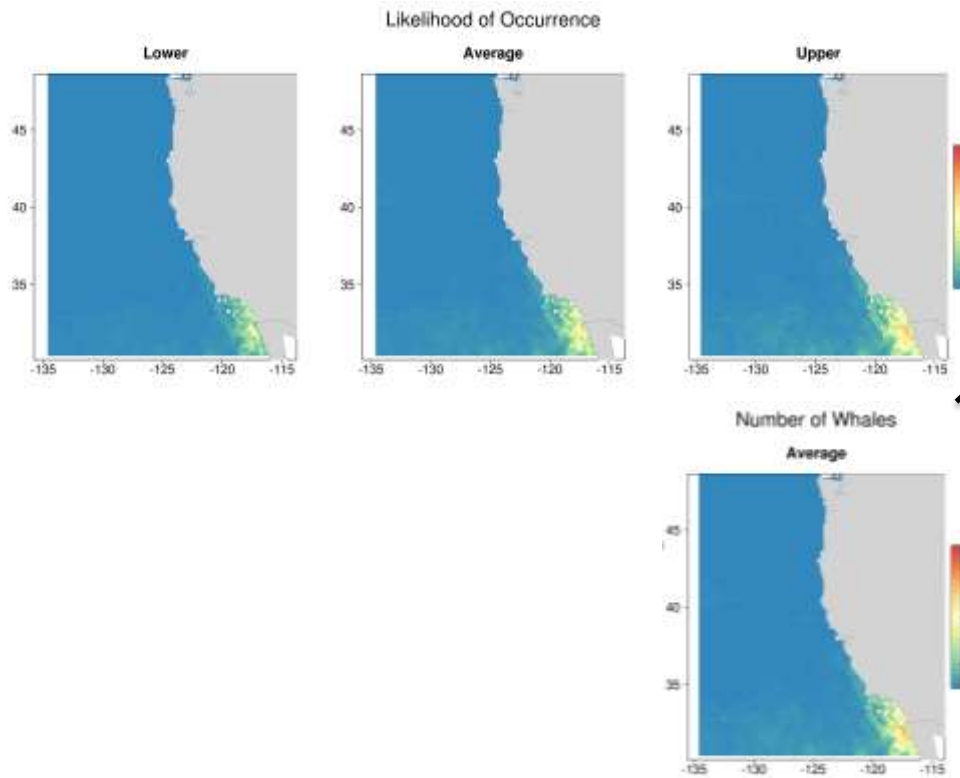
Predictions for 2009



Prediction tool

Website:

www.westcoast.fisheries.noaa.gov/whalewatch



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.

This research has been conducted by a multi-institutional team of academic groups and governmental organizations led by Helen Bailey ([University of Maryland Center for Environmental Science](#)) and in collaboration with the NOAA/NMFS West Coast Regional Office. The satellite telemetry data on whales were collected by Bruce Mate and colleagues ([Oregon State University](#)), geo-spatial distribution by Ladd Irvine (OSU), habitat modeling by Daniel Palacios (OSU), Elliott Hazen, Steven Bograd, Karin Forney ([NOAA/NMFS Southwest Fisheries Science Center](#)), and the web tool created by Evan Howell and Aimee Hoover ([NOAA/NMFS Pacific Islands Fisheries Science Center](#)).

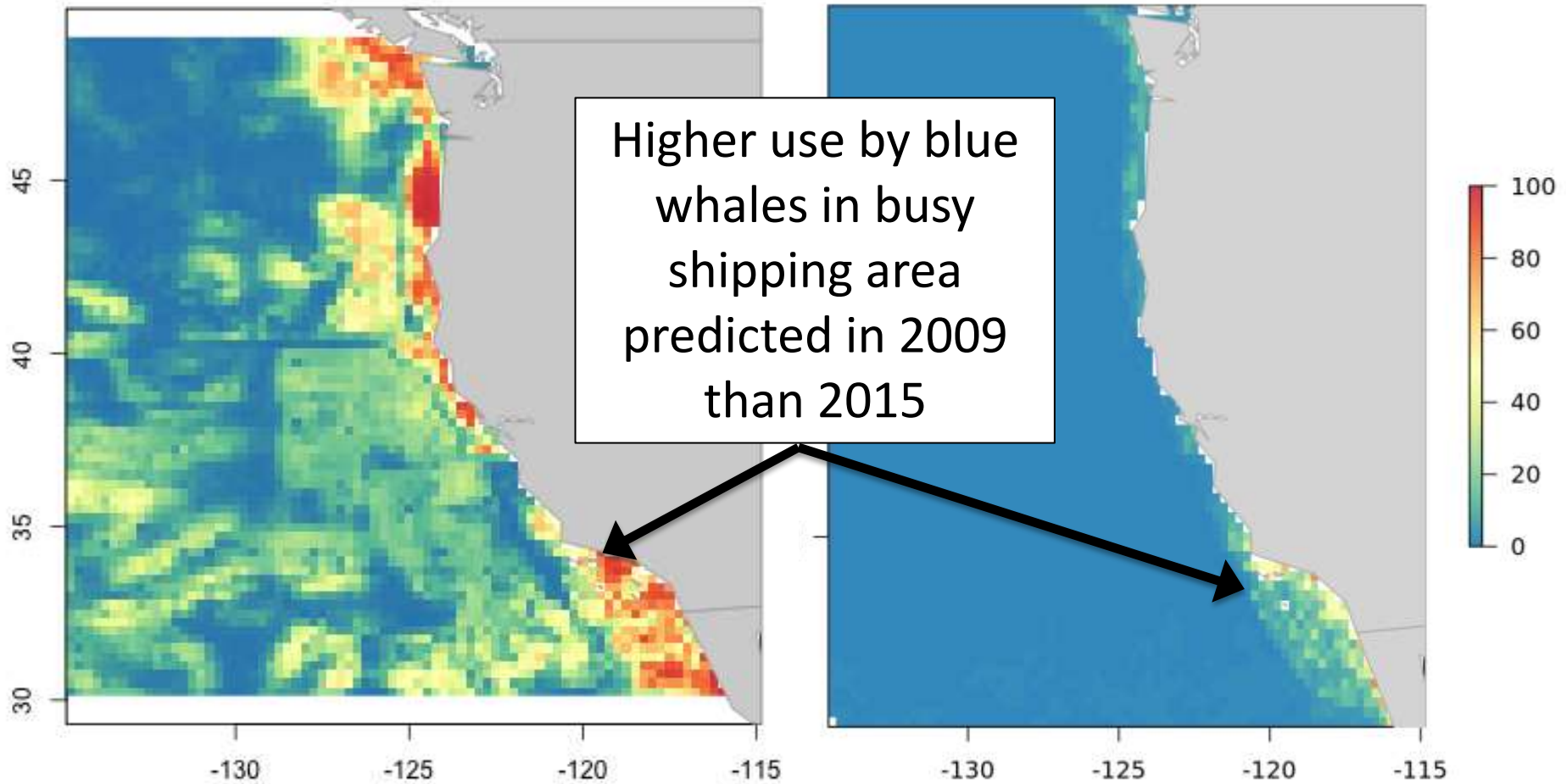
Funding for this project was provided under the interagency NASA, USGS, National Park Service, US Fish and Wildlife Service, Smithsonian Institution Climate and Biological Response program, Grant Number NNX11AP71G. Funding for whale tagging was provided by the [Office of Naval Research](#), the [Marine Mammal Institute at OSU](#), and the Sloan, Packard and Moore Foundations to the [Tagging of Pacific Predators Program](#).

For more information on [WhaleWatch](#) please contact [Helen Bailey](#).

September Prediction

2009

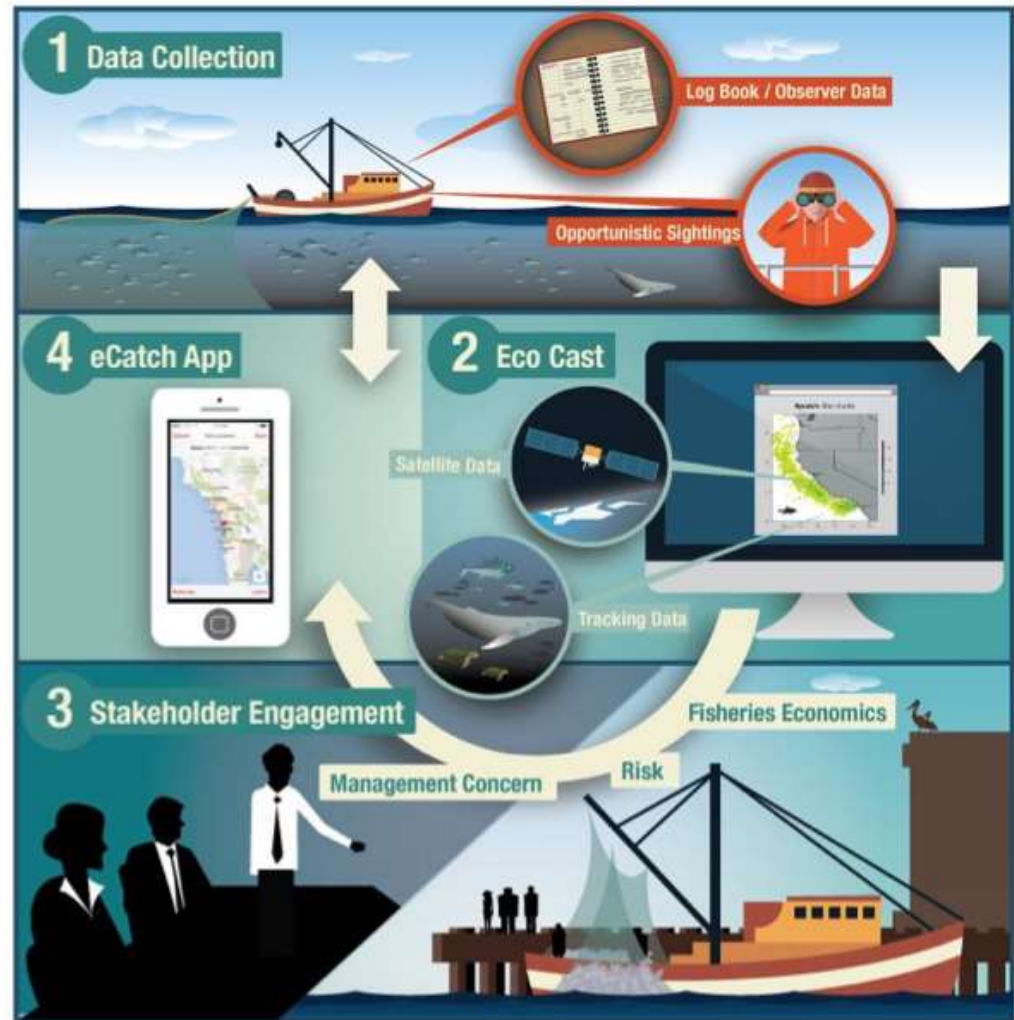
2015



Dynamic Ocean Management

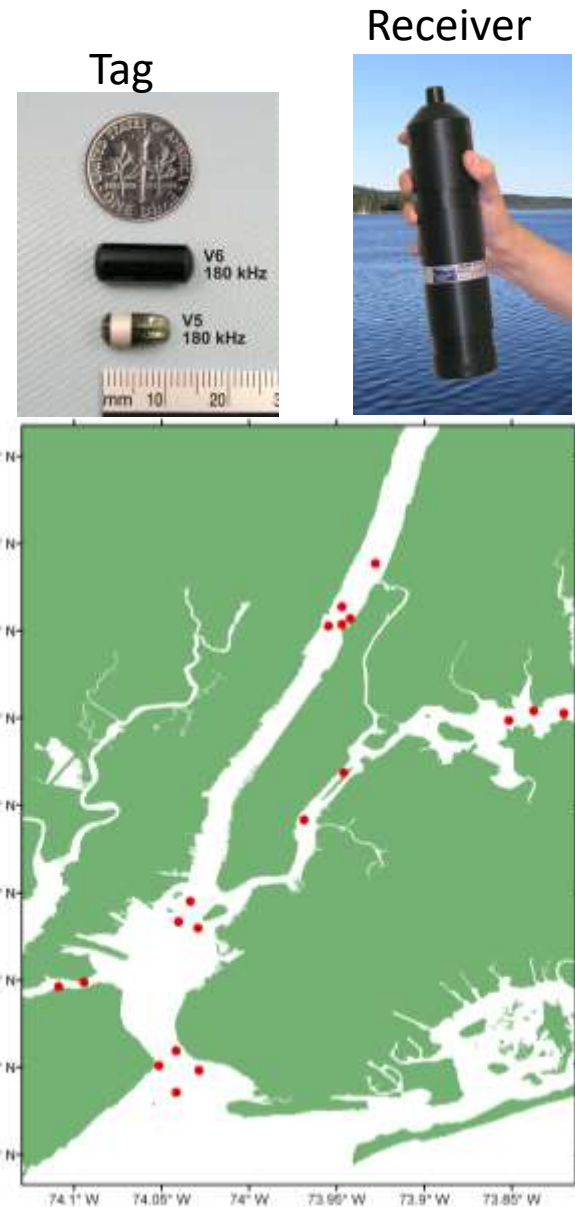
Dynamic ocean management (DOM): Management that changes in space and time in response to the shifting nature of the ocean and its users based on the integration of current biological, oceanographic, social, and/or economic data.

Hobday et al. 2014, Lewison et al. 2015 and Maxwell et al. 2015



Acoustic telemetry

- Tag animal with individually coded transmitters
- *Mobile tracking*: Use a hydrophone to follow tagged animals.
- *Fixed receivers*: Continuously monitor for transmitters at known locations.
- *Advantages*: Smaller than satellite tag and transmits underwater.
- *Disadvantages*: Receivers mainly used in shallow coastal environments. Detections only at pre-defined receiver locations.



Tagging striped bass

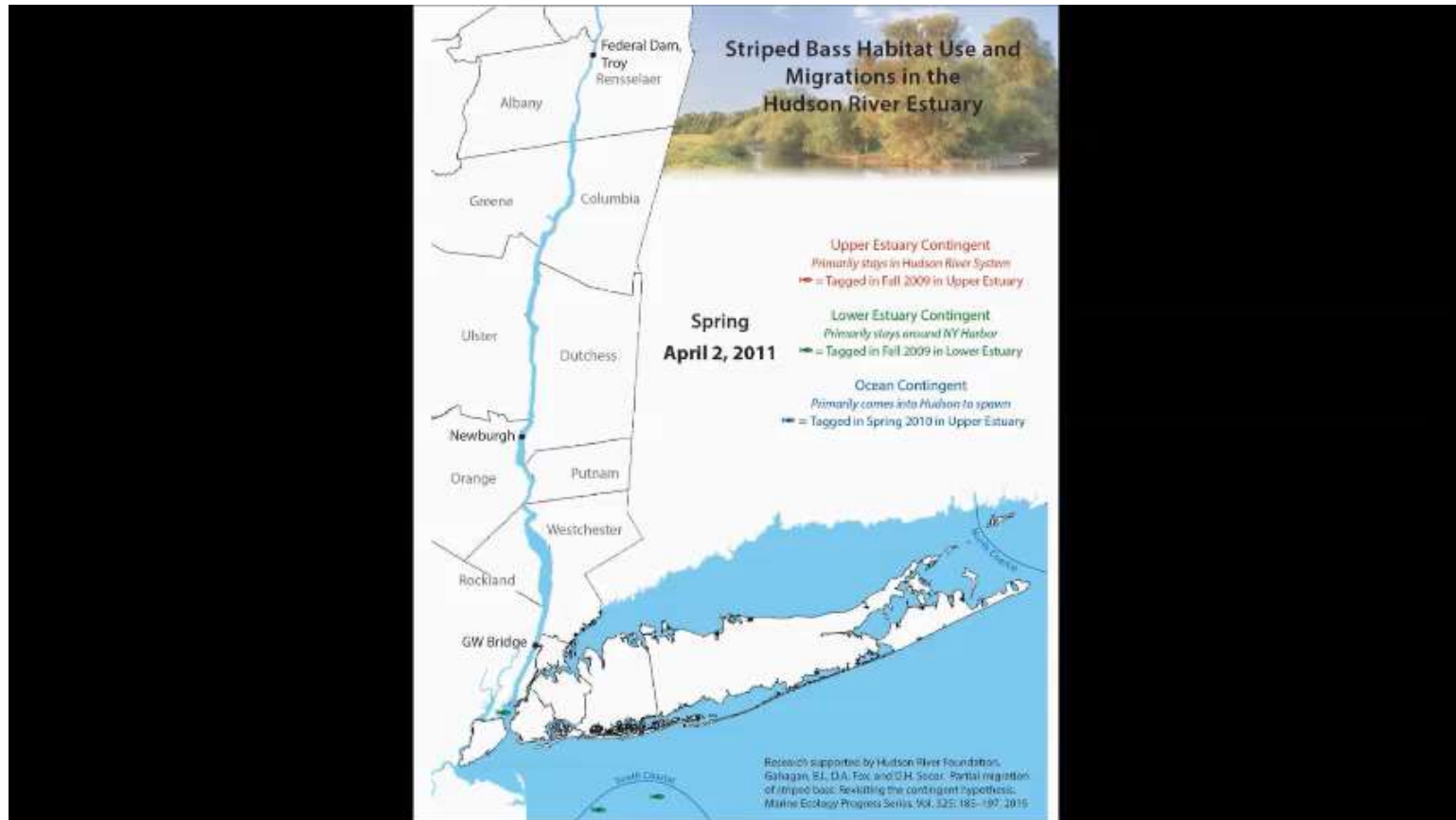
- 75 striped bass tagged with acoustic transmitters in October 2009 and May 2010.
- Upper estuary contingent (UEC), n=15.
- Lower estuary contingent (LEC), n=40
- Ocean contingent (OC), n=20
- Tracking duration up to 816 days

[Tagging video](#)



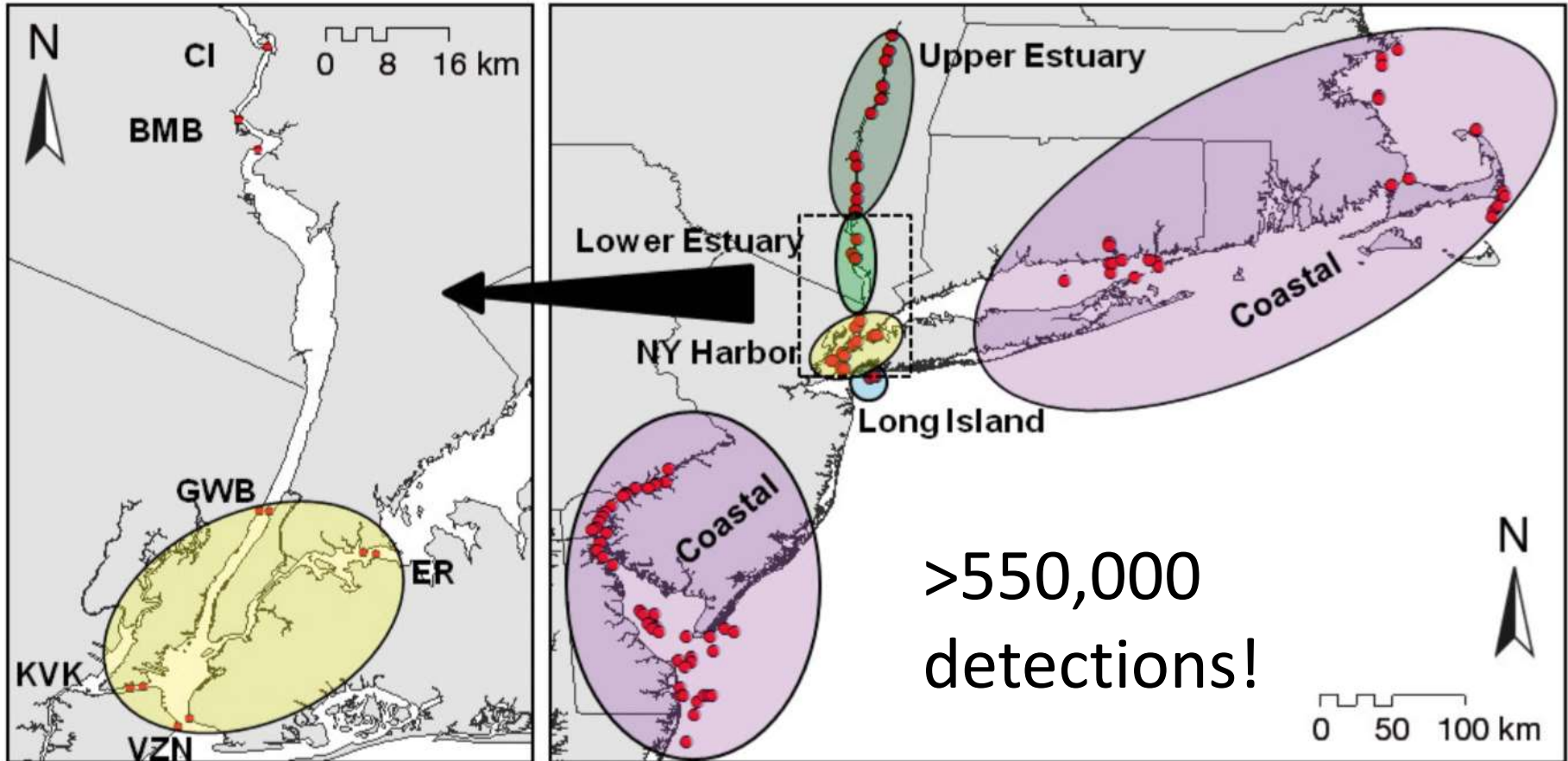
Tagging by David Secor,
CBL UMCES

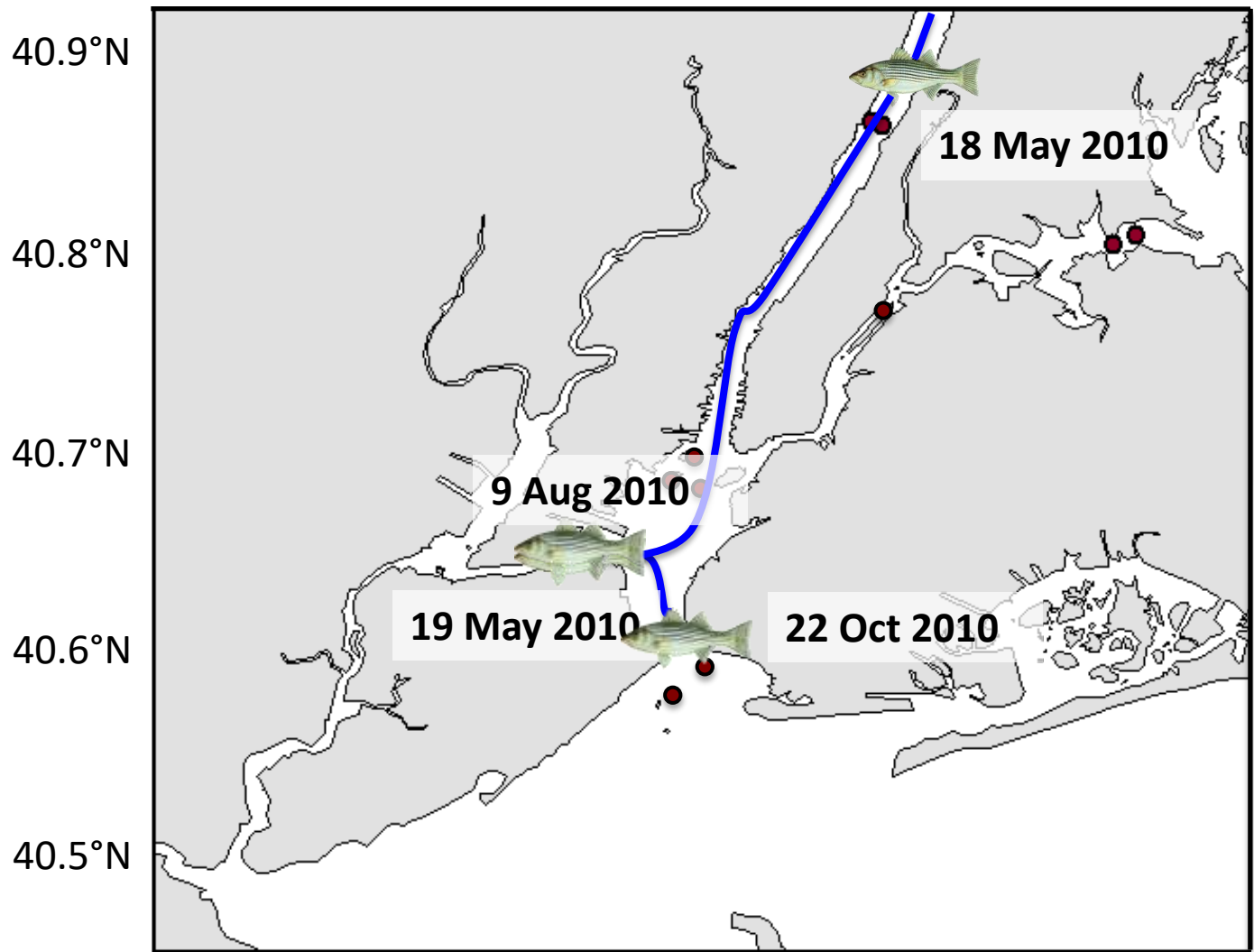
Acoustic detections



Track data: David Secor, CBL UMCES

Acoustic detections



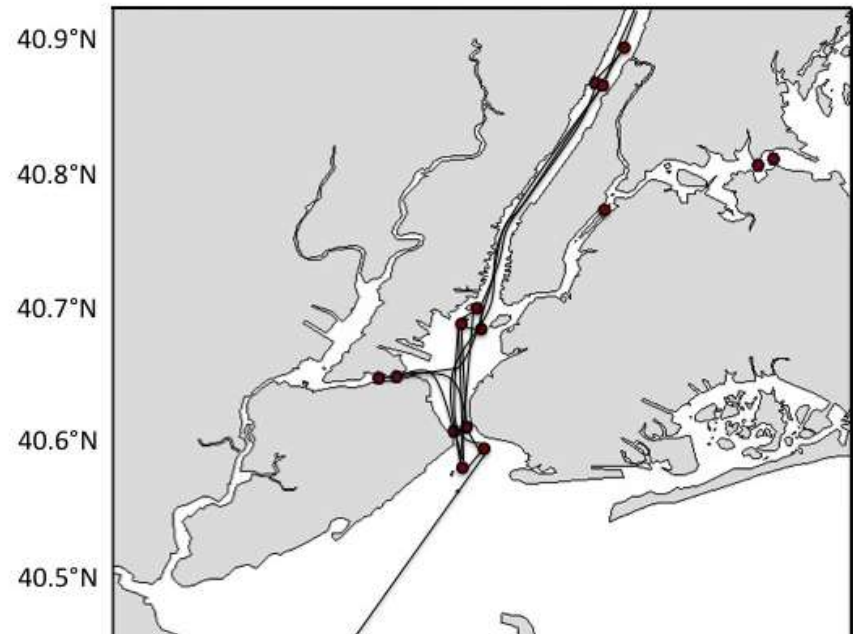


Movements of an individual fish, ID 11

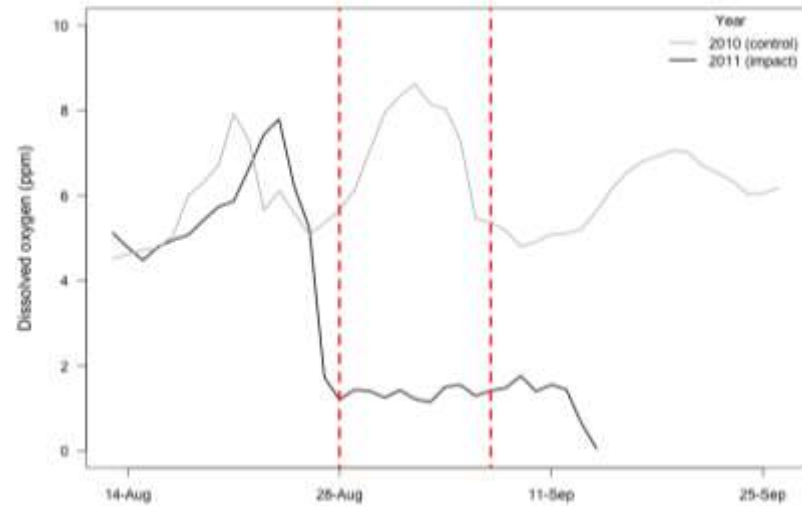
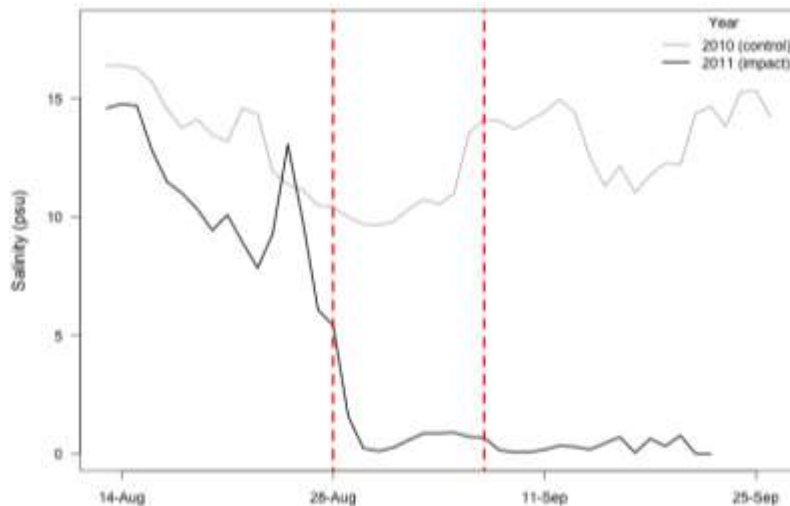
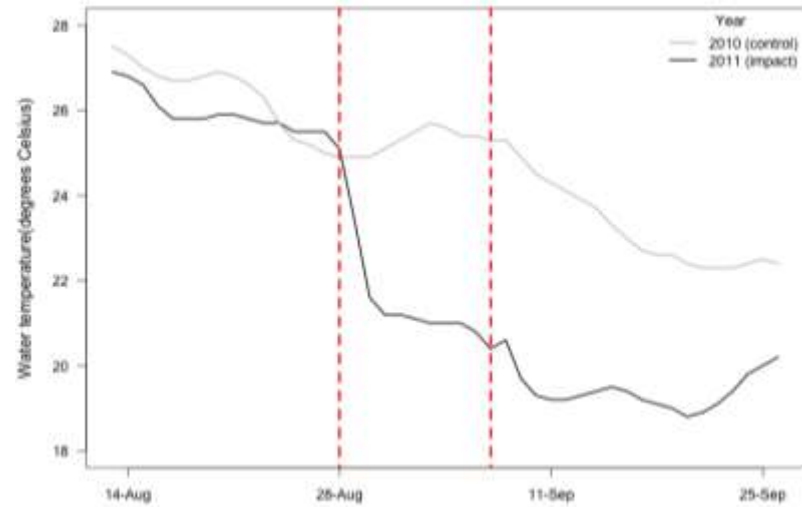
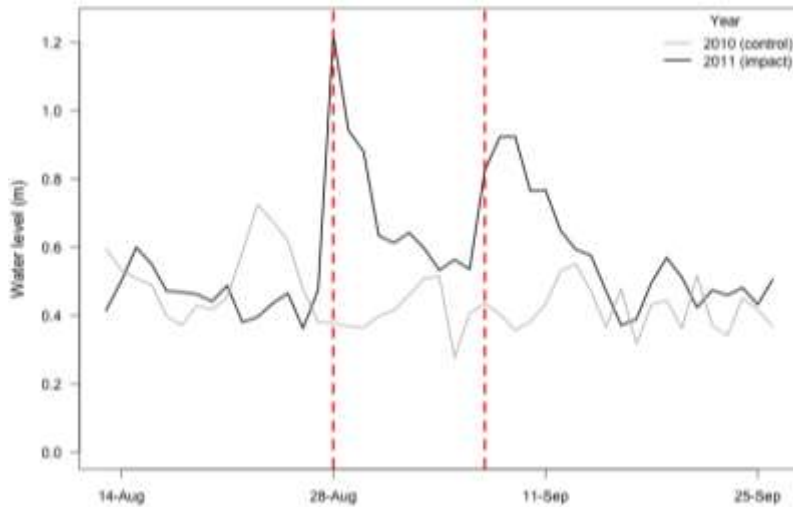
Extreme weather events

- Extreme events likely to increase in intensity and frequency with climate change
- Difficult to design and implement ecological studies for these rare, unpredictable events.
- Reconstruct movements from acoustic telemetry

Striped bass



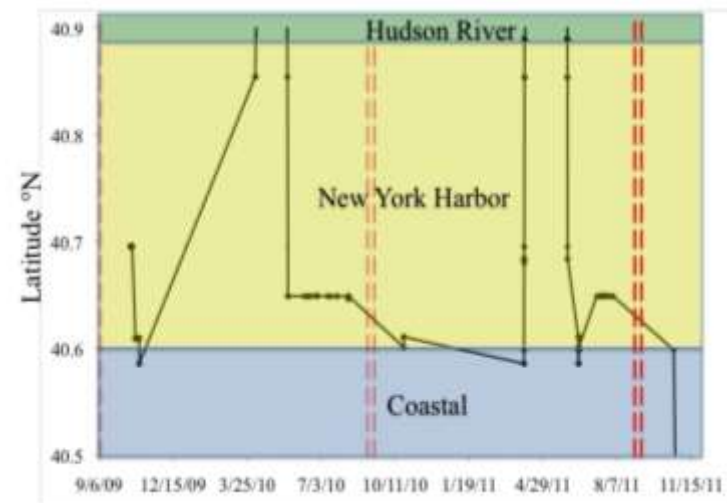
Tropical Storms 2011



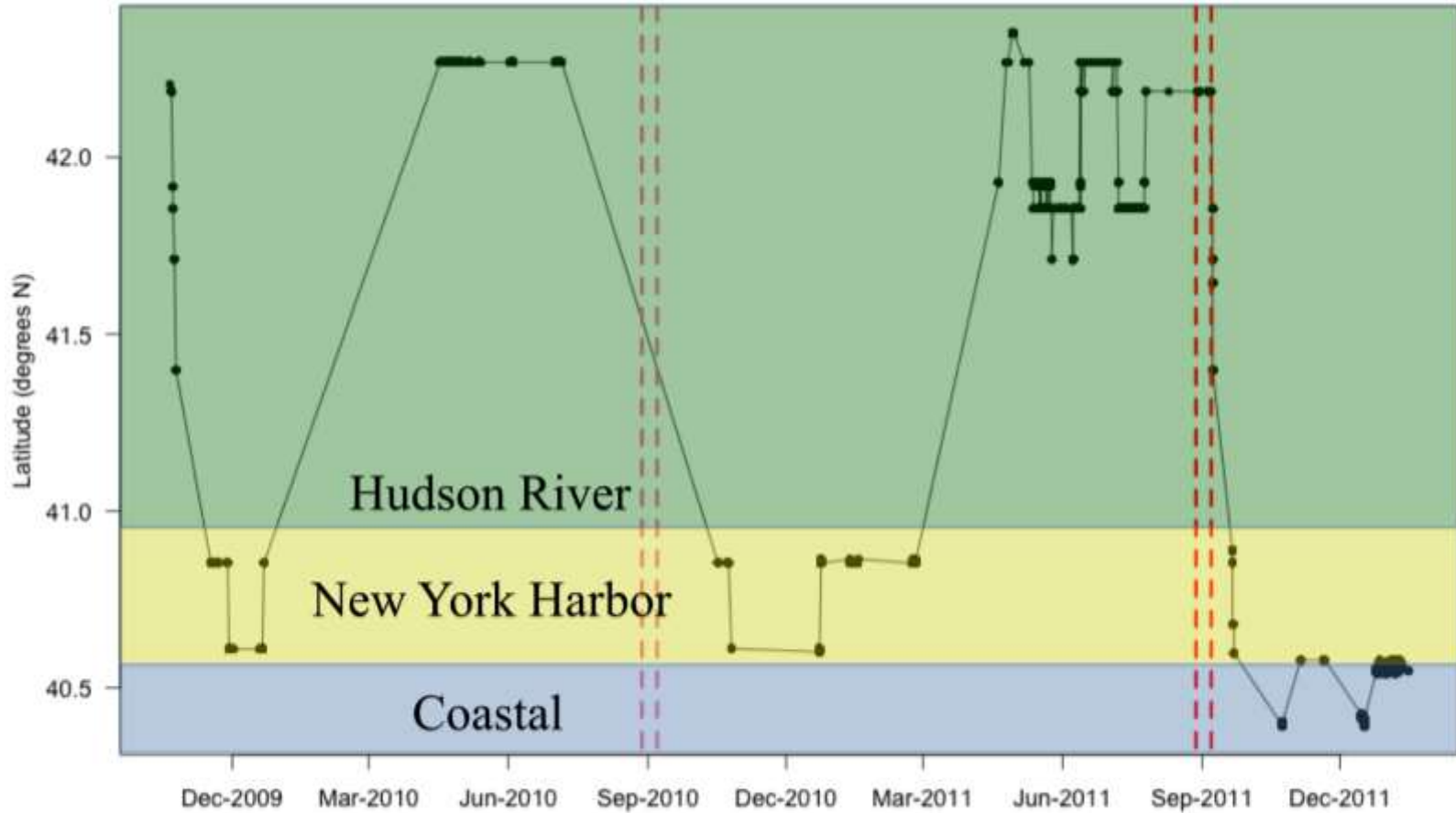
Water level and temperature data from USGS daily statistics at the south dock at West Point, NY, and salinity and DO from HRECOS GWB station.

Approach

- Before-during-after-control-impact design
- Before=13-27 Aug, During=28 Aug-11 Sep, After=12-26 Sep, Control=2010, Impact=2011
- Response= Mean daily latitude for each fish
- Fit generalized linear mixed model (GLMM) with the track section nested within the individual (n=22) as a random effect.

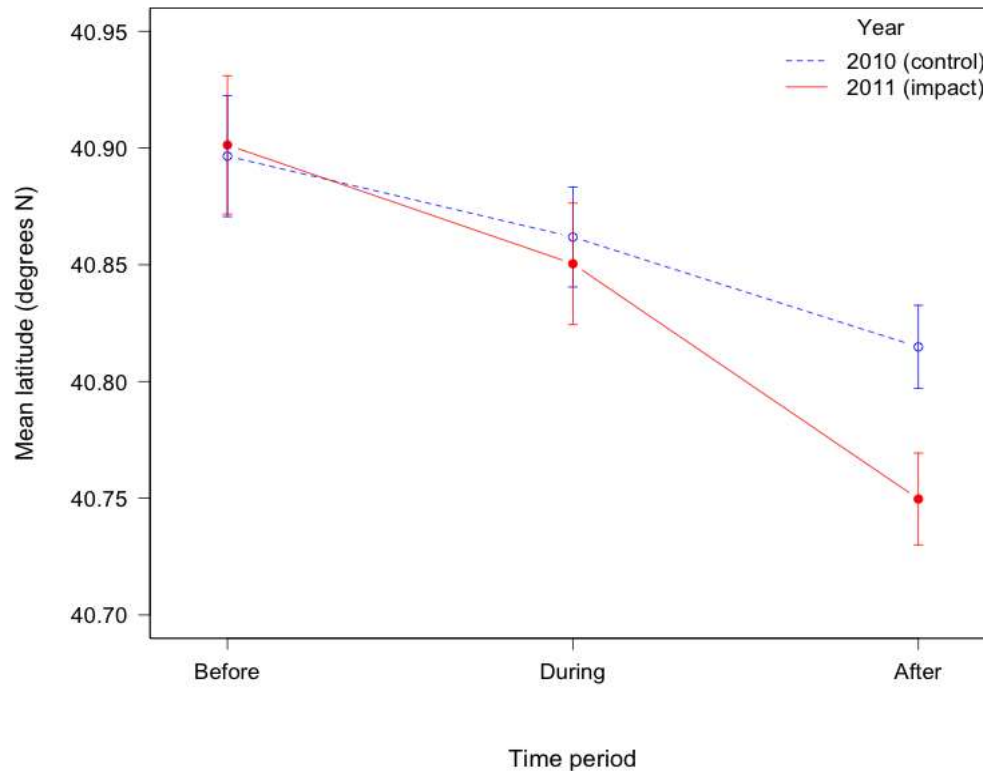


Fish ID 3 (UEC)



Average speed 0.02 m/s (0.04 BL/s) 0.70 m/s (1.45 BL/s)
ID 3 total length 483 mm (mean UEC tagged 490 mm)

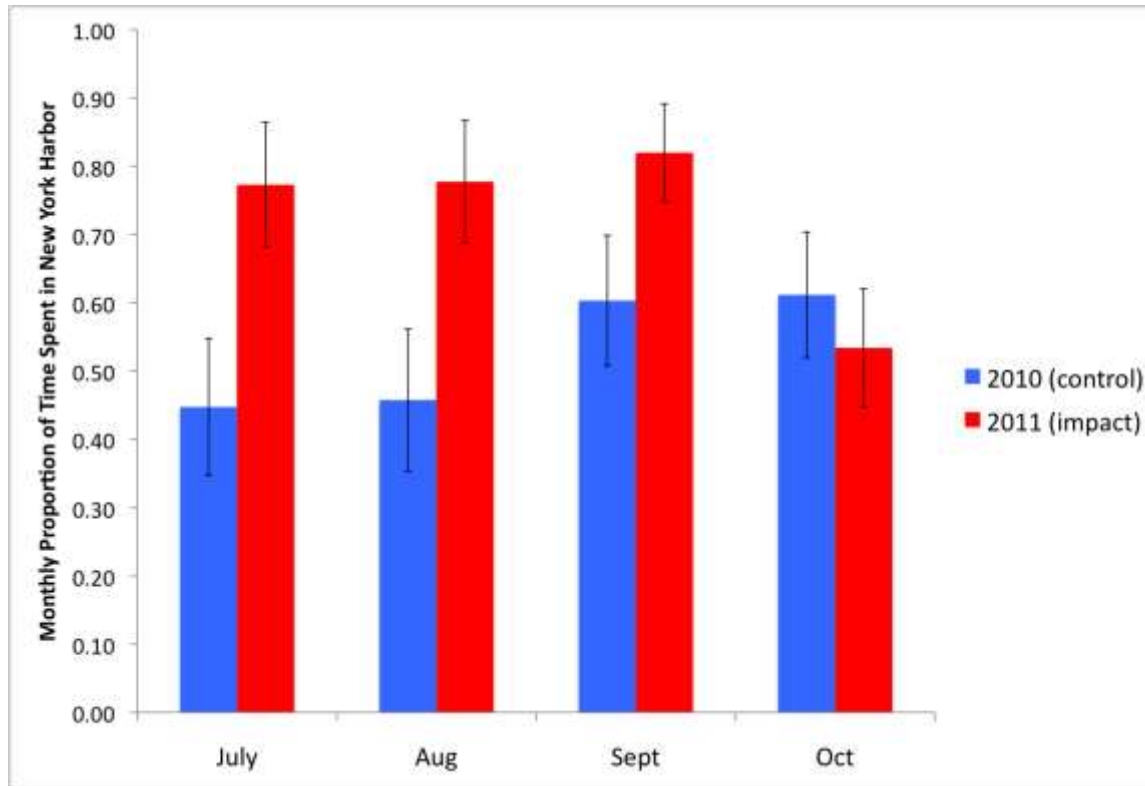
Response to storm events



Bailey and Secor 2016
Scientific Reports

Significant interaction between the time period (before-during-after) and year (2010 – control, 2011 – impact). More pronounced southward movement after the storms suggesting they caused a coastal evacuation of striped bass.

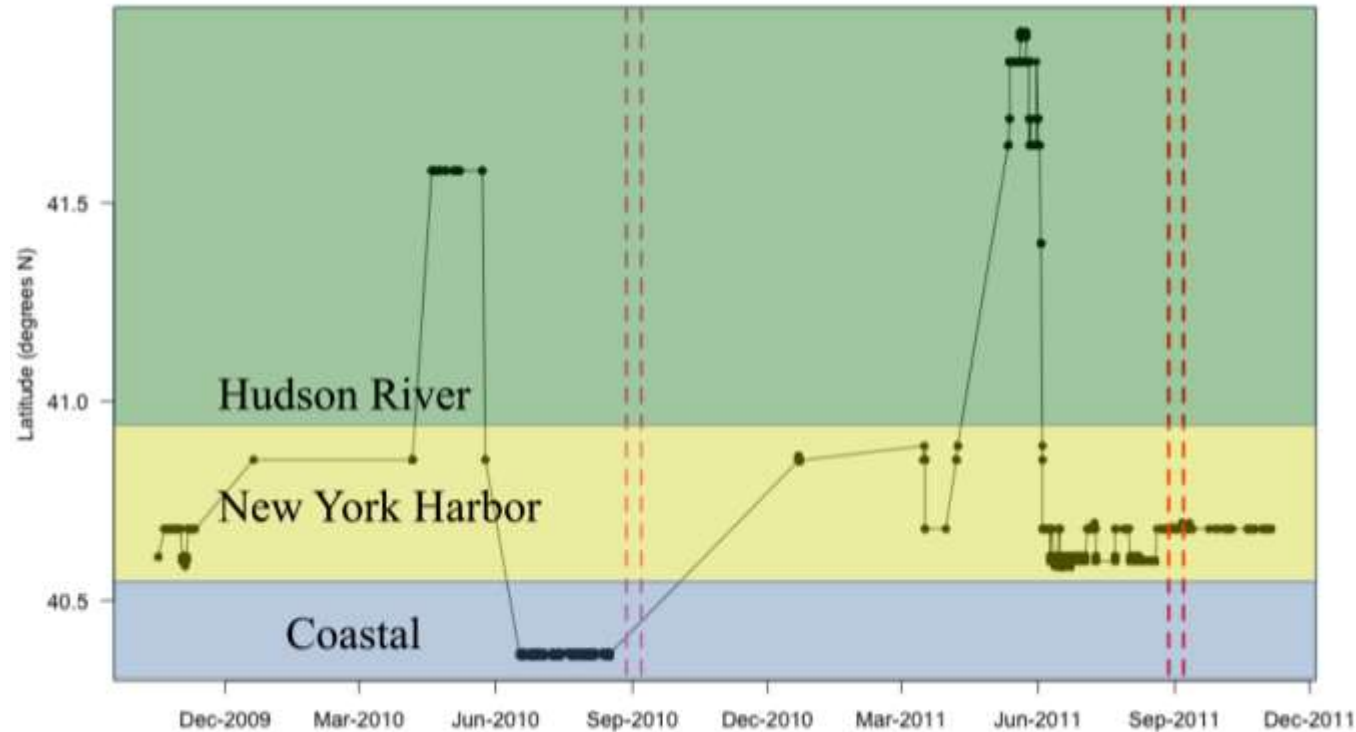
Residency in NY Harbor



Bailey and Secor 2016
Scientific Reports

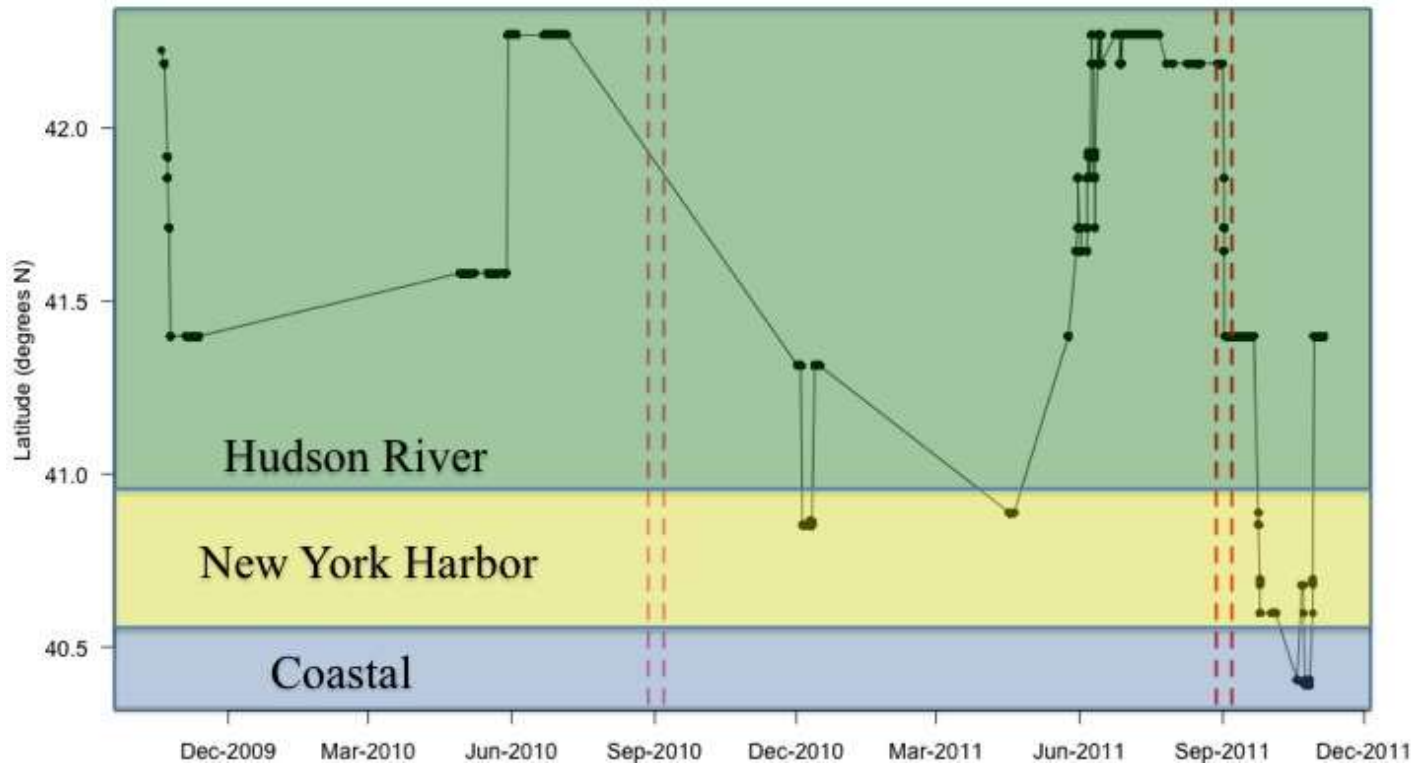
Significant interaction between month of October and the year, with less time spent in NY Harbor in October 2011, after the storms, than in 2010.

Resident behavior



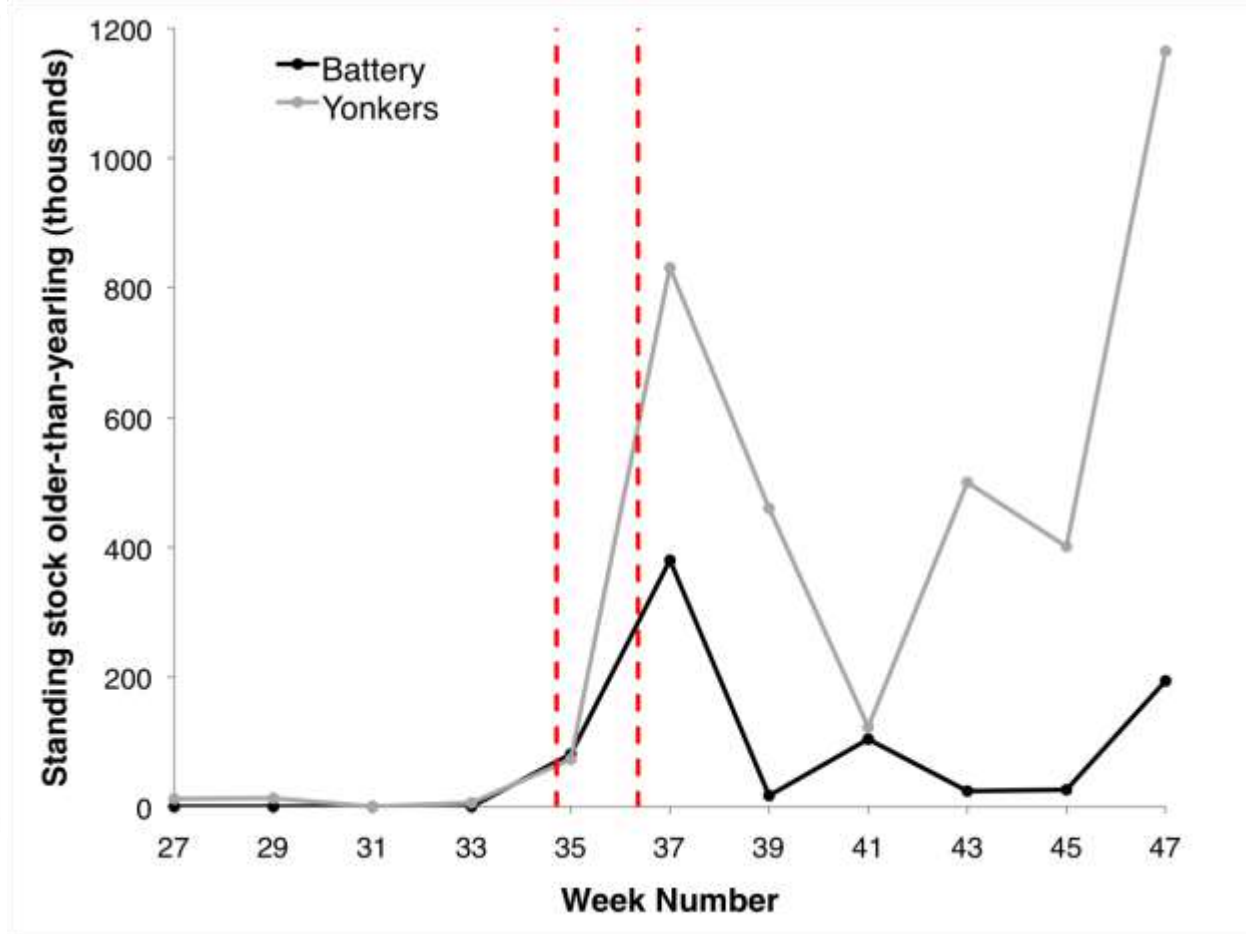
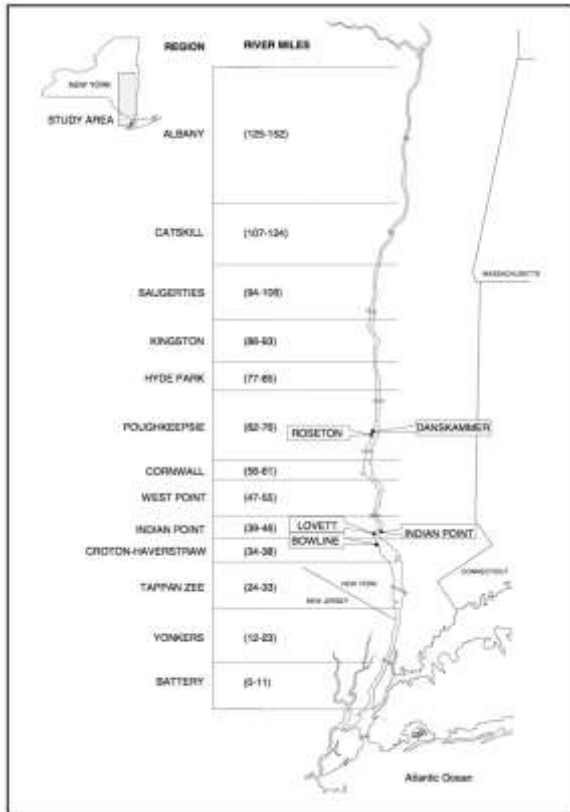
Fish ID 16 (LEC) remained in NY Harbor from 4 June 2011 to 5 November 2011 (last reported detection). During the period of the storms it was regularly detected near Liberty Island and Governors Island. Total length 590 mm (mean LEC tagged 607 mm).

Exploratory behavior



Fish ID 5 (UEC) returned to NY Harbor on 22 Oct 2011, moved out to the coast (off NJ Sandy Hook 24-27 Oct) and then entered NY Harbor on 29 Oct 2011 and swam upriver.

White perch



Data from Applied Science Associates Year Class Report

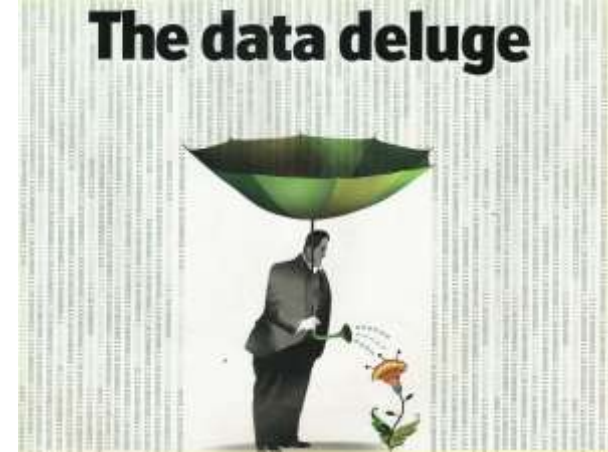
Next steps

- Developing striped bass habitat model by identifying environmental associations
- Coastal habitat use of striped bass (Hudson River Foundation award, co-PI with Dave Secor).
- Movements, habitat use and behavior of tagged fish in the Maryland Wind Energy Area (BOEM award, co-PI with Dave Secor)



Future work

- DATA DELUGE!
- Analysis techniques catching up with the abundance of telemetry data becoming available.
- Opportunities to study fine-scale movements, habitat use and behavior of fish using acoustic telemetry (VEMCO Positioning System)



Acknowledgements



- Funding for the whale study was funded by NOAA and NASA.
- Thank you to the Hudson River Foundation for supporting the striped bass project.

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for Science & Environmental Research