Exploring Blue Whale Large-scale Ecology in the Northeast Pacific

Daniel Palacios[1,2],
Bruce Mate[3], Helen Bailey[1], Elliott Hazen[1,2],
Ladd Irvine[3], Steven Bograd[1], Dan Costa[4]

[1]NOAA/SWFSC, Pacific Grove, CA & [2]JIMAR, Univ. Hawaii
[3]Marine Mammal Inst., Oregon State University, Newport, OR
[4]Long Marine Laboratory, UC Santa Cruz, Santa Cruz, CA

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Considerations

- BWs depend exclusively on dense krill aggregations for food and must forage constantly
- BW large-scale distribution must be dictated by regions where krill patches reliably develop and can be exploited
- A simple ‘upwelling-diatoms-krill’ food chain creates these conditions. This pathway has a predictable large-scale environmental mechanism.
- BWs should focus their ARS behavior in these regions and therefore large-scale blue whale movement behavior should be predictable on the basis of environment.

Mechanisms of a coastal upwelling ecosystem

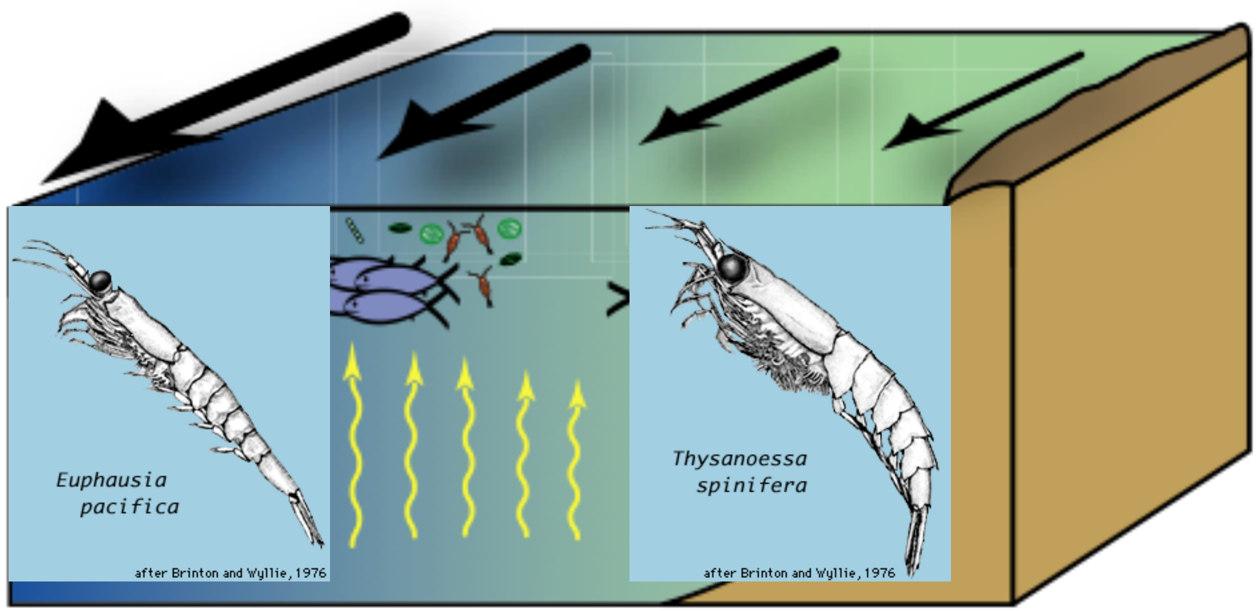
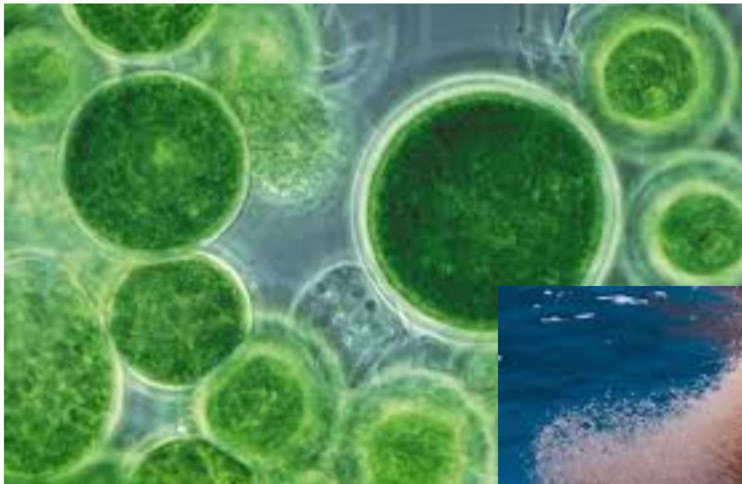


Fig. 1. Conceptual diagram displaying the hypothesized relationship between wind-forced upwelling and the pelagic ecosystem. Alongshore, equatorward wind stress results in coastal upwelling (red arrow), supporting production of large phytoplankters and zooplankters. Between the coast and the wind-stress maximum, cyclonic wind-stress curl results in curl-driven upwelling (yellow arrows) and production of smaller plankters. Anchovy (gray fish symbols) prey on large plankters, whereas sardine (blue fish symbols) specialize on small plankters. Black arrows represent winds at the ocean surface, and their widths are representative of wind magnitude.

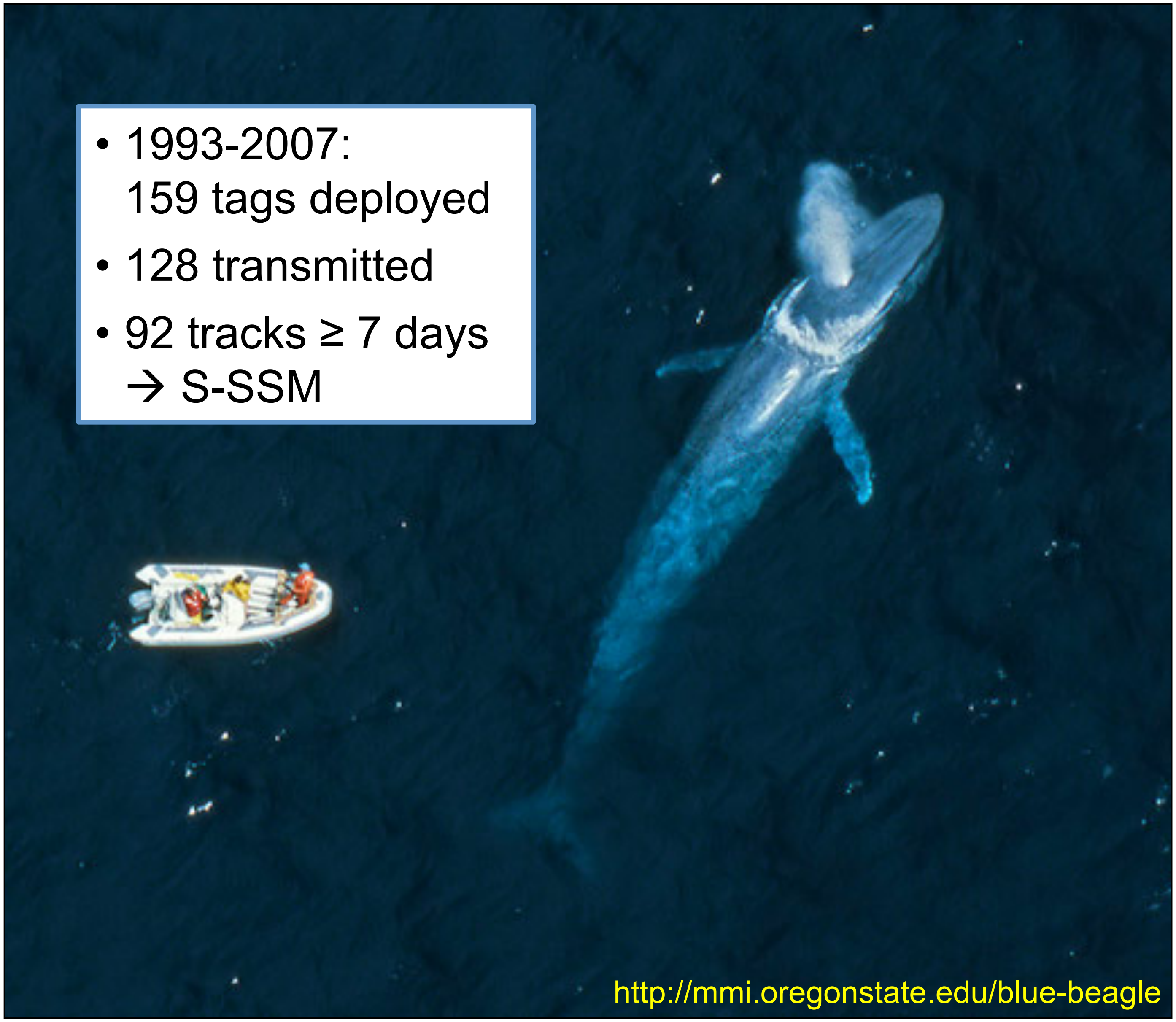
Rykaczewski *et al*. (2008), *PNAS*

From wind to whales

Mangel *et al*. (2002), *Bull Mar Sci*
Croll *et al*. (2005), *MEPS*

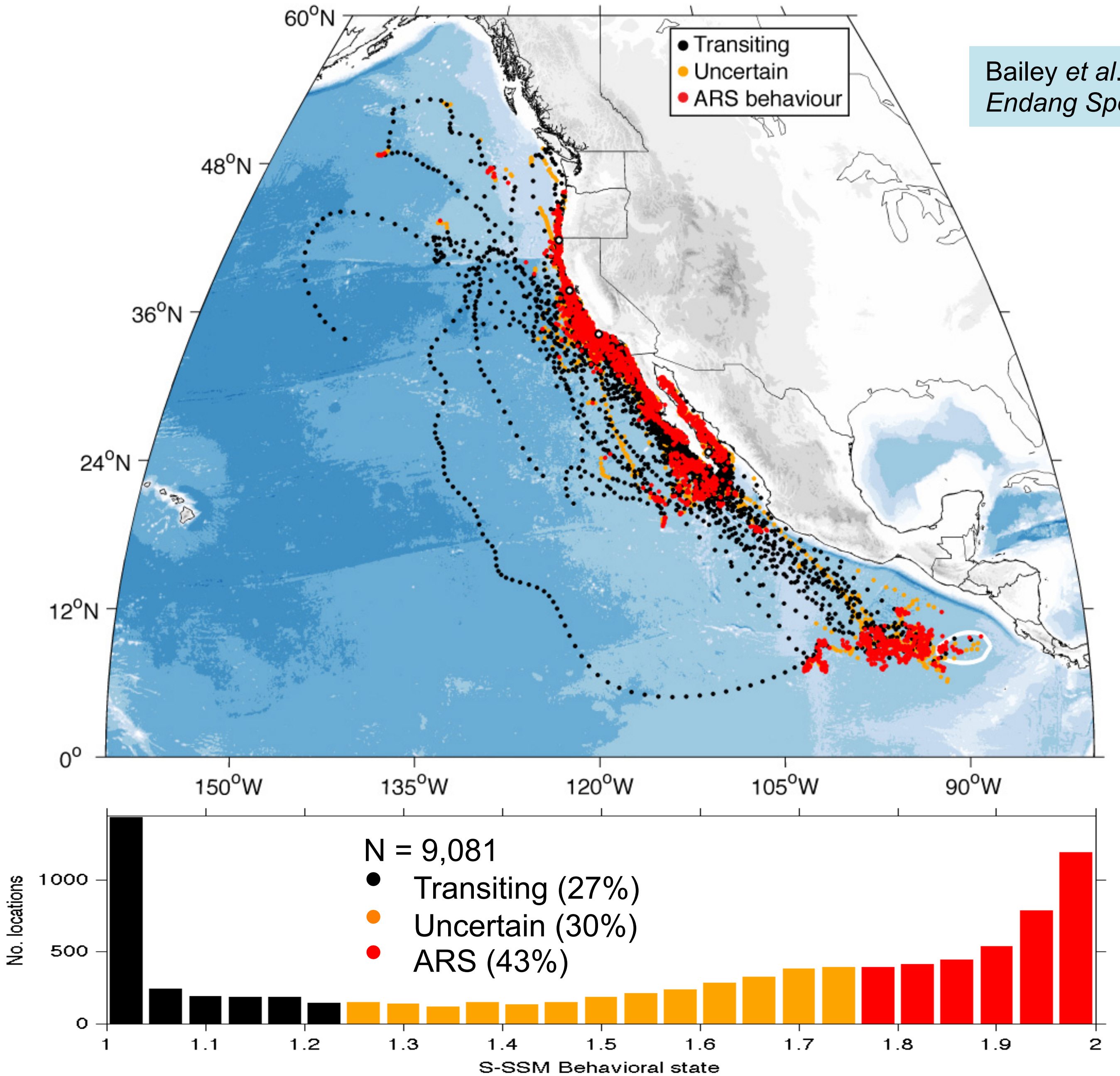


Blue whale tagging

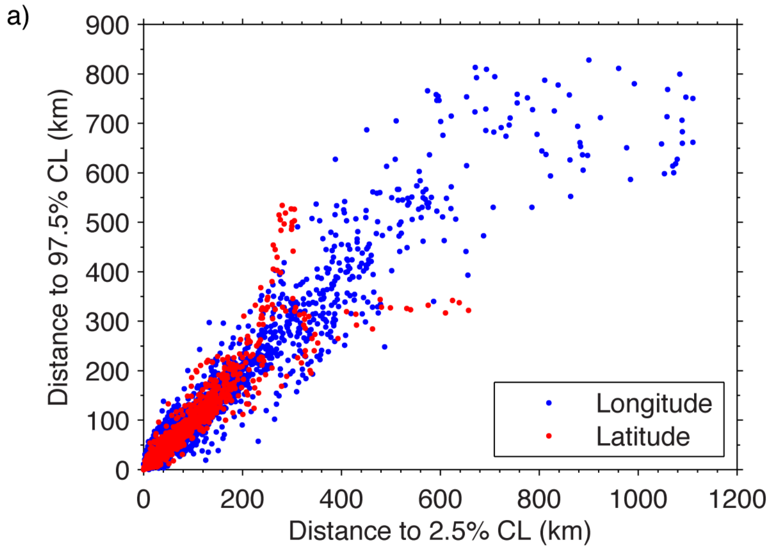


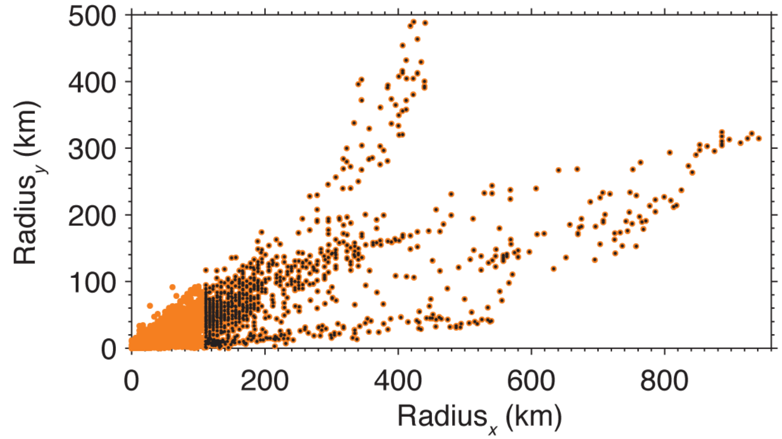
Blue whale behavior in the NE Pacific

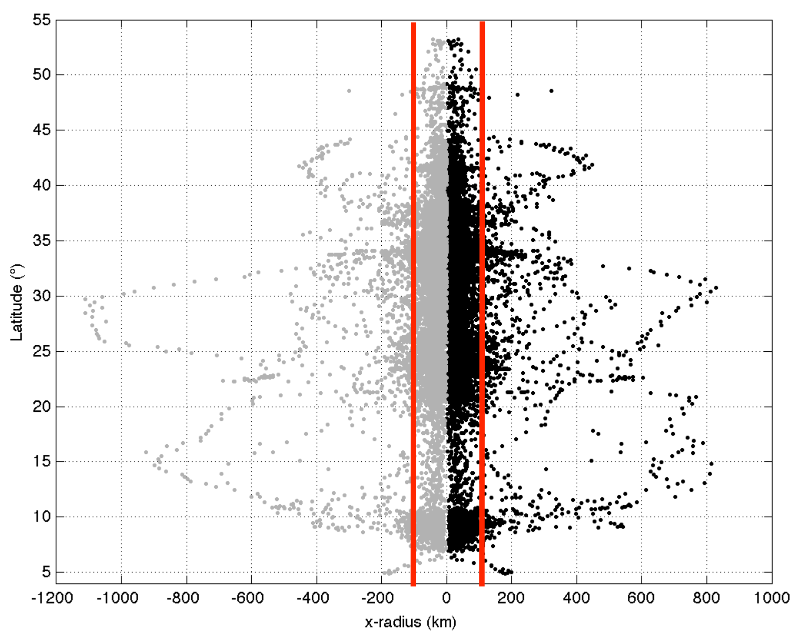
Bailey *et al.*, 2009, *Endang Spec Res*

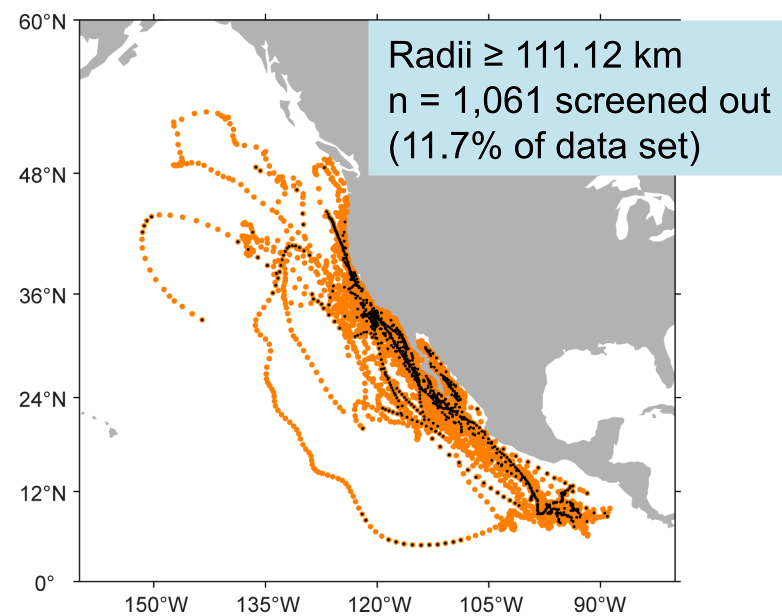


95% CL's as search radii for environmental variables

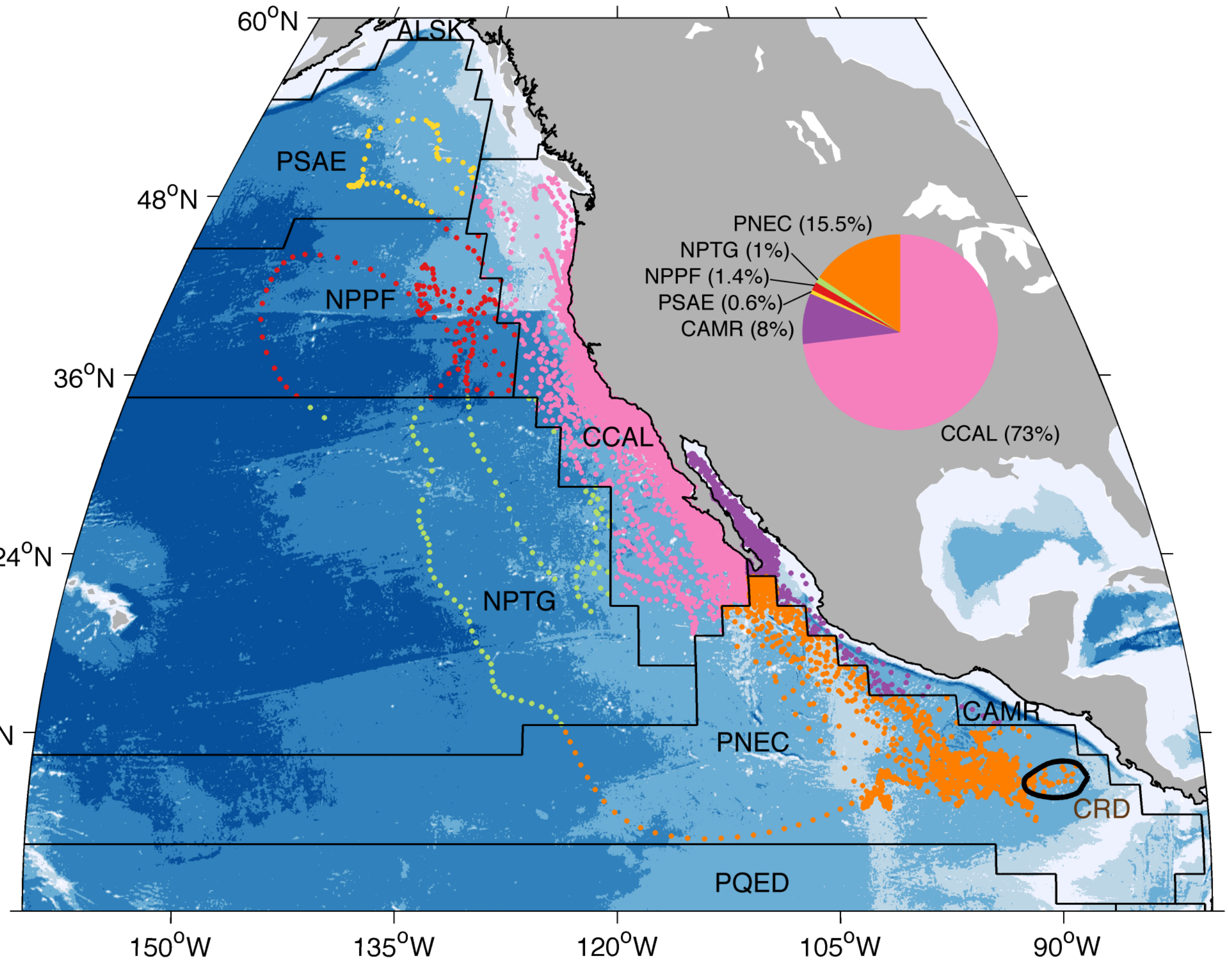








Blue whale biogeography



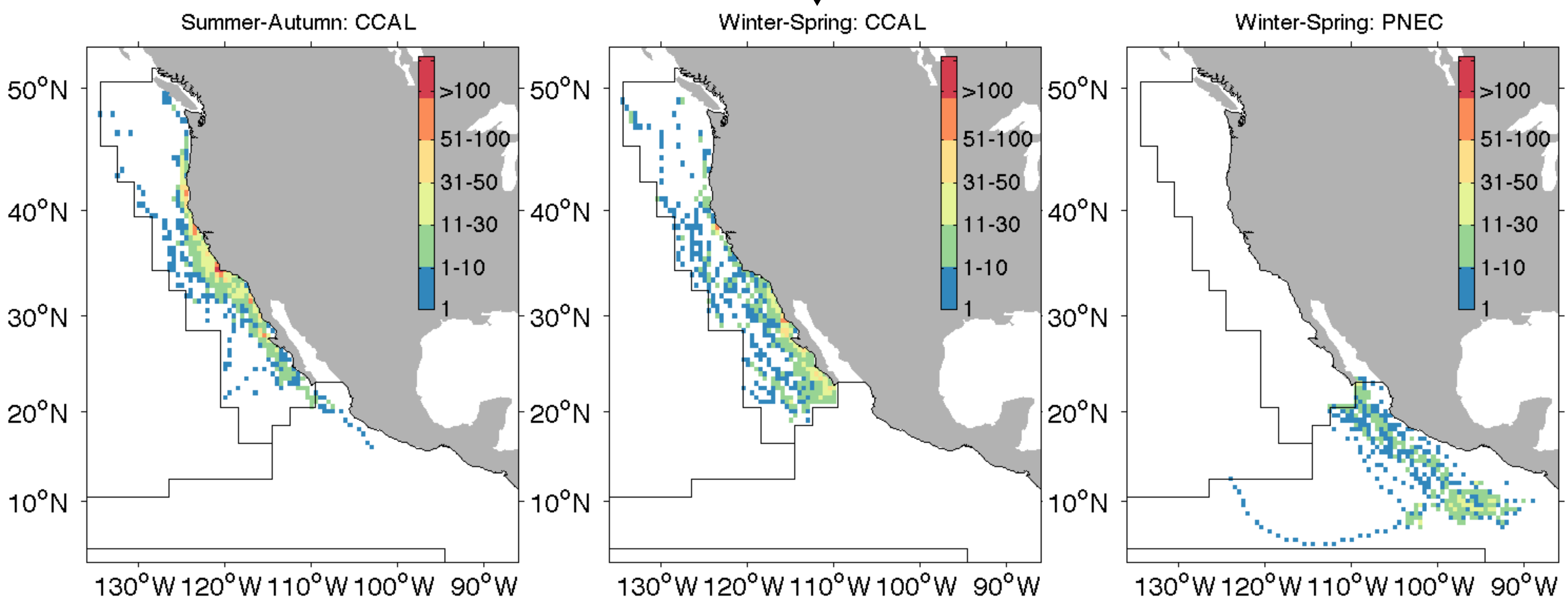
Longhurst's biogeographic provinces

- ARS behavior is tied to favorable foraging conditions **throughout** the migration cycle (vs. feeding-fasting strategy of other migratory whales)
- Mechanisms leading to krill aggregation:
  - CCAL: Ekman upwelling, primary productivity, bottom slope
  - PNEC: Ekman upwelling, primary productivity, sea-surface height anomaly

Seasonal binning (0.5° grid cells)

Summer-Autumn
(June-October)

Winter-Spring
(November-May)

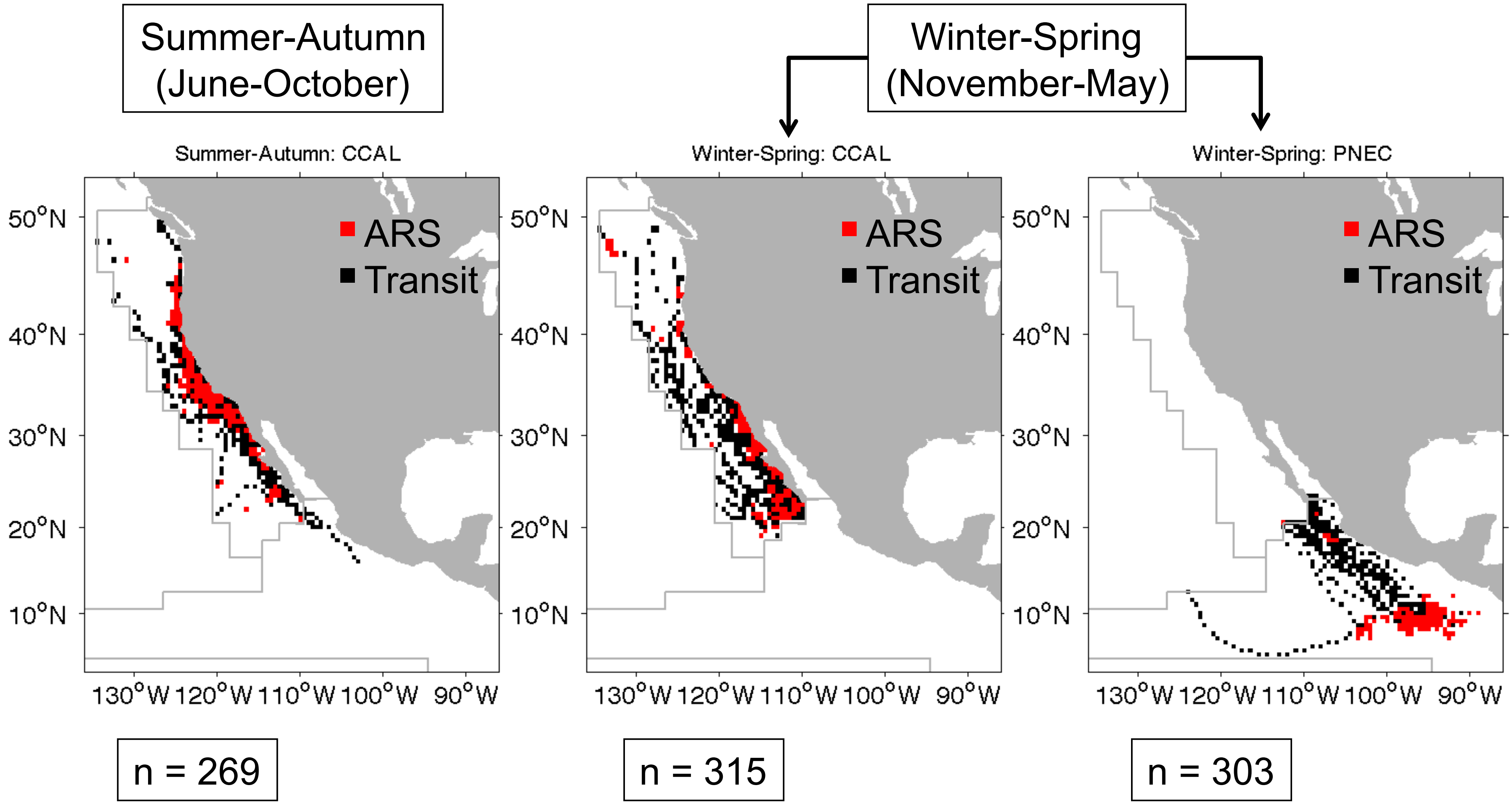


No. locs/cell: 1-218
avg = 7.9
n = 269

No. locs/cell: 1-68
avg = 4.4
n = 315

No. locs/cell: 1-21
avg = 2.7
n = 303

Seasonal ARS presence/absence



Habitat modeling

For each **season** and **province**, model:

Behavior ~ f(Environment)

Response: presence/absence of ARS (binary)

Predictors: mechanistic environmental proxies

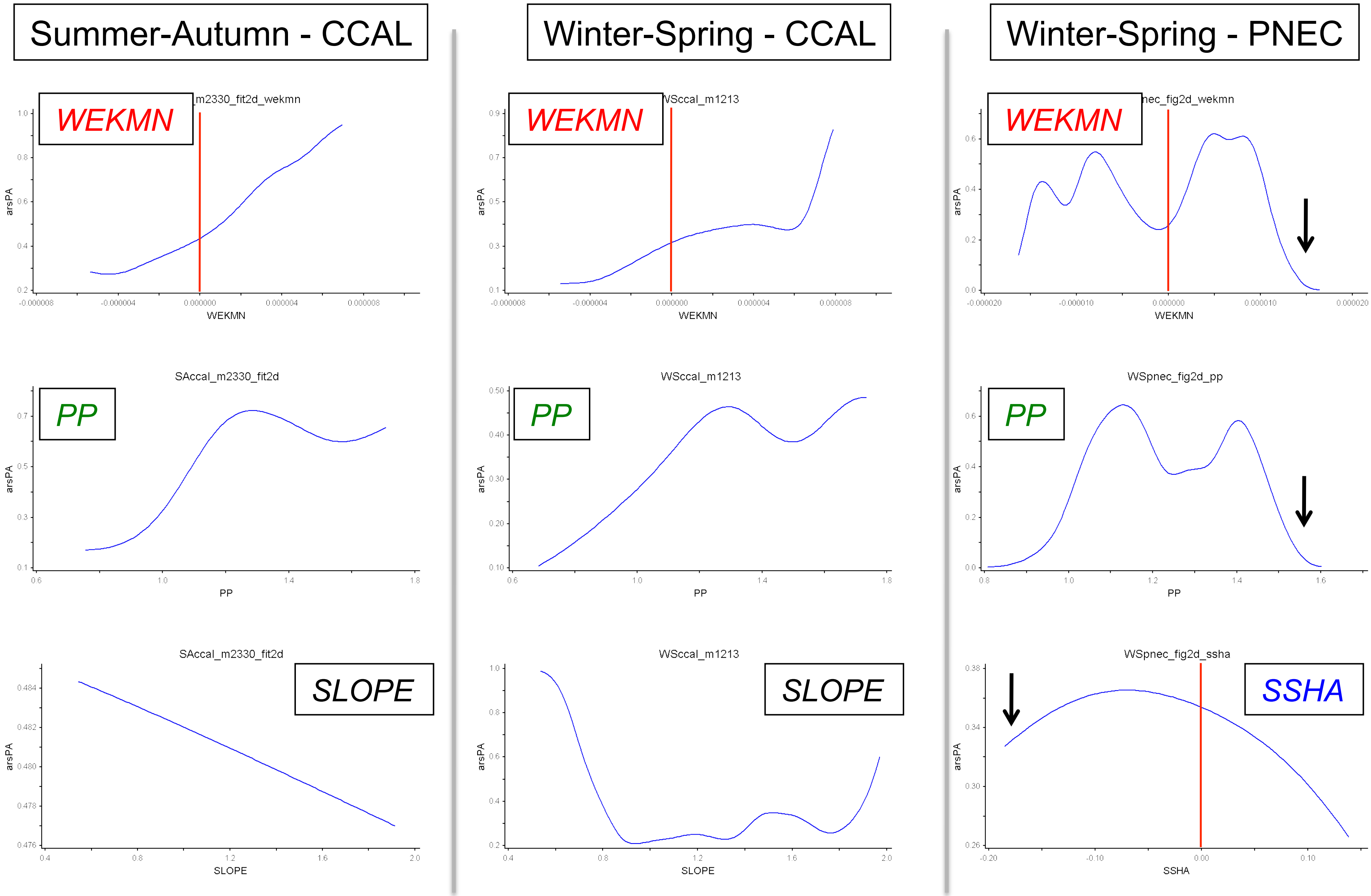
Method: Nonparametric multiplicative regression (local mean, Gaussian kernels with leave-one-out cross-validation) using the HyperNiche package (McCune 2004, 2009)

$$\Pr[ARS] \sim WEKMN \times PP \times SLOPE$$

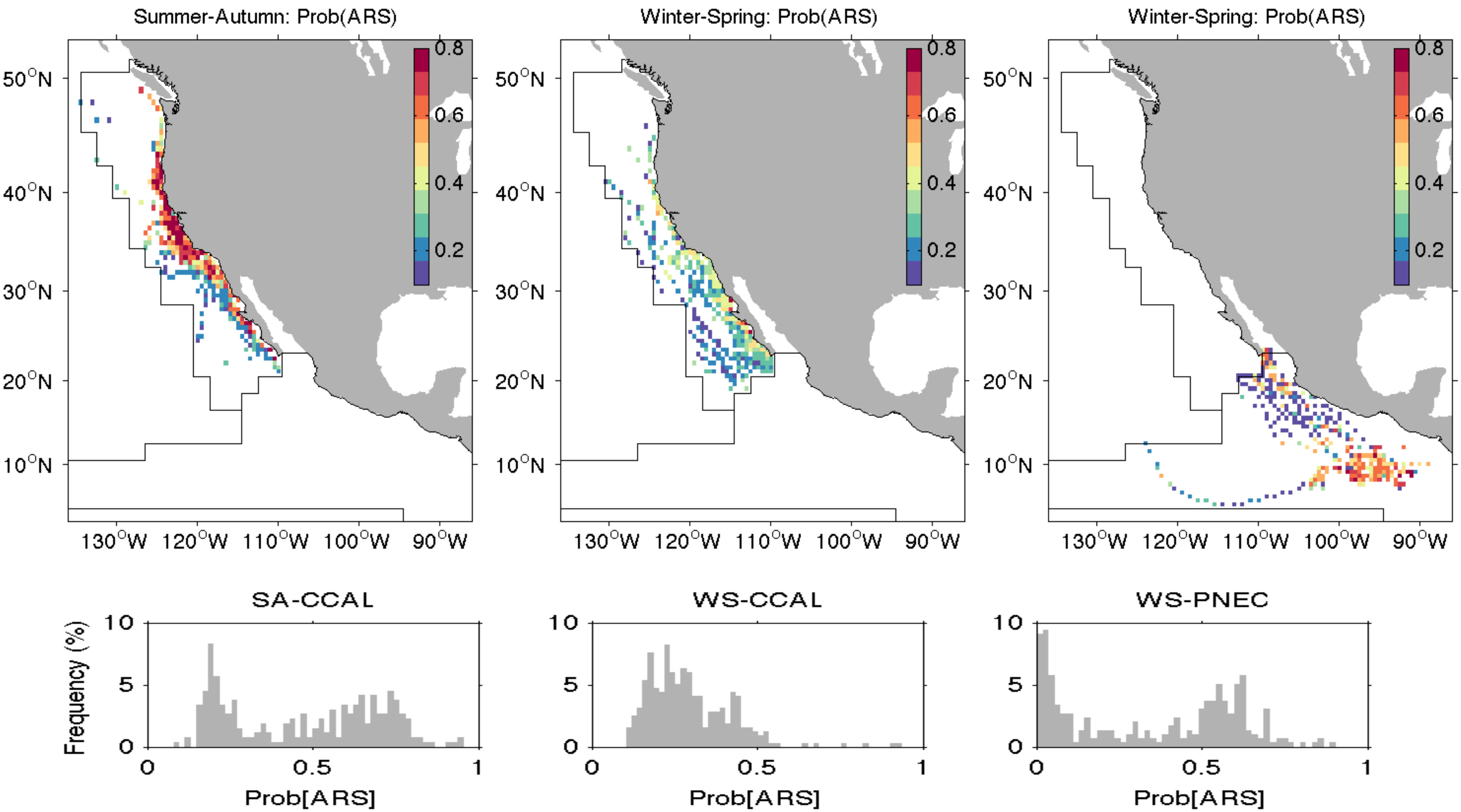
cf. GAM:

$$\Pr[ARS] \sim WEKMN + PP + SLOPE$$

NPMR partial fits



NPMR predictions



M2330, n = 269, LogB = 14.1
PP x WEKMN x SLOPE
(0.9) (0.6) (0.3)

M1213, n = 315, LogB = 7.7
PP x WEKMN x SLOPE
(0.8) (0.13) (0.4)

M649, n = 303, LogB = 23.7
PP x WEKMN x SSHA
(1.7) (0.5) (0.2)

Conclusions

- Consideration of drivers of ecosystem structure and biogeography provided a useful framework to explore hypotheses about blue whale movement behavior in relation to environment
- Predictions were ecologically interpretable and response curves yielded insight about the environmental conditions most conducive to blue whale foraging behavior
- Persistent areas of ARS behavior throughout the migratory cycle were strongly tied to upwelling ecosystems that support large krill standing stocks (further evidence that blue whales feed year-round)
- Blue whales appear to optimize ARS behavior along environmental gradients, making it a useful measure of ecological performance

Caveats and limitations

- Behavioral states from 1 location/day capture meaningful and relevant scales of blue whale behavior
- Spatial and temporal resolution of predictor variables obtained from remote sensing capture relevant oceanographic processes
- ARS is uniquely tied to foraging behavior throughout the range
- Province boundaries are fixed (vs. seasonal processes)
- Seasonal binning reduces statistical issues with tagging bias and track autocorrelation but leads to smearing and loss of variability and ‘degrees of freedom’
- Error in behavioral state estimation not incorporated

Acknowledgments

- The support of field crews was essential to the success of tagging operations
- Satellite data are produced and distributed by NASA, NOAA and AVISO
- Dave Foley provided useful discussions about the data sets served by CoastWatch through the OPeNDAP and THREDDS protocols
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