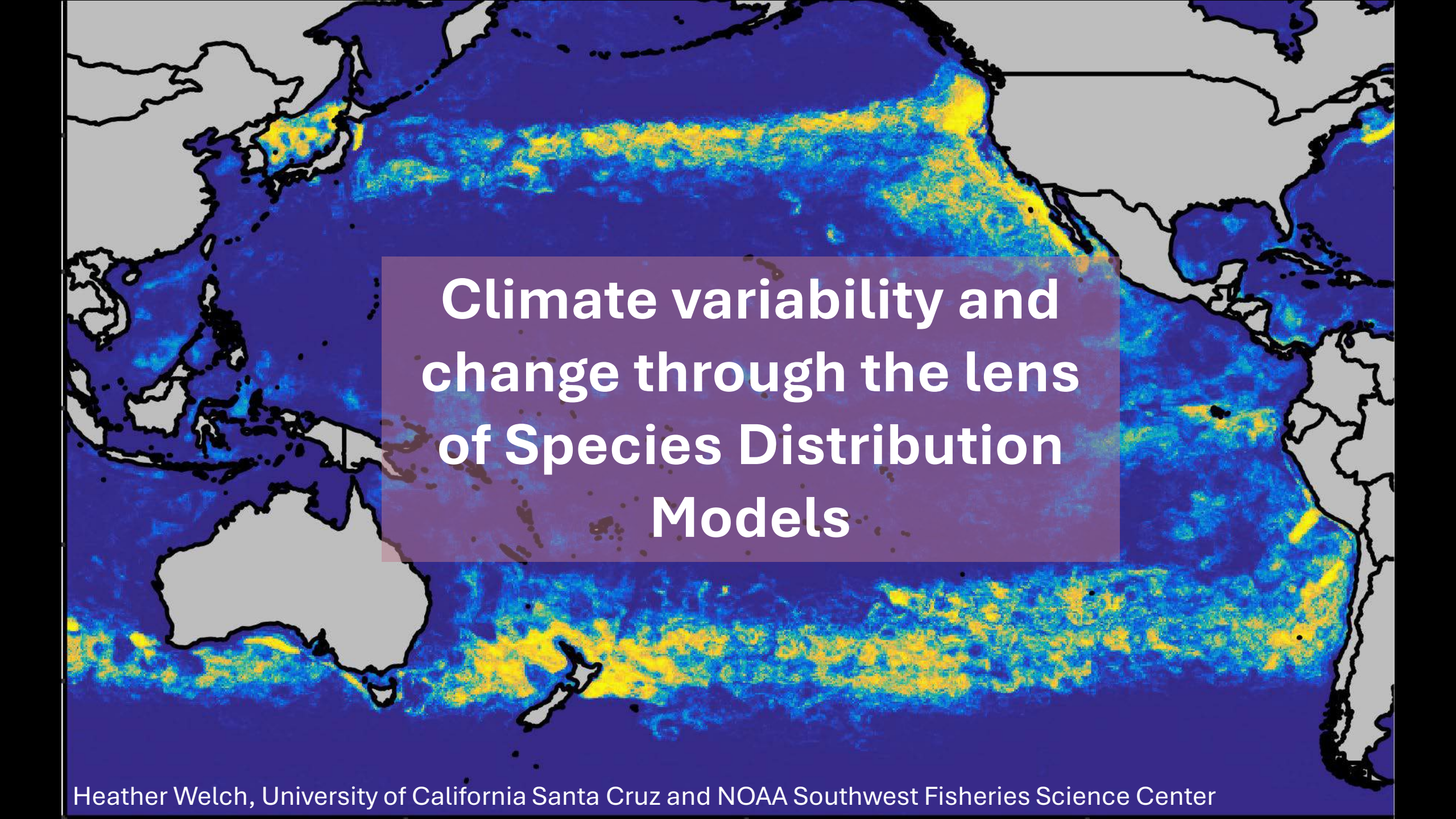

Climate variability and change through the lens of Species Distribution Models

Heather Welch, University of California Santa Cruz and NOAA Southwest Fisheries Science Center

Species Distribution Models (SDMs) at their most basic:
animal distribution ~ environment

Purpose: 1) to **explain** how animals respond to the environment,
2) to **predict** animal distributions across space and time

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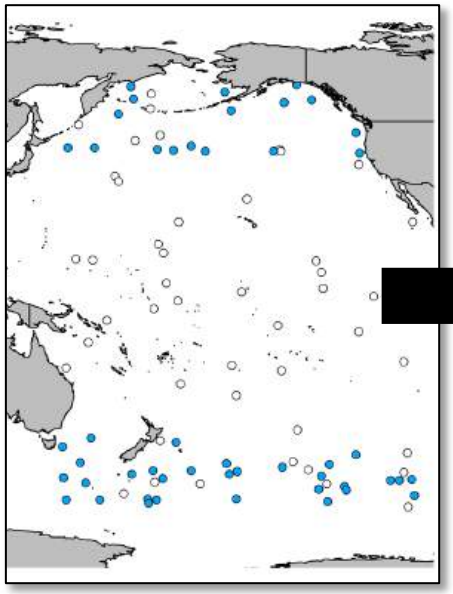
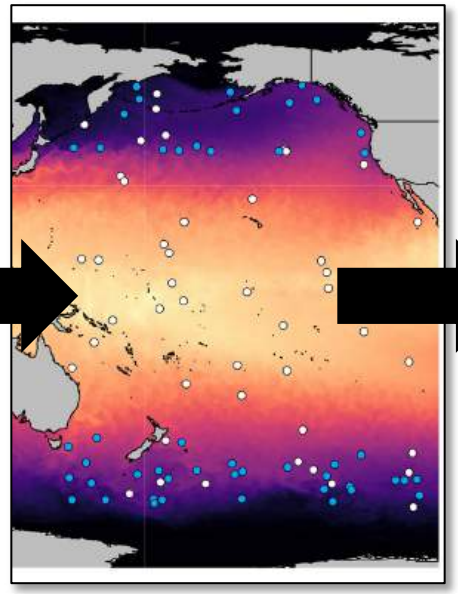
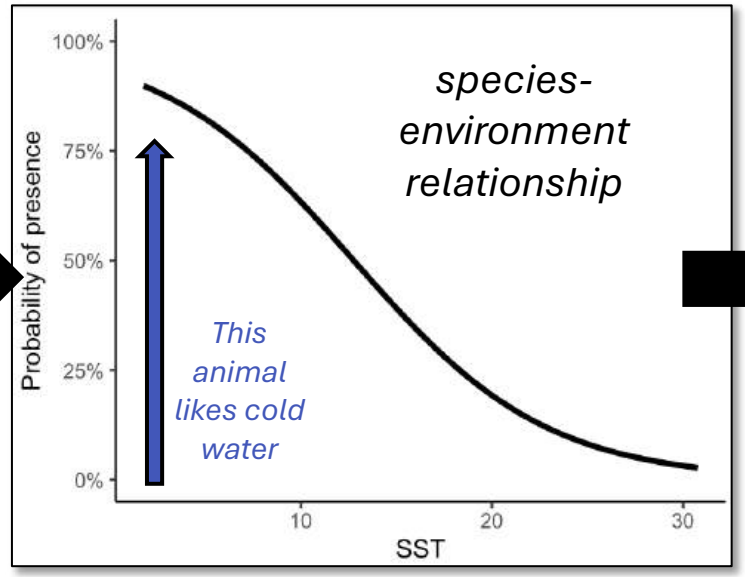


environment



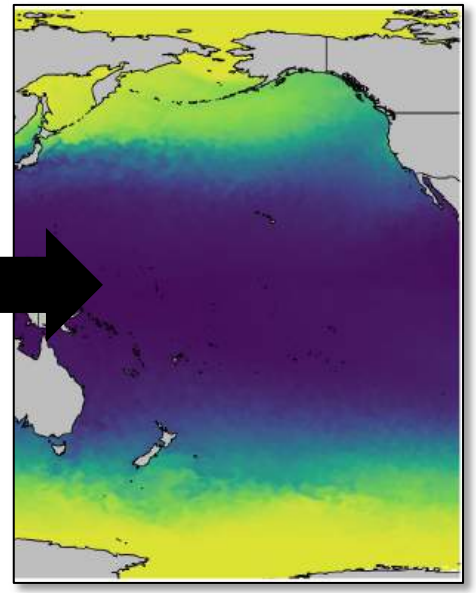
model (**GLM**)

explanation



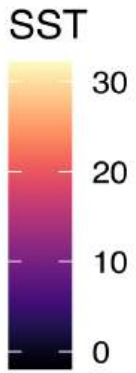
Explaining how animals respond to the environment

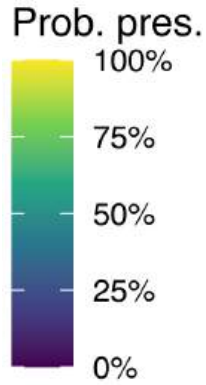
prediction



Predicting where animals are likely to be

Observations
- Absent (0s)
- Present (1s)





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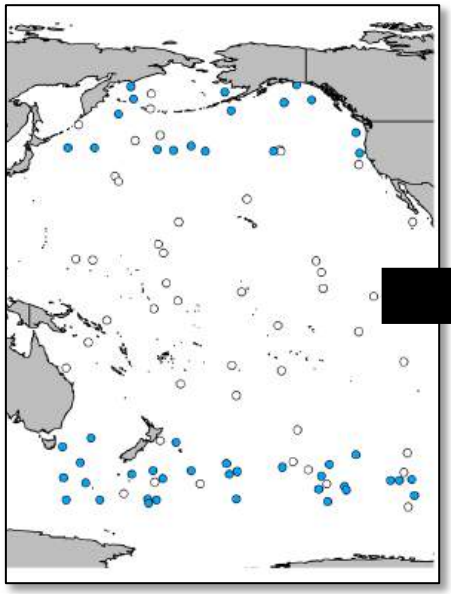
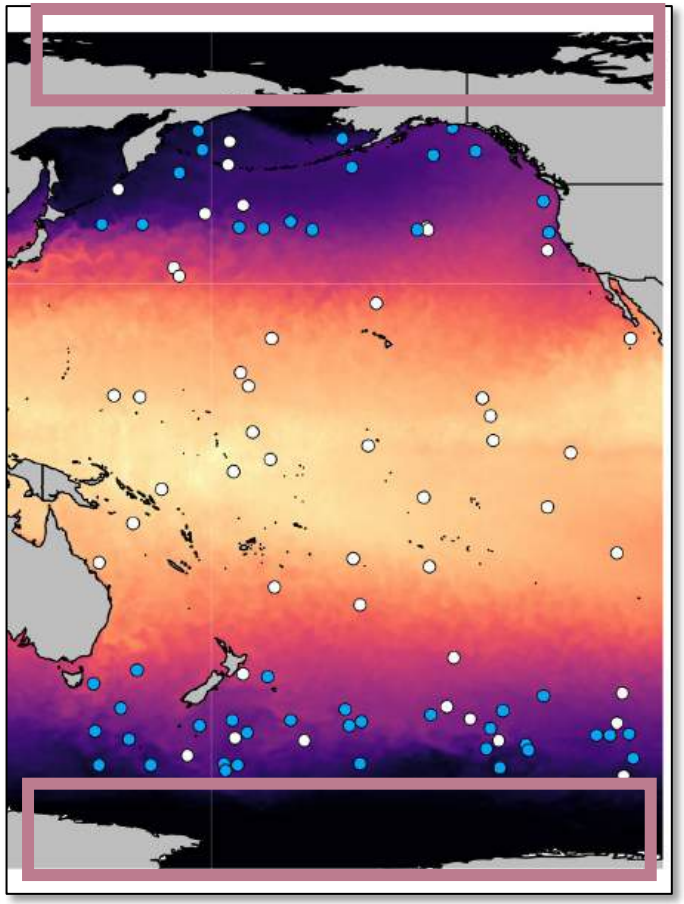
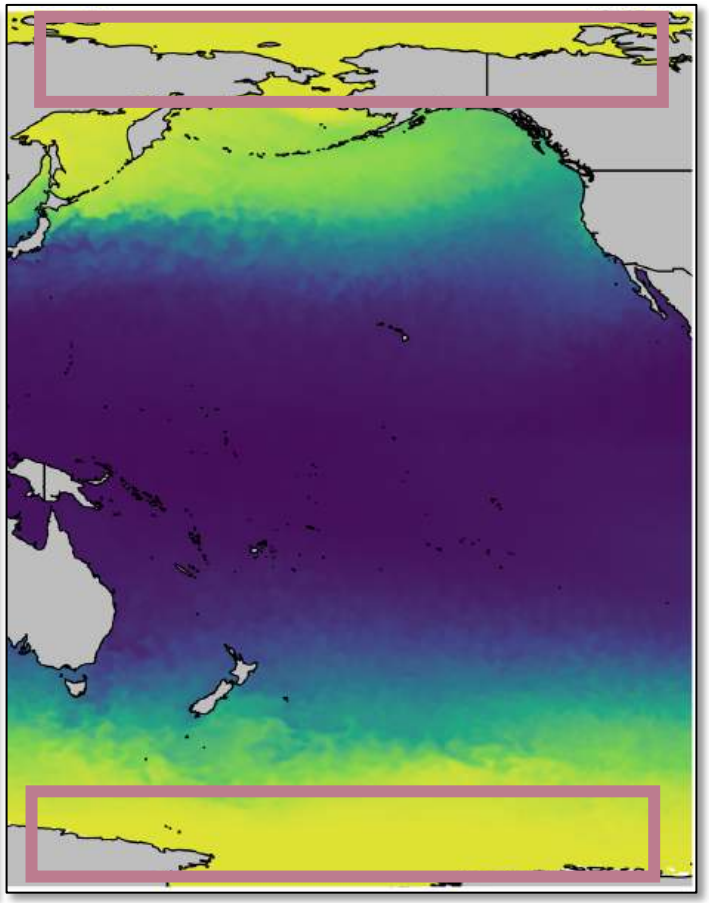
Purpose: 1) to **explain** how animals respond to the environment, 2) to **predict** animal distributions across space and time

animal distribution

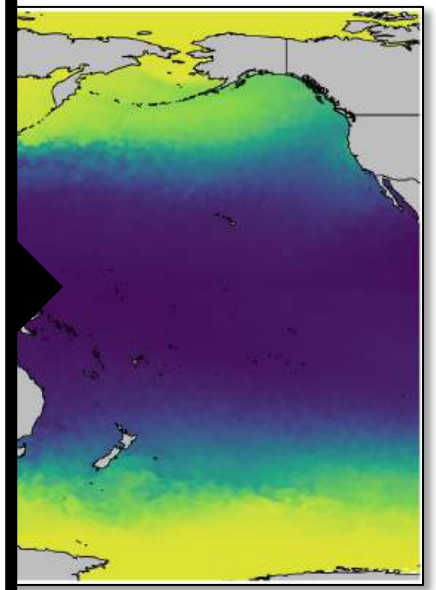


e





prediction

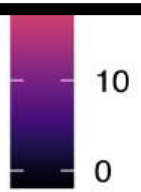


Predicting where
imals are likely to be

Prob. pres.
100%
75%
50%
25%
0%

Take caution when extrapolating SDMs

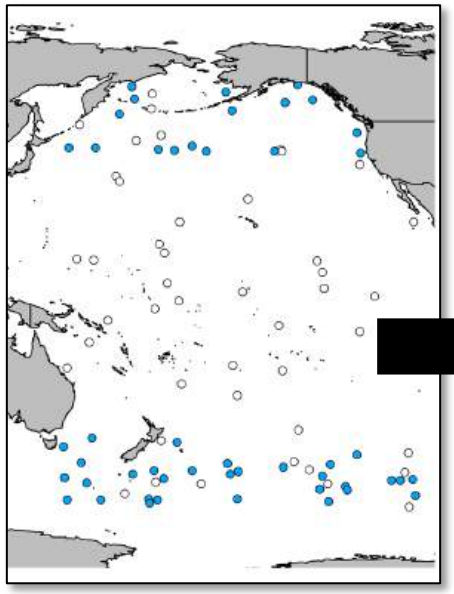
Observations
Absent (0s)
Present (1s)



Species Distribution Models (SDMs) in practice:
animal distribution ~ environment

animal distribution

Input data: logbook, observer data, landings, telemetry, survey, diet, *vessel distribution:* AIS, VMS



Response: probability of presence, abundance, density, size, yumminess, CPUE

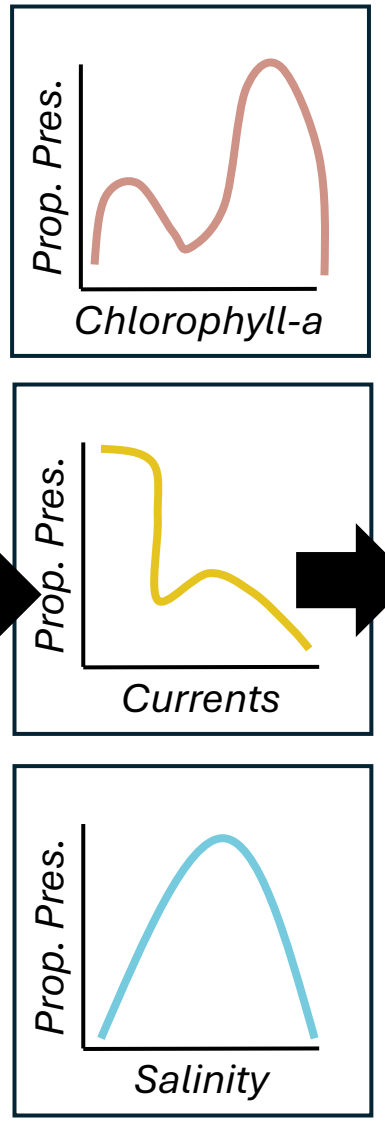
environment

SST
Chlorophyll-a
Sea surface height
Salinity
Currents
Bottom temperature
Dissolved oxygen

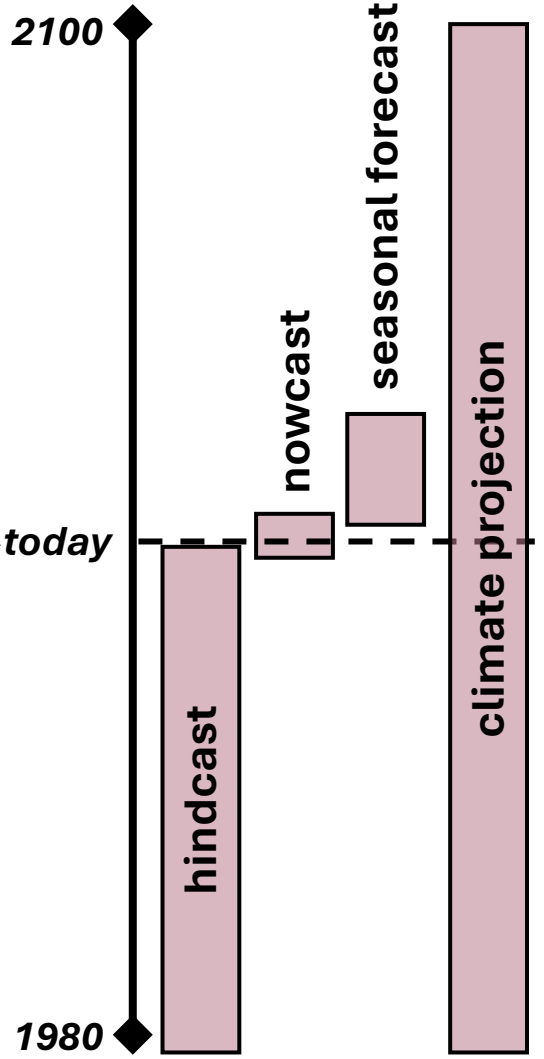
RF, GAM, BART, INLA, sdmTMB, VAST, maxent, GLMM, GAMM

More flexible model (**BRT**)

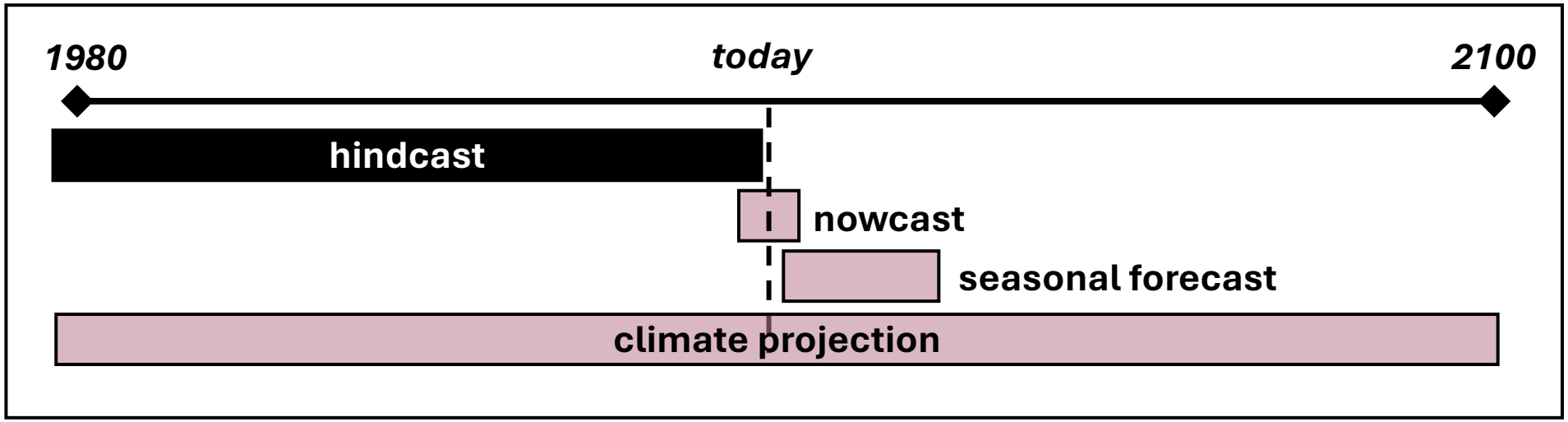
explanation



prediction



What happened in the past



Quantifying the ecological impacts of events (e.g. marine heatwaves, El Ninos, hypoxia, HABs, etc)

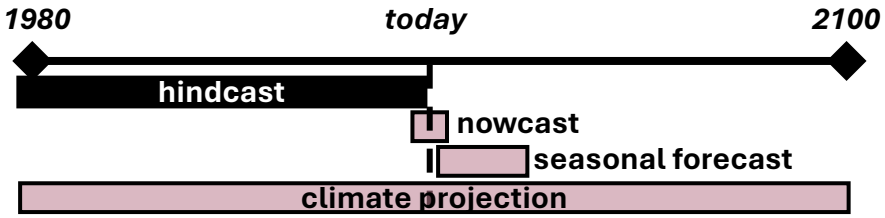
Quantifying the impact of the last ~40 years of long-term warming

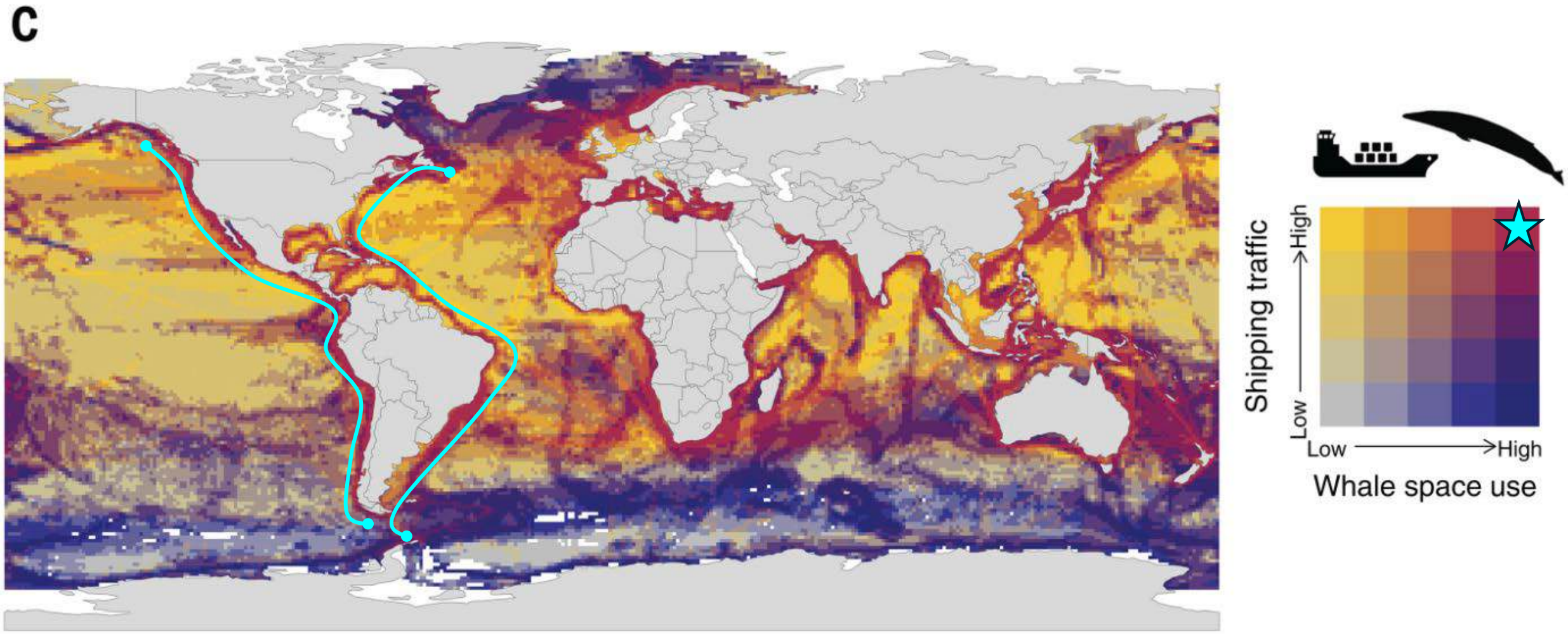
Retrospective analysis of management actions (e.g. fishing closures, move on rules, season delays)

SDMs can be used to:

Map human-wildlife conflict

Integrated SDM (multiple data types) ~ environment overlapped with AIS shipping activity



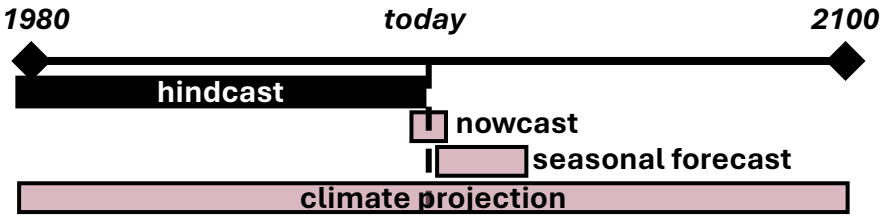


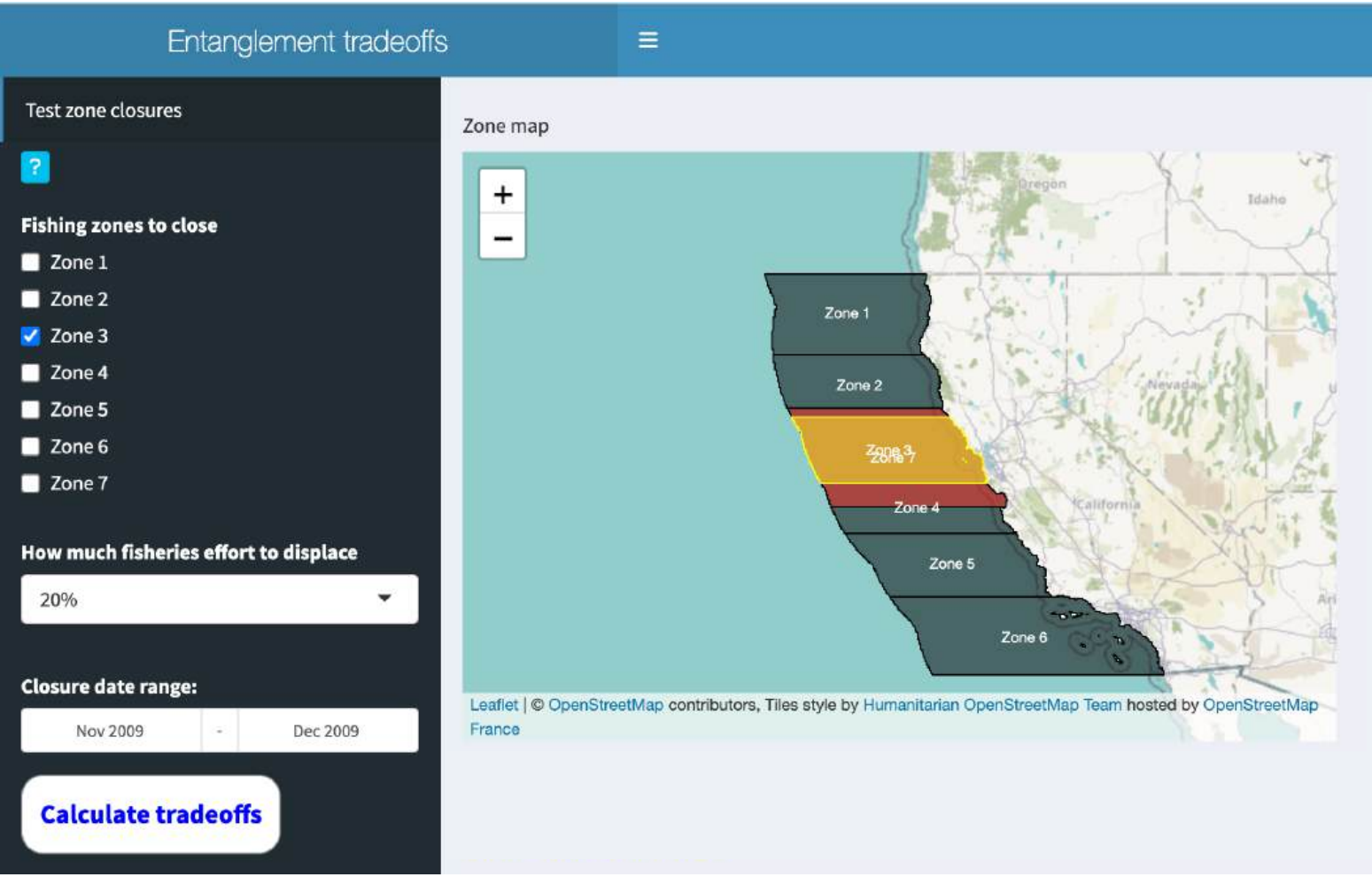
Nisi et al. Ship collision risk threatens whales across the world's oceans. 2024.

SDMs can be used to:

Retroactively examine the impacts of fisheries closures

Telemetry and survey-based whale presence/pseudo-absence ~ environment





Enact hypothetical fishing zone closures to examine trade-offs between **maintaining** fisheries revenue vs **avoiding** whale entanglement risk

https://www.integratedecosystemassessment.noaa.gov/regions/california-current/the-ecosystem-context-reducing-west-coast-whale-entanglements

SDMs can be used to:

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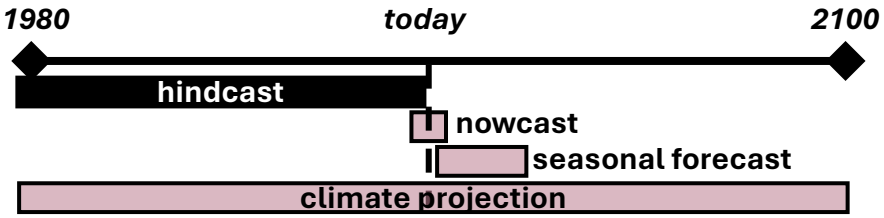
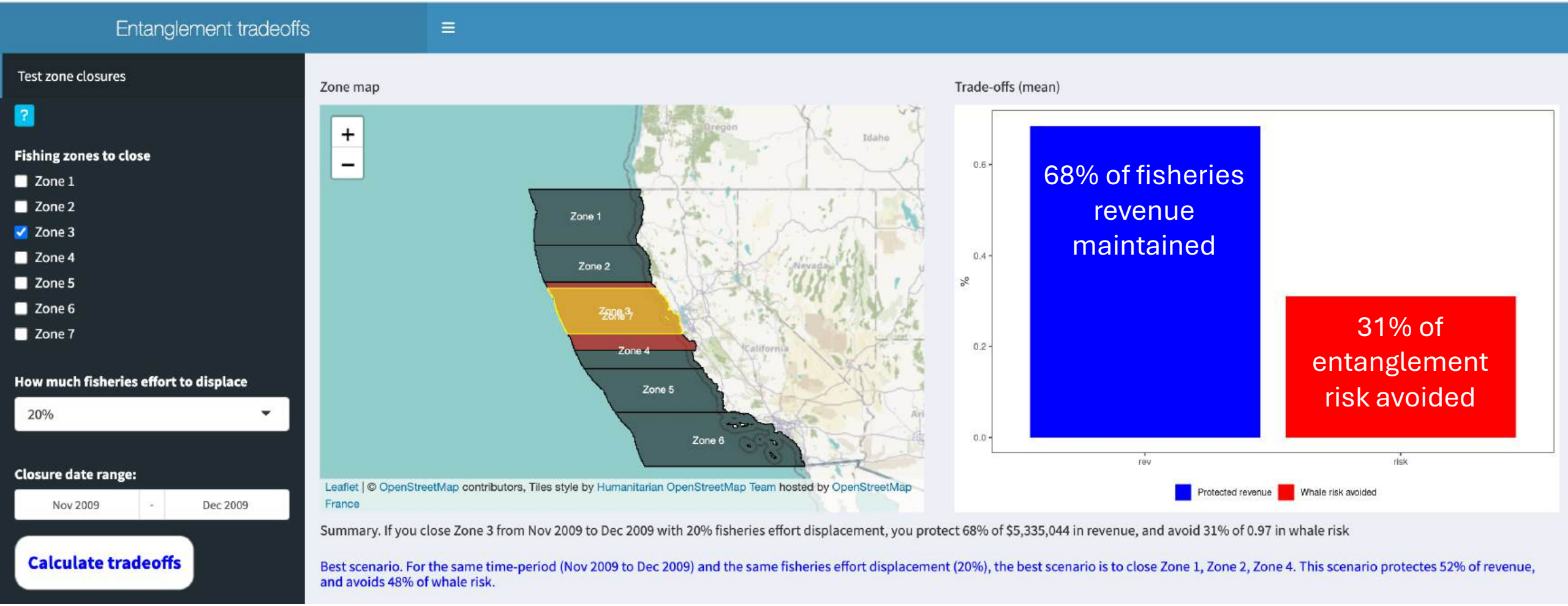


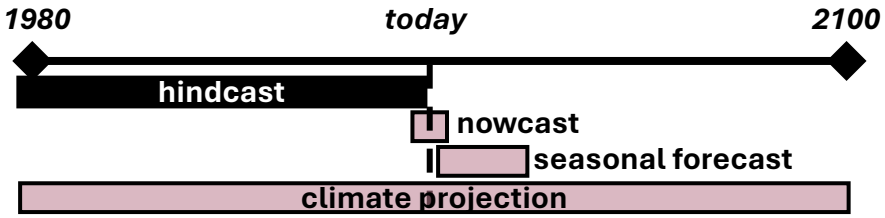


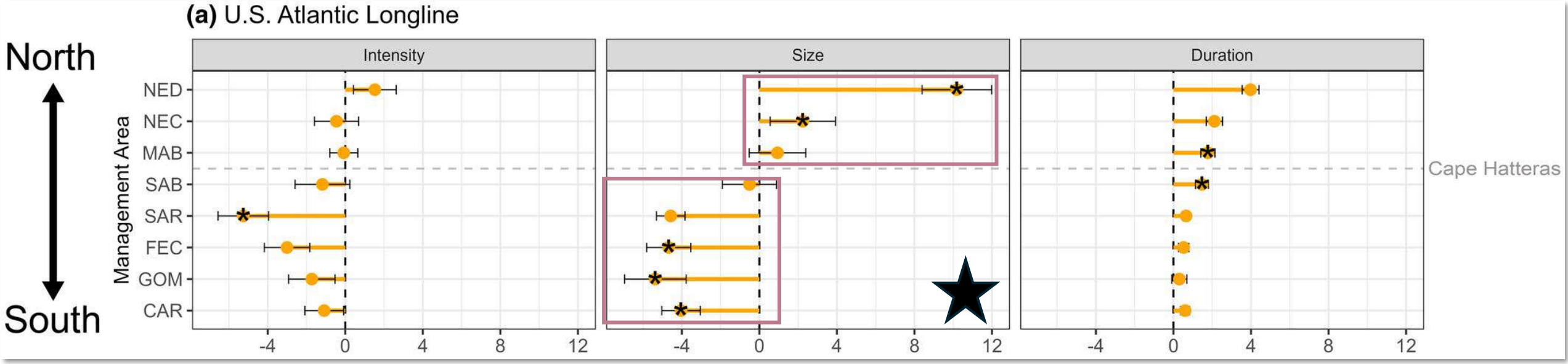
https://www.integratedecosystemassessment.noaa.gov/regions/california-current/the-ecosystem-context-reducing-west-coast-whale-entanglements

~~SDMs~~ VDMs can be used to:

Understand the impacts of marine heatwaves on pelagic fishing fleets

AIS-based fishing presence/pseudo-absence ~ environment





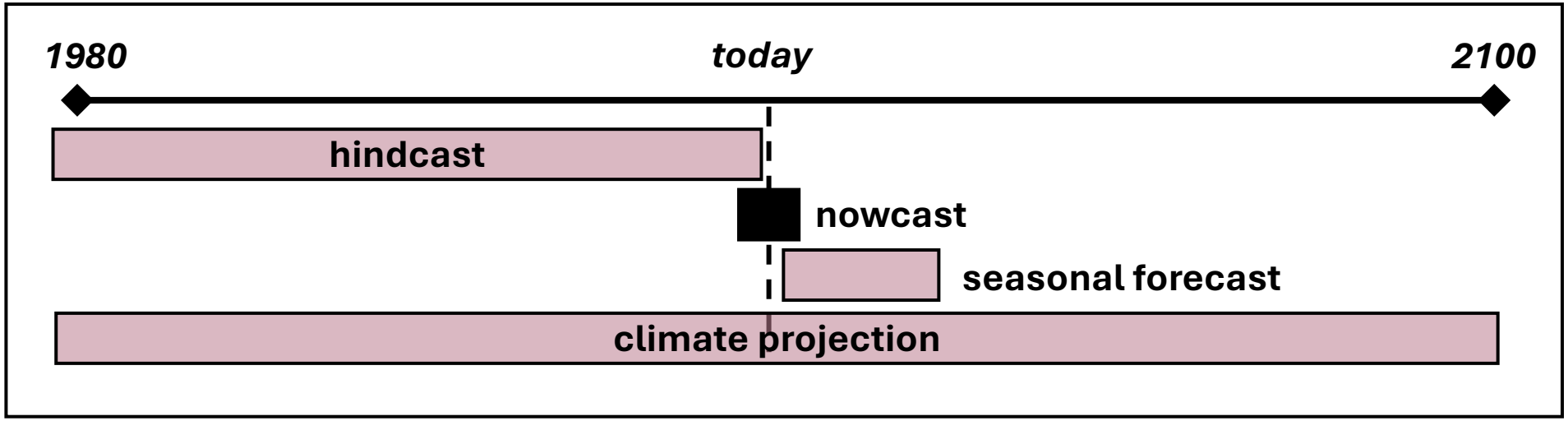
% change in core fishing ground area

Northern fleets gain fishing ground area during large MHWs, southern fleets lose fishing ground area

★ MHW size has more impact on fishing fleets than MHW intensity or duration

Farchadi et al. Marine heatwaves redistribute pelagic fishing fleets. 2024

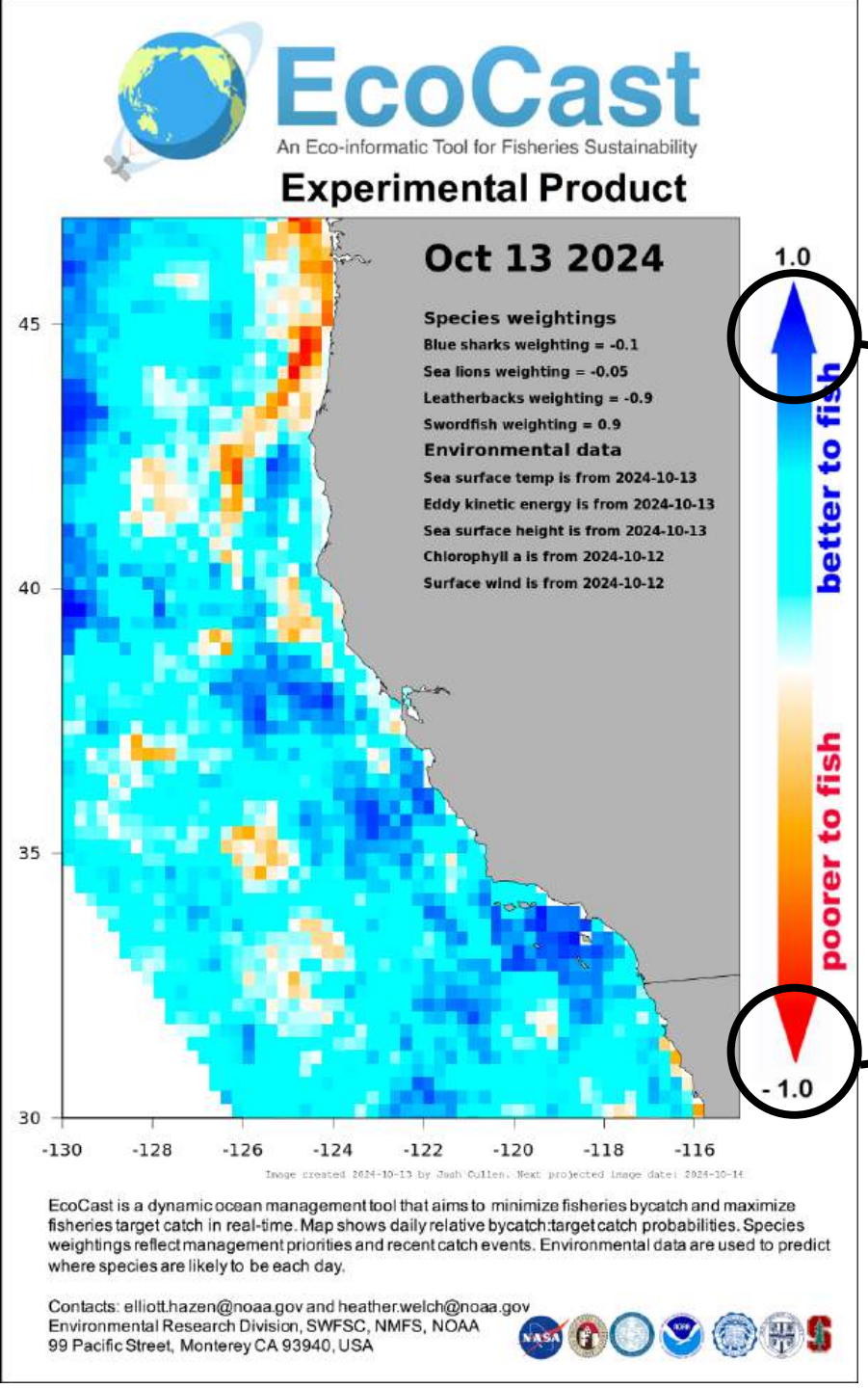
What's happening now



Real-time information on where vessels should fish

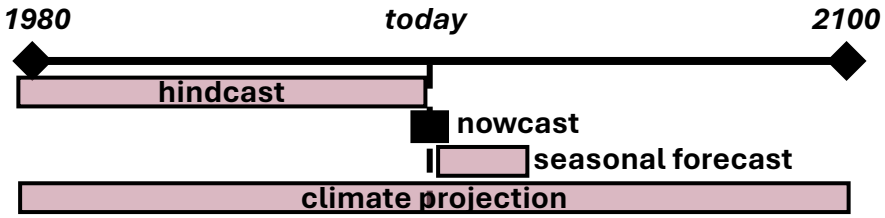
Real-time information to guide dynamic fisheries closures

Real-time information on ocean state (e.g. how is an ongoing marine heatwave affecting the ecosystem?)



More likely to encounter swordfish (target species) than bycatch species (leatherback, sea lion, blue shark)

More likely to encounter bycatch species (leatherback, sea lion, blue shark) than swordfish (target species)



SDMs can be used to:

Recommend waters that are better and poorer to fishing today based on the distributions of bycatch and target species

Telemetry and fisheries observed-based whale presence/pseudo-absence ~ environment

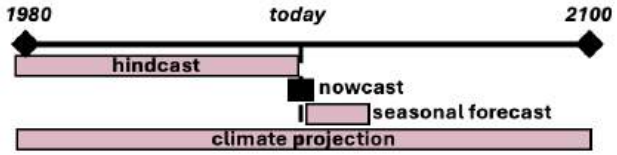
https://coastwatch.pfeg.noaa.gov/ecocast/explorer.html

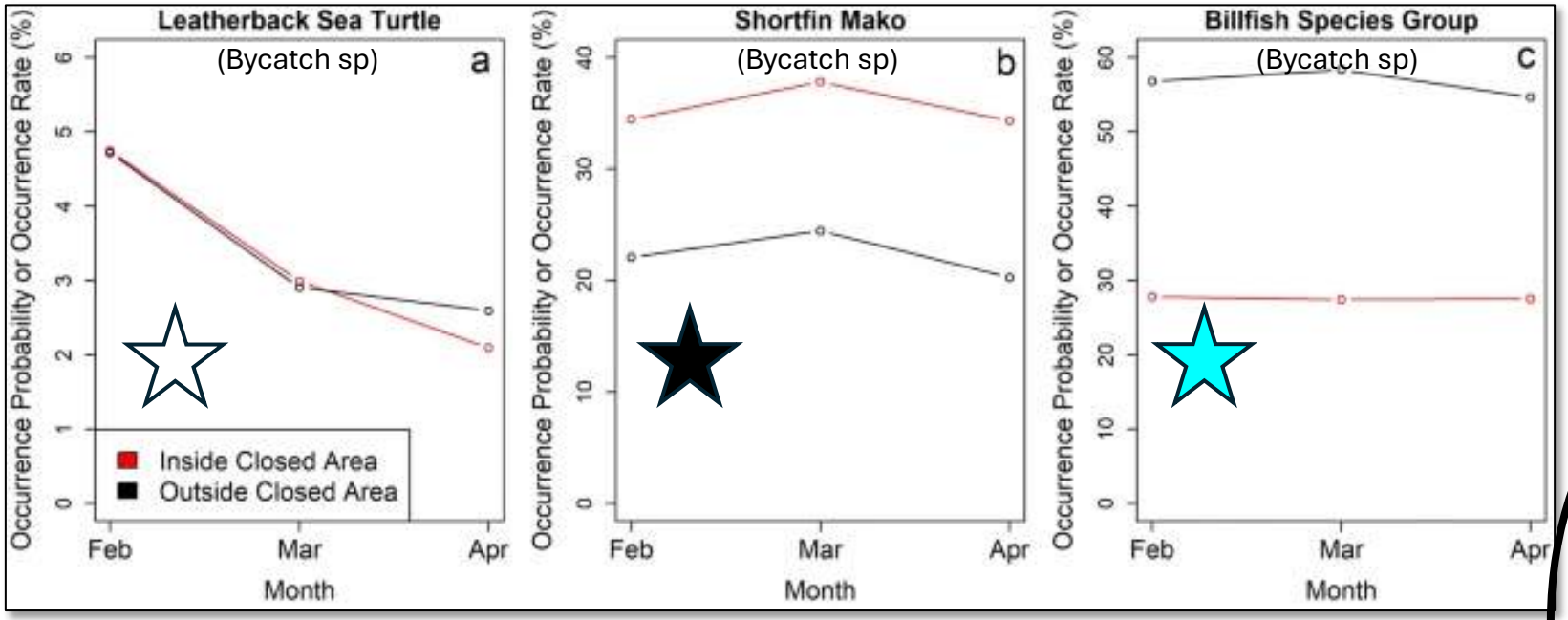
Hazen et al. A dynamic ocean management tool to reduce bycatch and support sustainable fisheries. 2018.

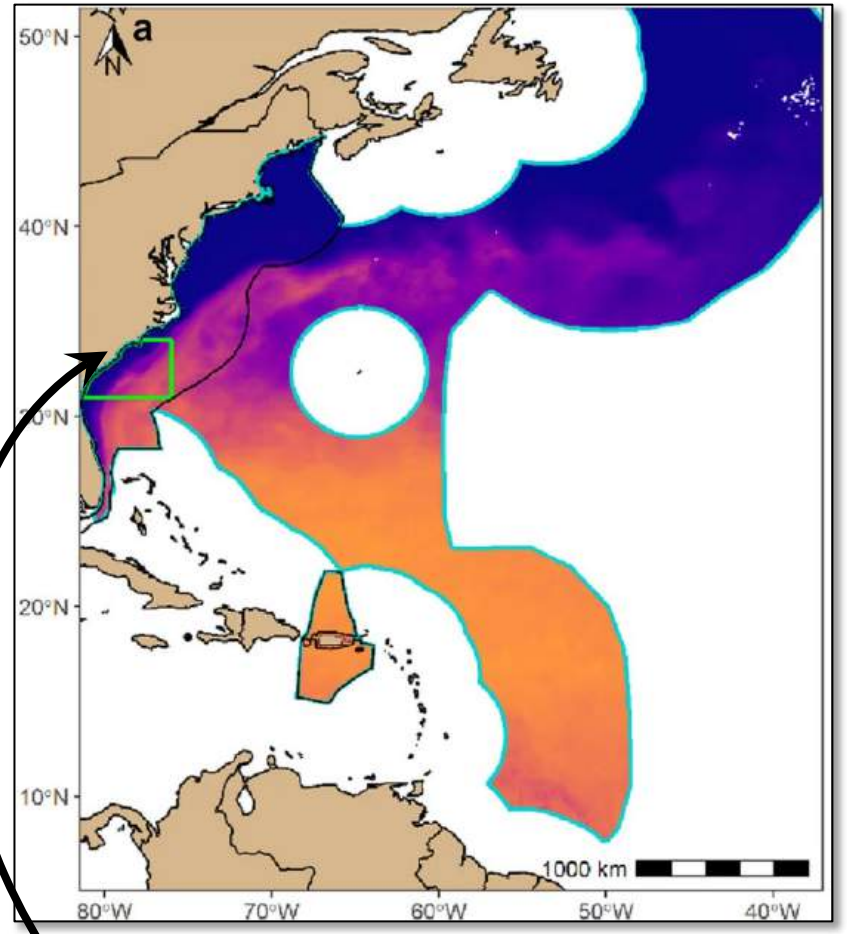
SDMs can be used to:

Assess the real-time performance of fisheries closures

Observer-based HMS ~ environment







The closure doesn't protect waters with high leatherback occurrence probability

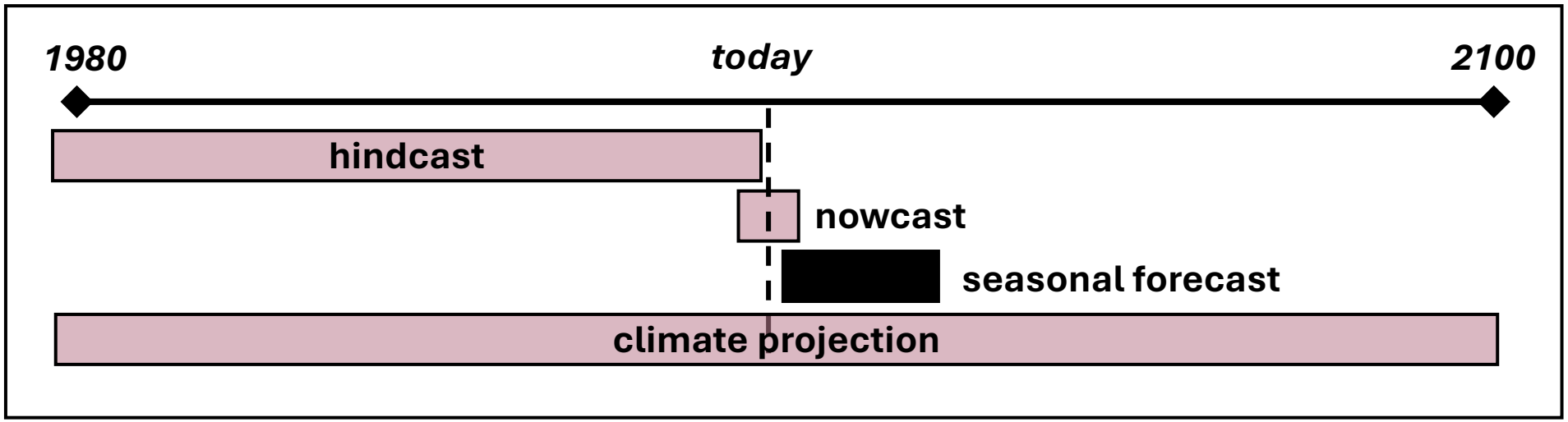
And it doesn't protect waters with high billfish occurrence probability

But it does protect waters with high mako occurrence probability

Charleston Bump closure

Crear et al. Highly migratory species predictive spatial modeling (PRiSM): an analytical framework for assessing the performance of spatial fisheries management. 2021.

What will happen 1-12 months from now



Advanced warning of potential fishing closures

Advanced warning of increased bycatch risk

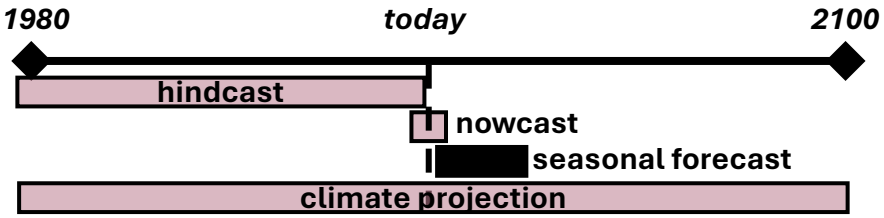
Advanced information on the locations of target species

SDMs can be used to:

Improve fishing economic efficiency

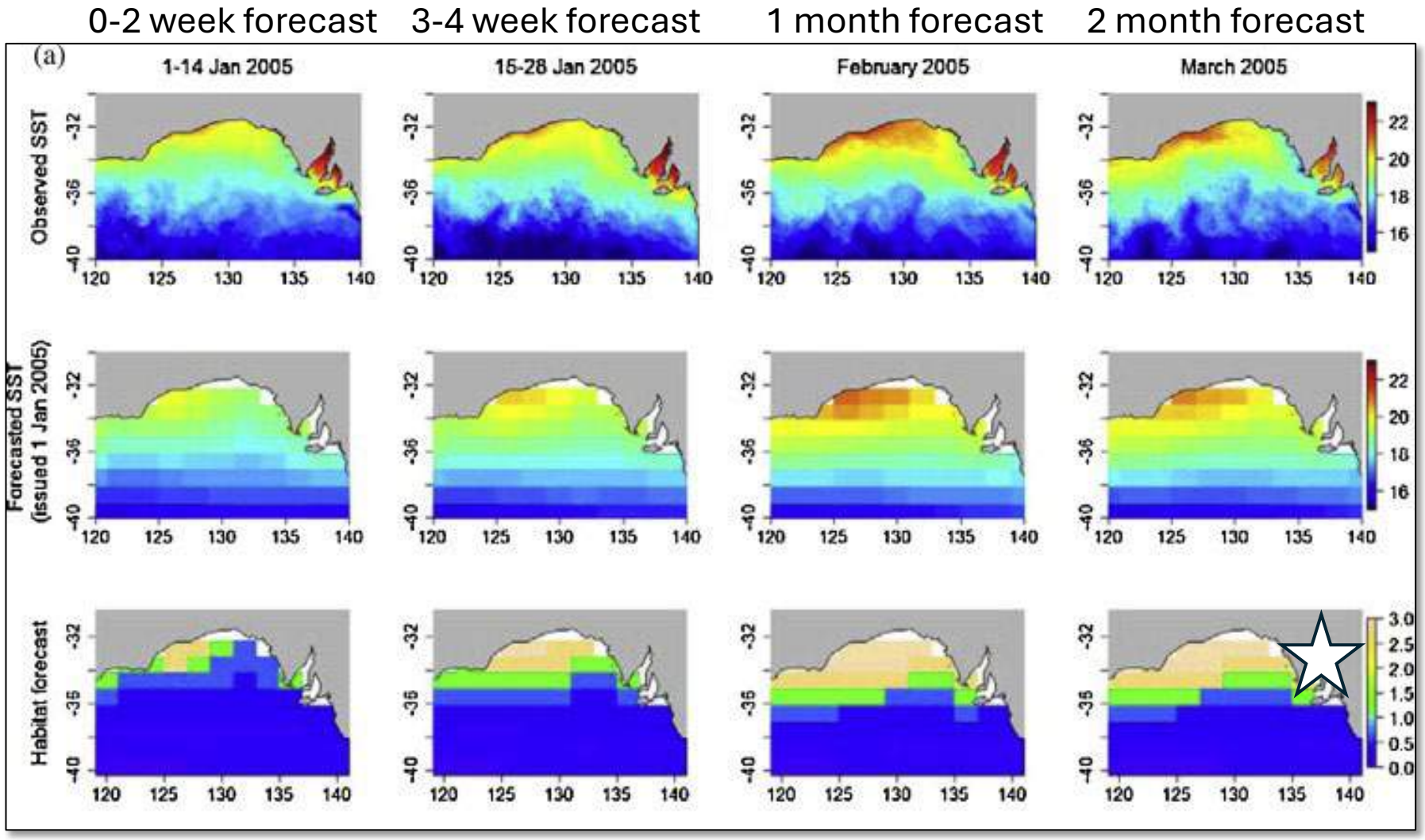
Telemetry-based bluefin tuna presence ~ temperature

Not a true SDM but an SDM-like framework



Bluefin are captured by purse-seine vessels and transferred to tow vessel for live transport to port. The speed at which tow vessels move (<5 km/h) precludes rapid movements to new areas, so vessels need to be pre-positioned in areas bluefin are abundant

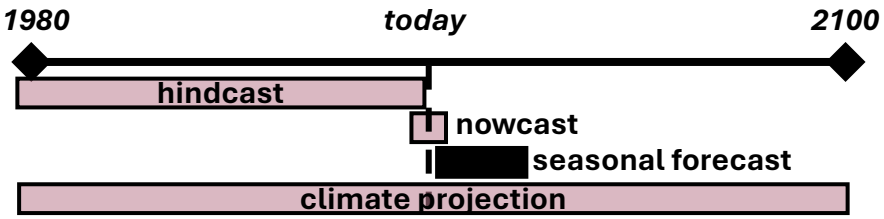
Forecasts of bluefin habitat had skill two months into the future

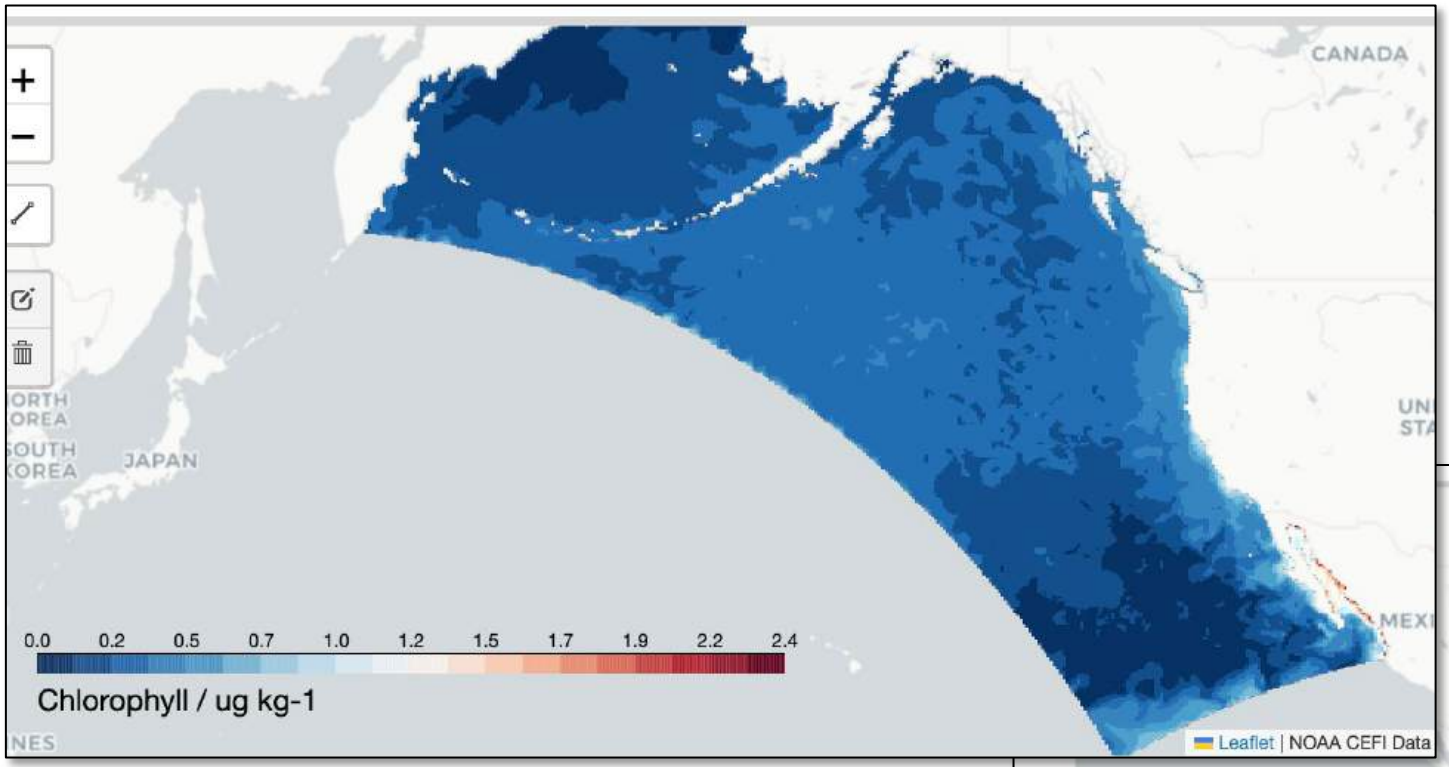


Eveson et al. Seasonal forecasting of tuna habitat in the Great Australian Bight. 2015

Pacific SDM forecasting capability is about to expand:

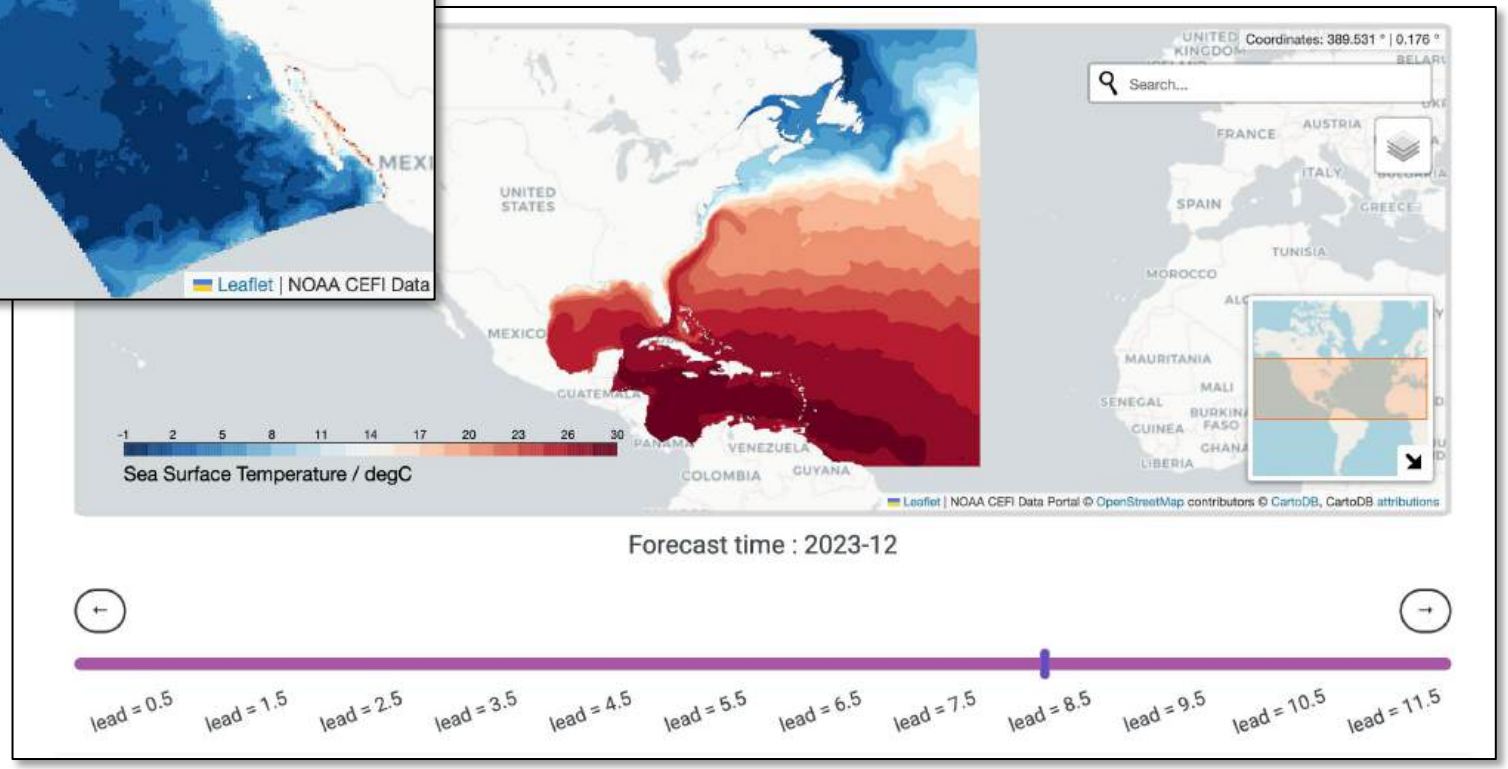
MOM6 - Changing Ecosystems and Fisheries Initiative (NOAA)





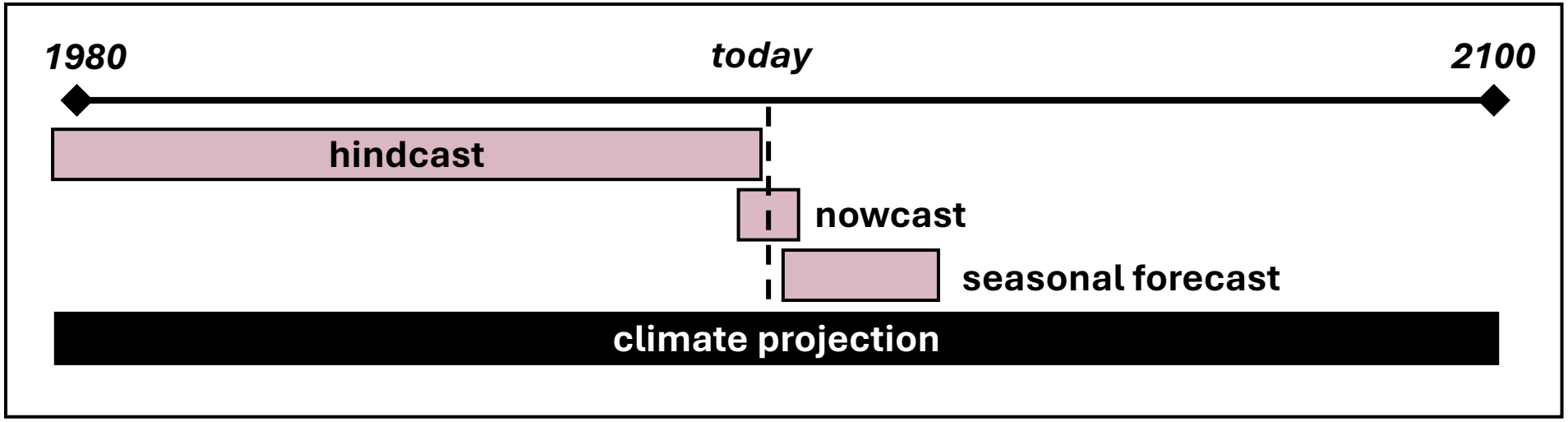
Pacific chlorophyll hindcast

Atlantic temperature 8.5 month forecast



https://psl.noaa.gov/cefi_portal/

What will happen decades from now



Designing / citing marine protected areas

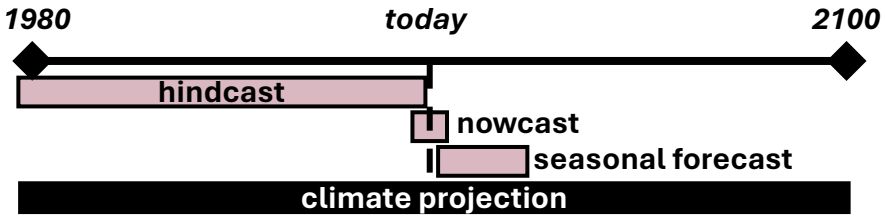
Designing / citing offshore wind energy areas, oil and gas rigs

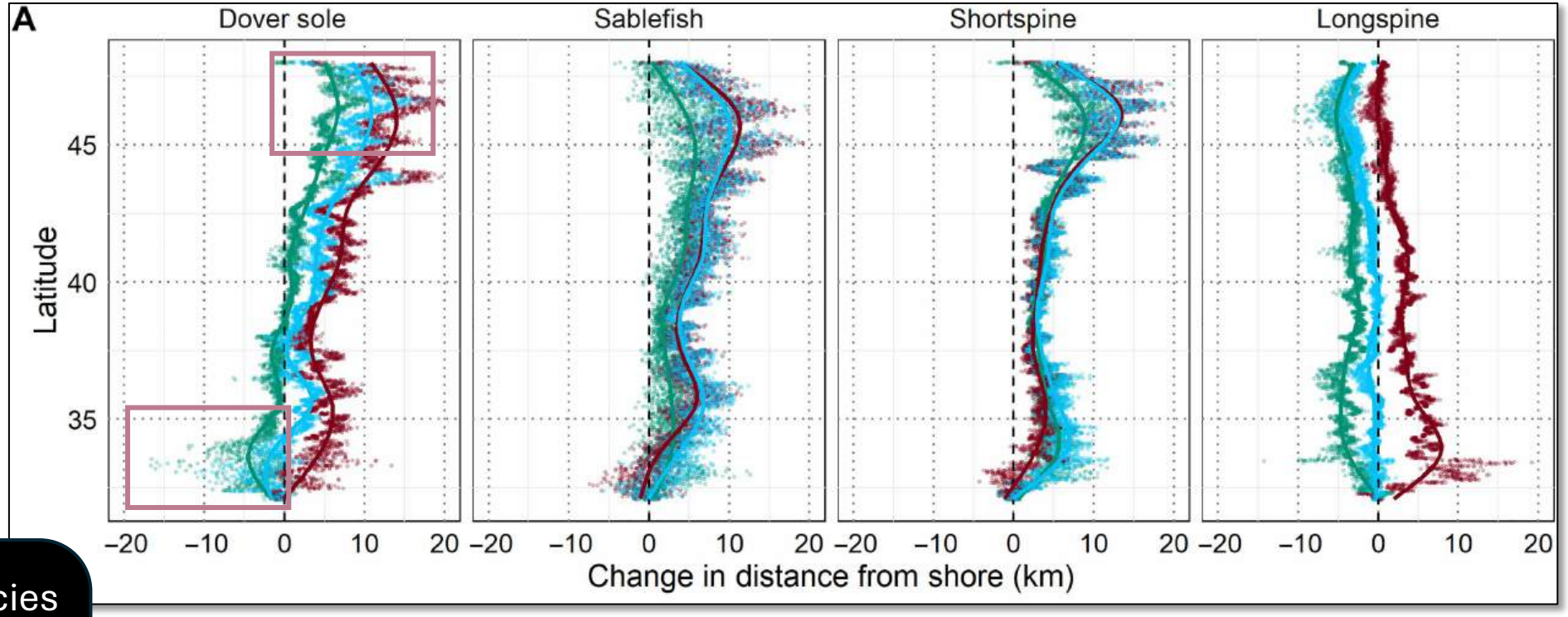
Anticipating transboundary shifts of target species

SDMs can be used to:

Identify future unequal resource access across fishing communities

Bottom trawl survey CPUE ~ environment





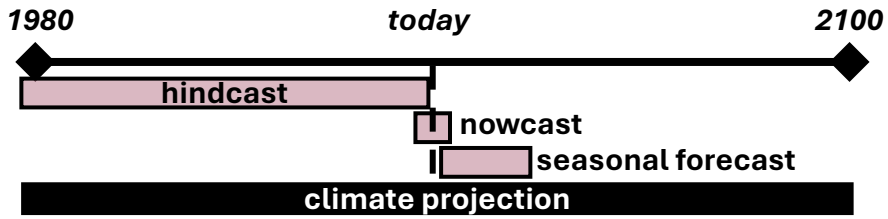
Southern target species will shift offshore by the end of the century, requiring southern fleets to travel further

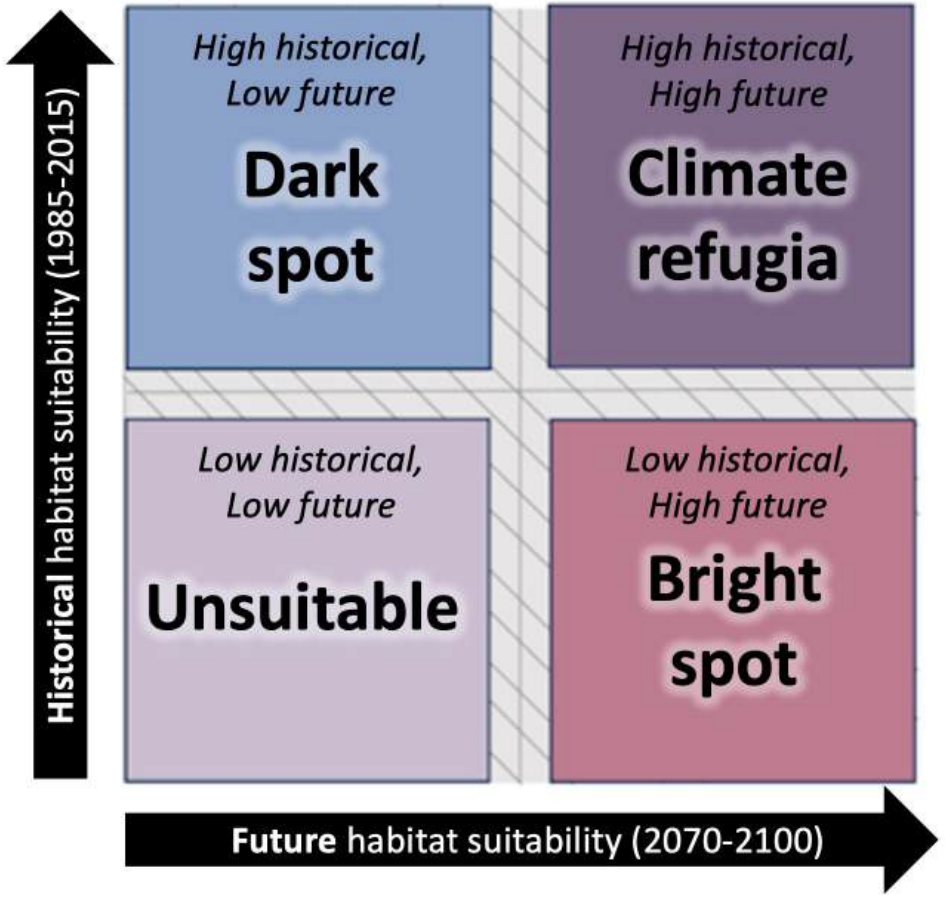
Liu et al. Species redistribution creates unequal outcomes for multispecies fisheries under projected climate change. 2023

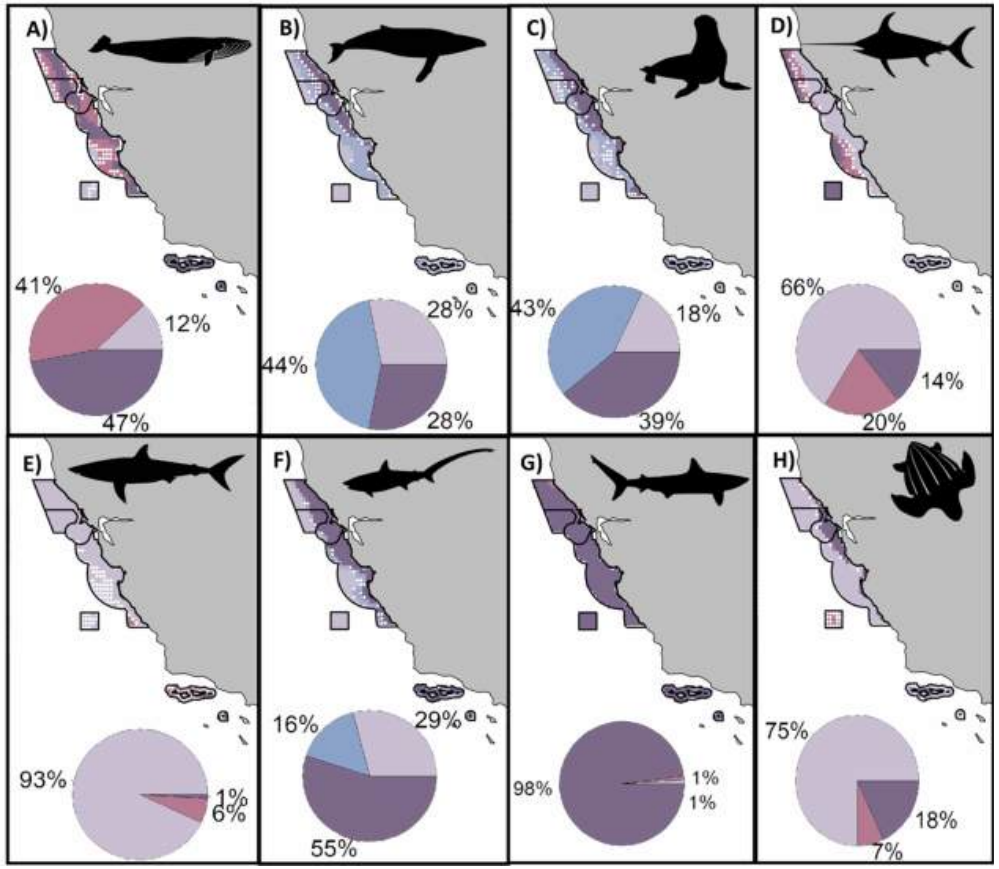
SDMs can be used to:

Evaluate the climate-readiness of Marine Protected Areas

Observer and telemetry based SDMs ~ environment



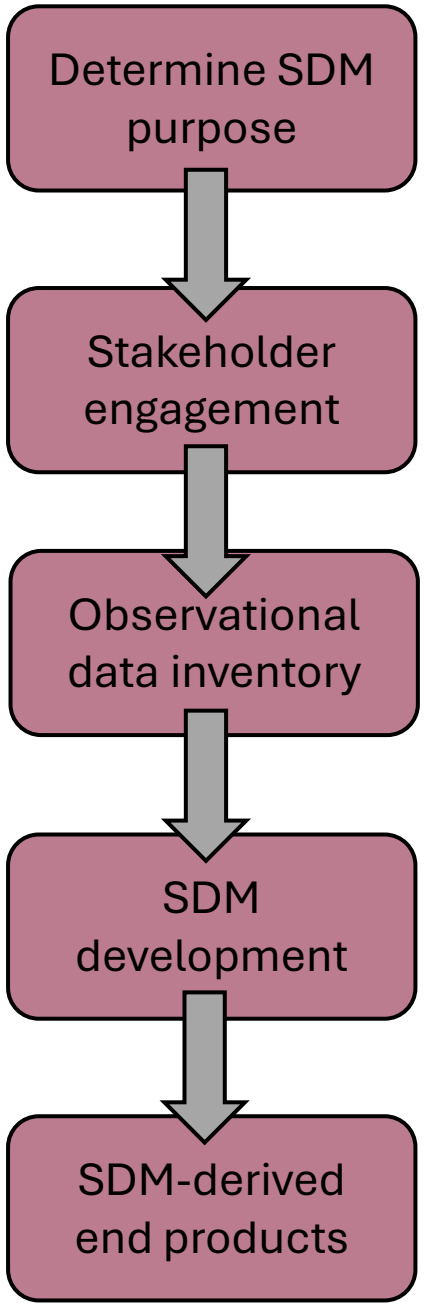




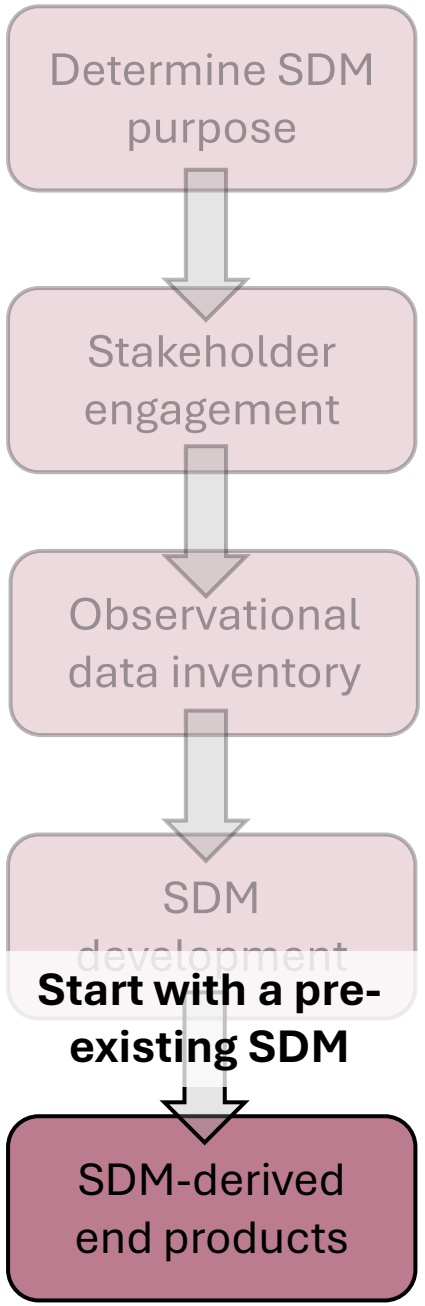
➔ Nearly 100% of CA NMS area is refugia for blue shark **(G)**

Lezama-Ochoa et al. Identifying climate refugia and bright spots for highly mobile species. 2025

SDM pipeline



SDM pipeline



SDM pipeline

Determine SDM purpose

Stakeholder engagement

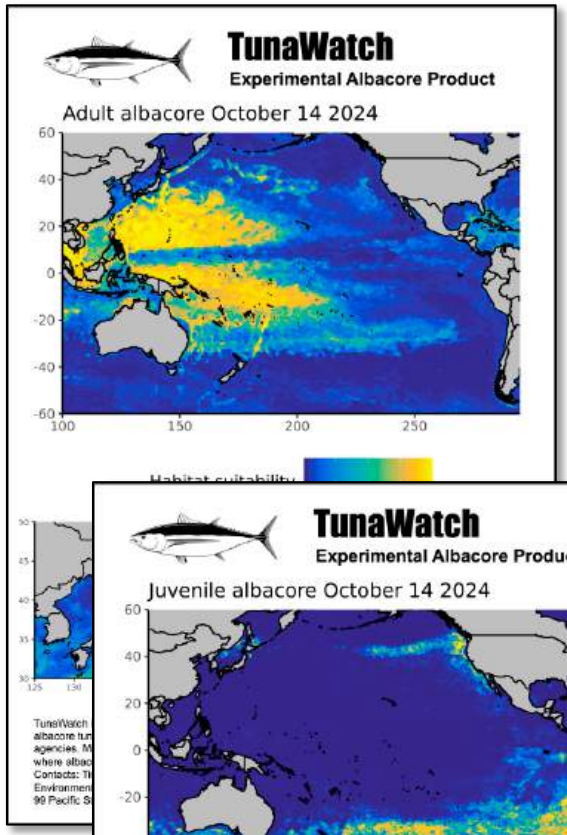
Observational data inventory

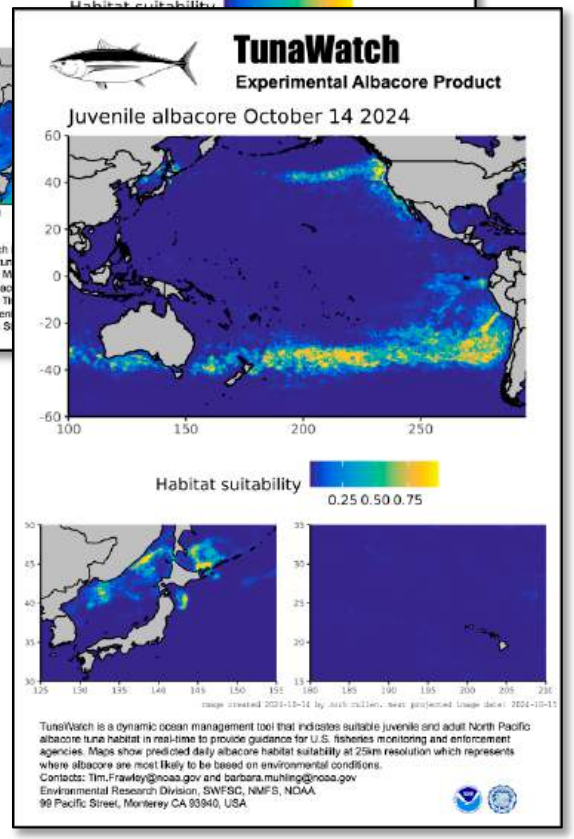
SDM development

Start with a pre-existing SDM

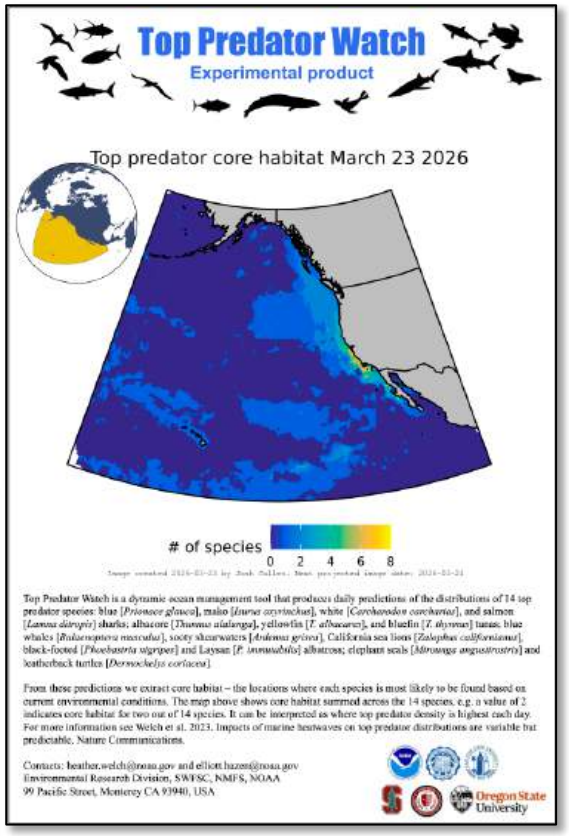
SDM-derived end products

TunaWatch[1]

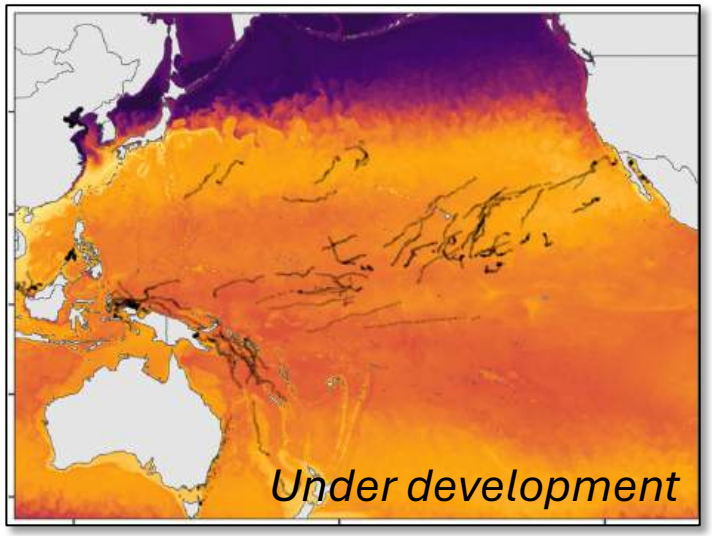




Top Predator Watch[2]



Western Pacific Leatherback SDM[3]



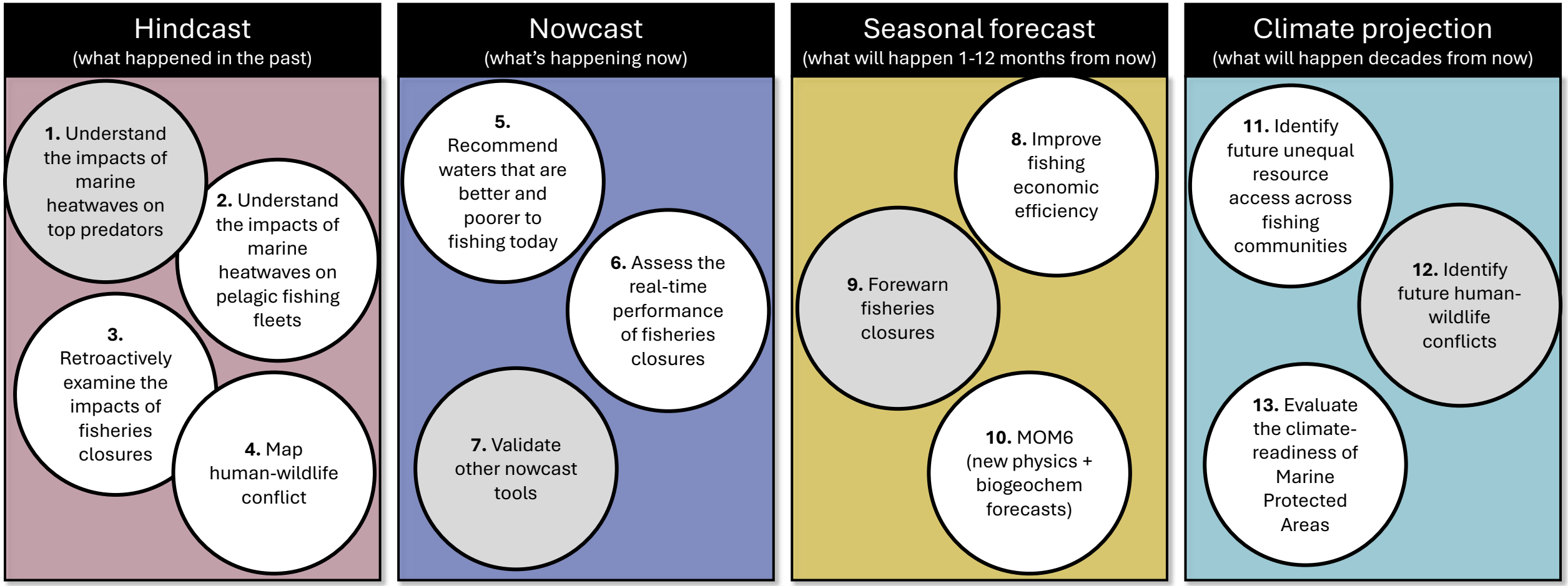
1. URL: https://oceanview.pfeg.noaa.gov/tunawatch/ ; paper: Frawley et al. Dynamic human, oceanographic, and ecological factors mediate transboundary fishery overlap across the Pacific high seas. 2023.

2. URL: https://oceanview.pfeg.noaa.gov/top-predator-watch/ ; paper: Welch et al. Impacts of marine heatwaves on top predator distributions are variable but predictable. 2023.

3. Cullen et al. Integrated species distribution models improve predictions of critically endangered leatherback turtles. In prep.

Point of contact for 1-3: josh.cullen@noaa.gov

SDM case studies presented here



1. Welch et al. Impacts of marine heatwaves on top predator distributions are variable but predictable. 2023
2. Farchadi et al. Marine heatwaves redistribute pelagic fishing fleets. 2024
3. https://www.integratedecosystemassessment.noaa.gov/regions/california-current/the-ecosystem-context-reducing-west-coast-whale-entanglements
4. Nisi et al. Ship collision risk threatens whales across the world's oceans. 2024.
5. Hazen et al. A dynamic ocean management tool to reduce bycatch and support sustainable fisheries. 2018.
6. Crear et al. Highly migratory species predictive spatial modeling (PRiSM): an analytical framework for assessing the performance of spatial fisheries management. 2021.
7. Welch et al. Fishing fleets as ecosystem sentinels. 2025
8. Eveson et al. Seasonal forecasting of tuna habitat in the Great Australian Bight. 2015
9. Brodie et al. Ecological forecasts for marine resource management during climate extremes. 2023
10. https://psl.noaa.gov/cefi_portal/
11. Liu et al. Species redistribution creates unequal outcomes for multispecies fisheries under projected climate change. 2023
12. Lezama-Ochoa et al. Divergent responses of highly migratory species to climate change in the California Current. 2024
13. Lezama-Ochoa et al. Identifying climate refugia and bright spots for highly mobile species. 2025

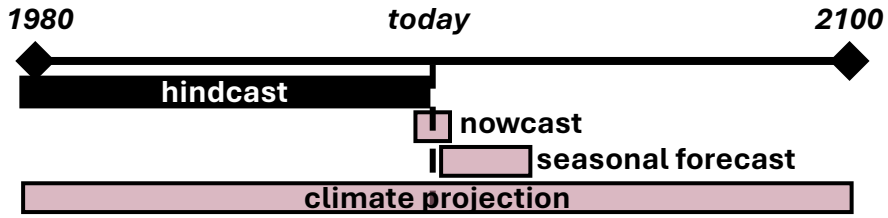
Grey case-studies cut for time

Case studies cut for time

SDMs can be used to:

Understand the impacts of marine heatwaves on top predators

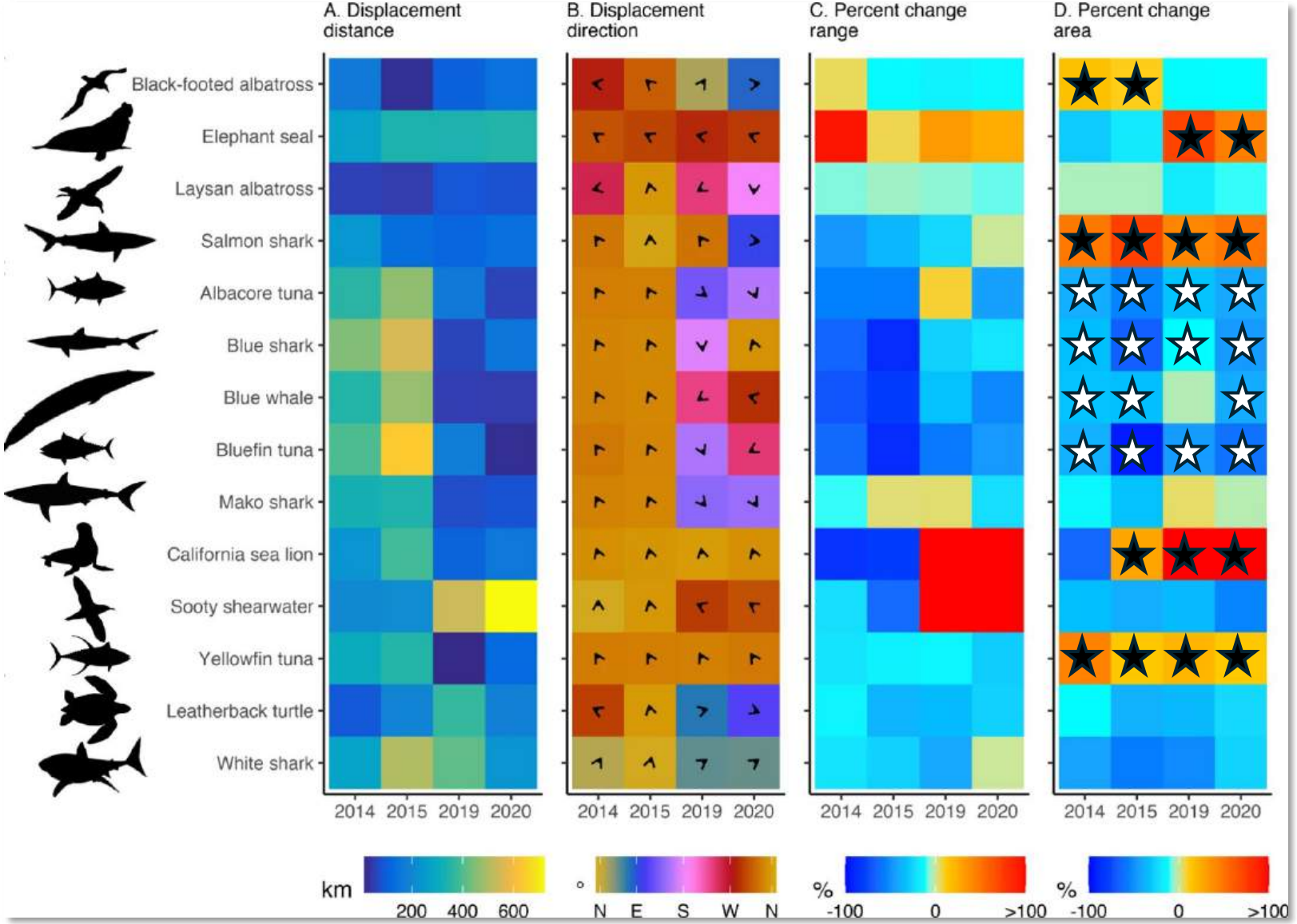
Telemetry-based predator presence/pseudo-absence ~ environment



☆ Many species lose habitat during MHWs

★ But some species gain habitat during MHWs

Species impacts vary within and among marine heatwaves

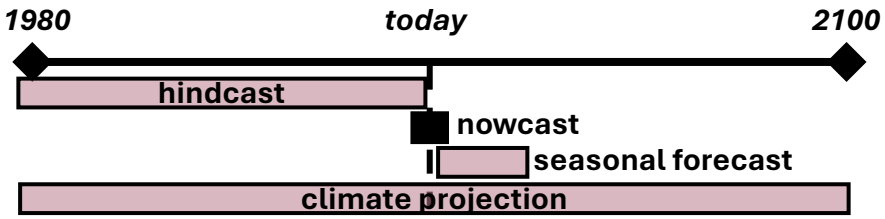


Welch et al. Impacts of marine heatwaves on top predator distributions are variable but predictable. 2023

SDMs can be used to:

Validate other nowcast tools

Telemetry-based albacore and bluefin presence/pseudo absence ~ environment



☆ The fishery and both tunas shifted north during The Blob MHW (2014-2016)

★ Looking only at SST, northward shifts would be expected during MHWs in 2019 and 2023

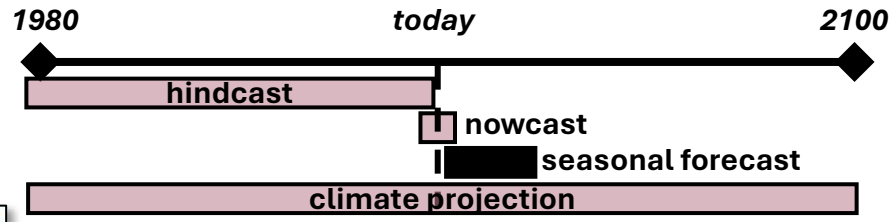
MHWs occur frequently, only some have pronounced ecological consequences

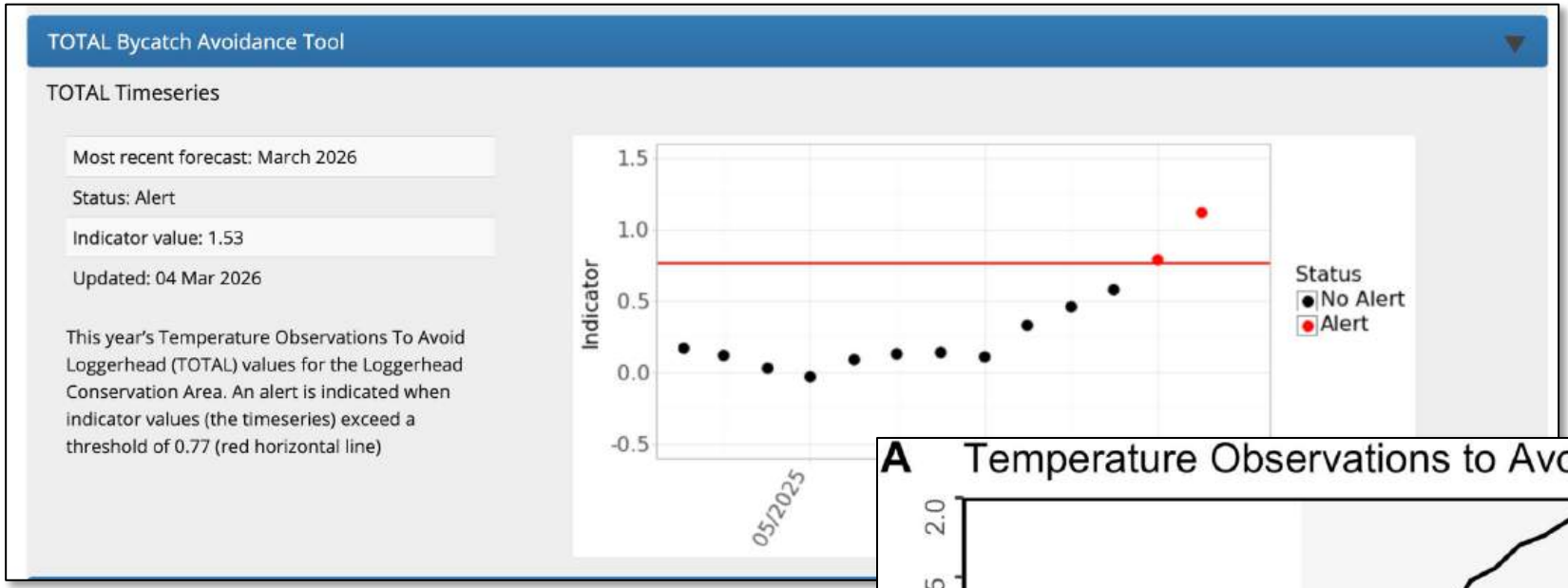
Welch et al. Fishing fleets as ecosystem sentinels. 2025

SDMs can be used to:

Forewarn fisheries closures

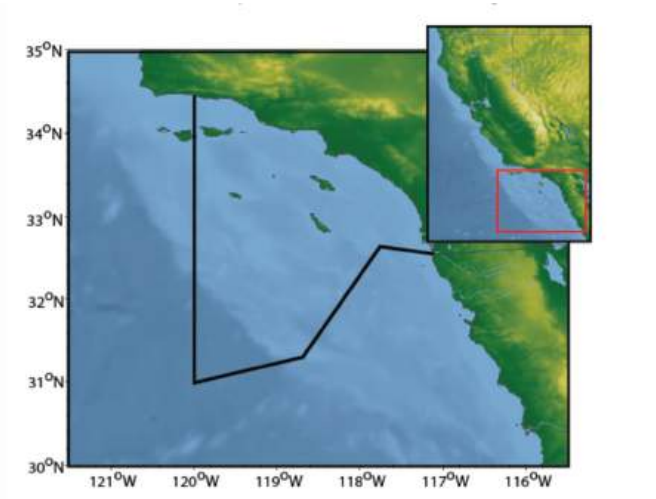
Multi-data sourced loggerhead presences ~ temperature

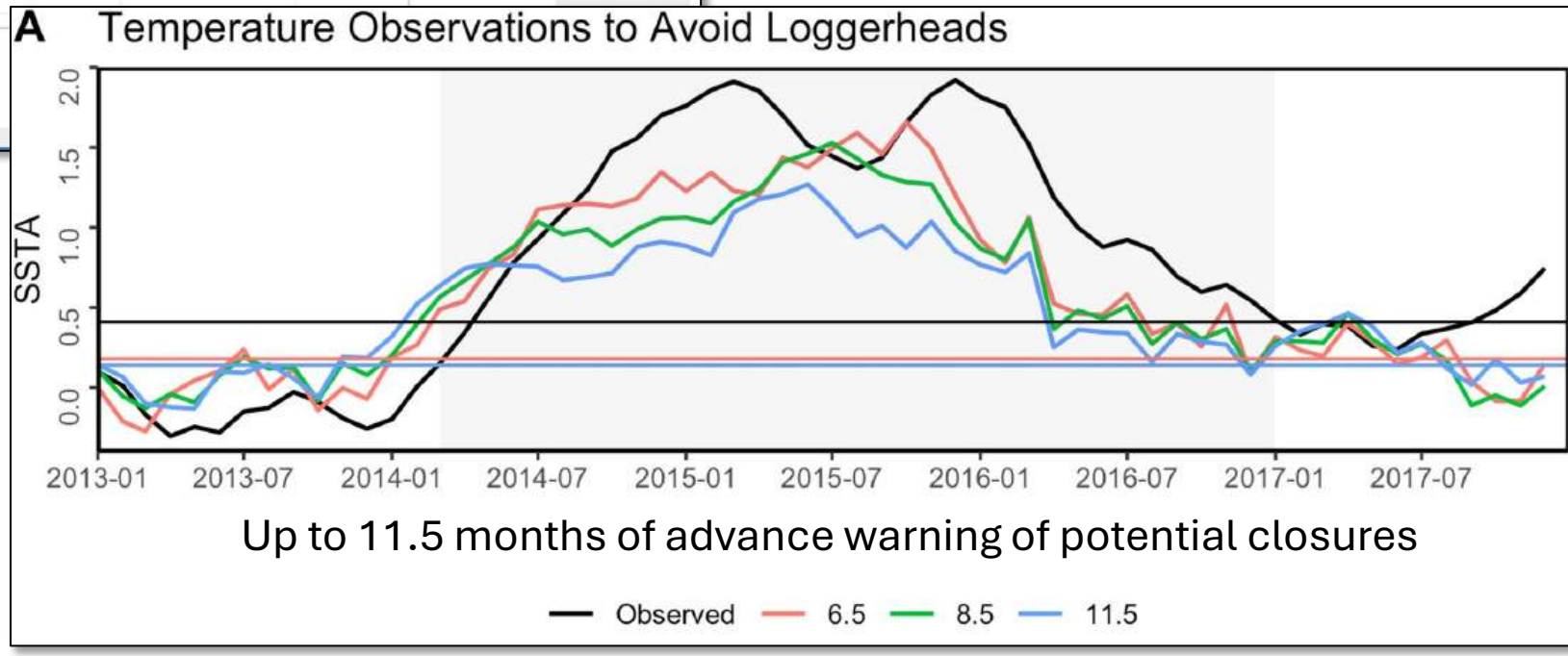




Not a true SDM but an SDM-like framework

https://coastwatch.pfeg.noaa.gov/loggerheads/loggerhead_background.html



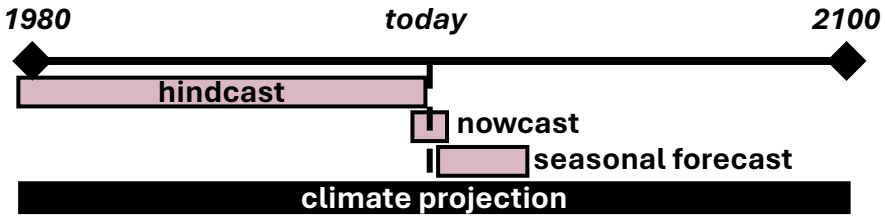


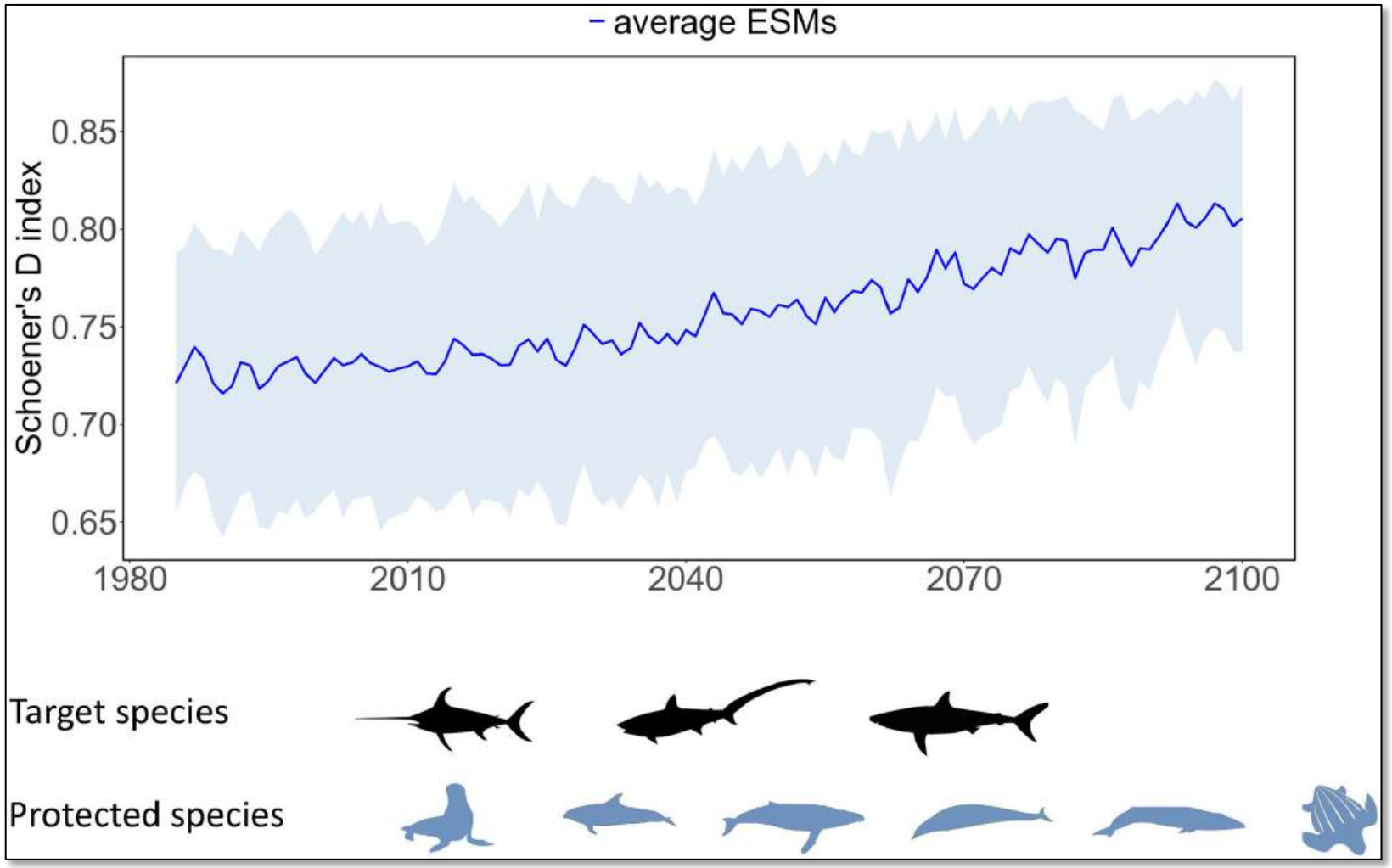
Brodie et al. Ecological forecasts for marine resource management during climate extremes. 2023

SDMs can be used to:

Identify future human-wildlife conflicts

Observer and telemetry based SDMs ~ environment





More overlap between fisheries target species and protected species at the end of the century -> trade-offs between fishing and conservation steepen

Lezama-Ochoa et al. Divergent responses of highly migratory species to climate change in the California Current. 2024