Effects of warming ocean conditions on the feeding ecology of small pelagic fishes in the Northern California Current

Mary Hunsicker, Richard Brodeur and Ashley Hann
NOAA, Northwest Fisheries Science Center Newport, OR

Todd Miller
NOAA, Alaska Fisheries Science Center Juneau, AK

Yi Gong
Oregon State University, Newport OR
Shanghai Ocean University, China

Forage fish are ecologically and commercially valuable

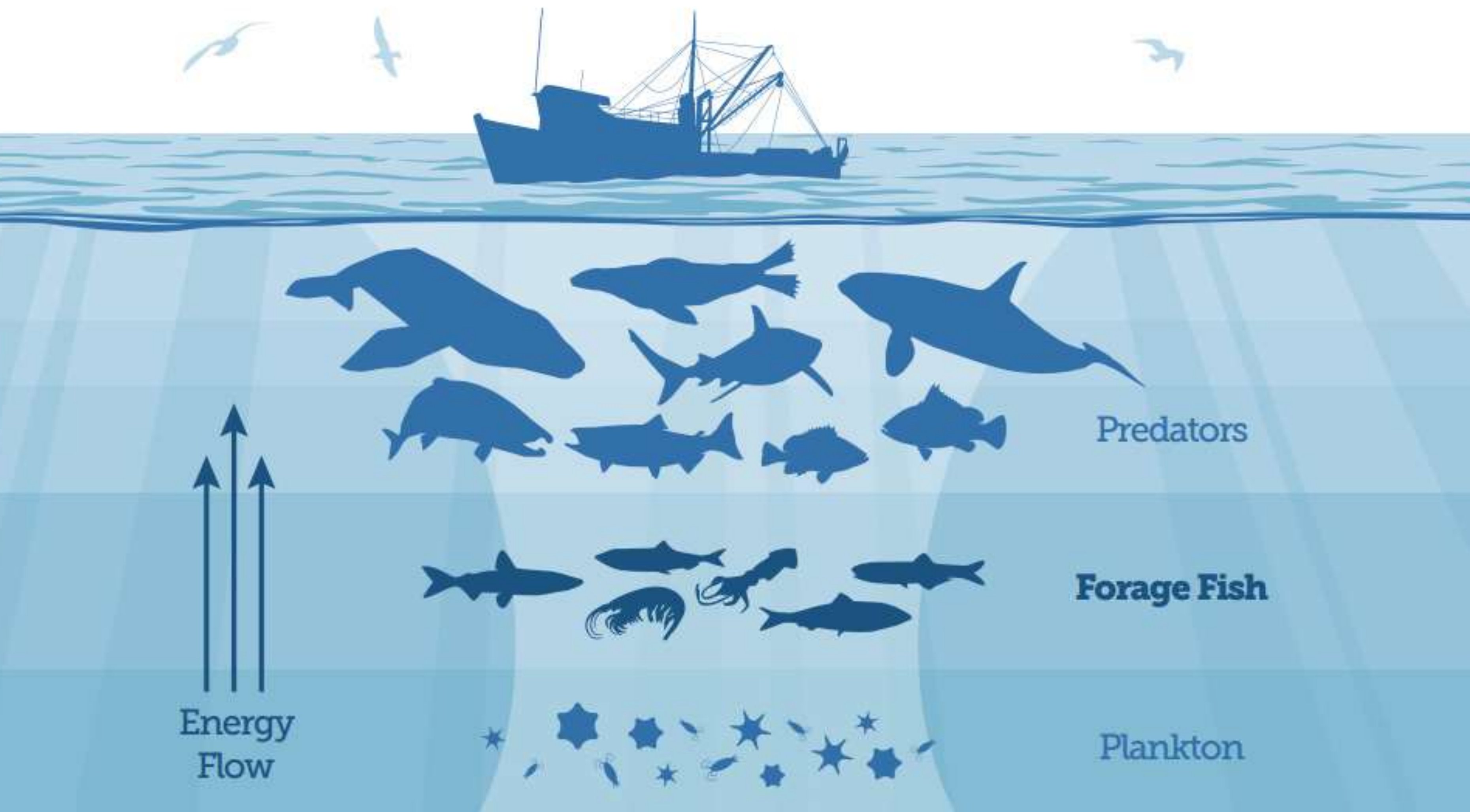
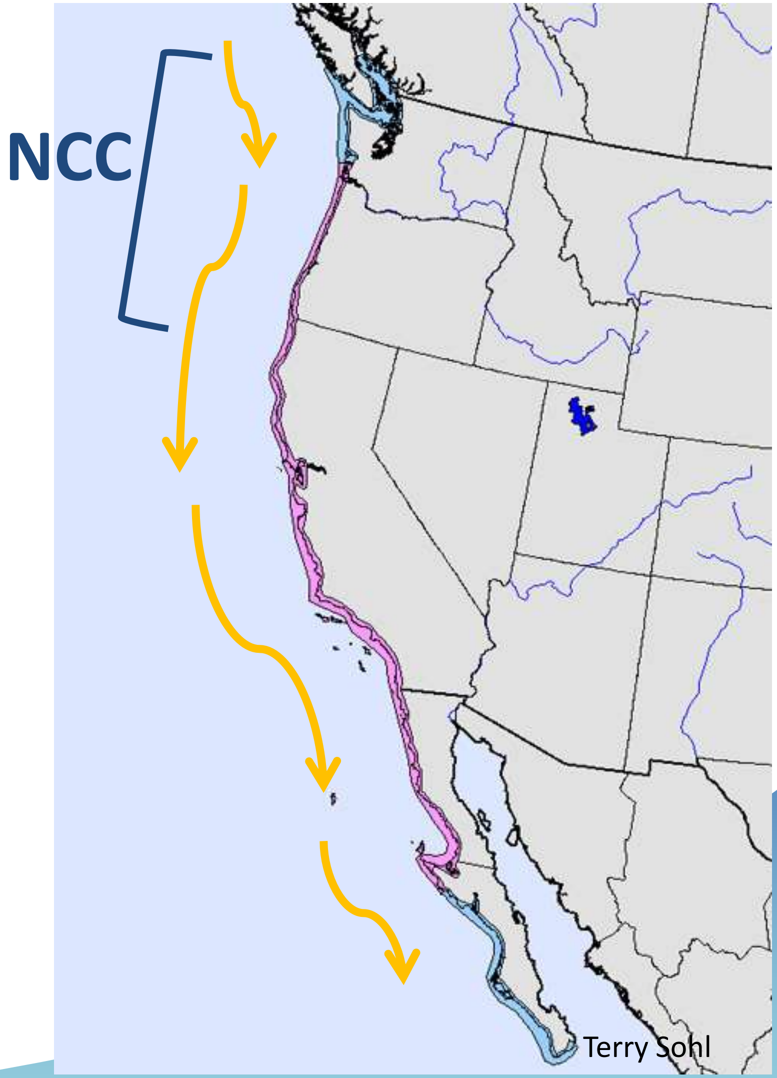


Image: Pew Charitable Trusts

The Northern California Current

- Productive ecosystem dominated by strong seasonal upwelling periods

- Important prey item



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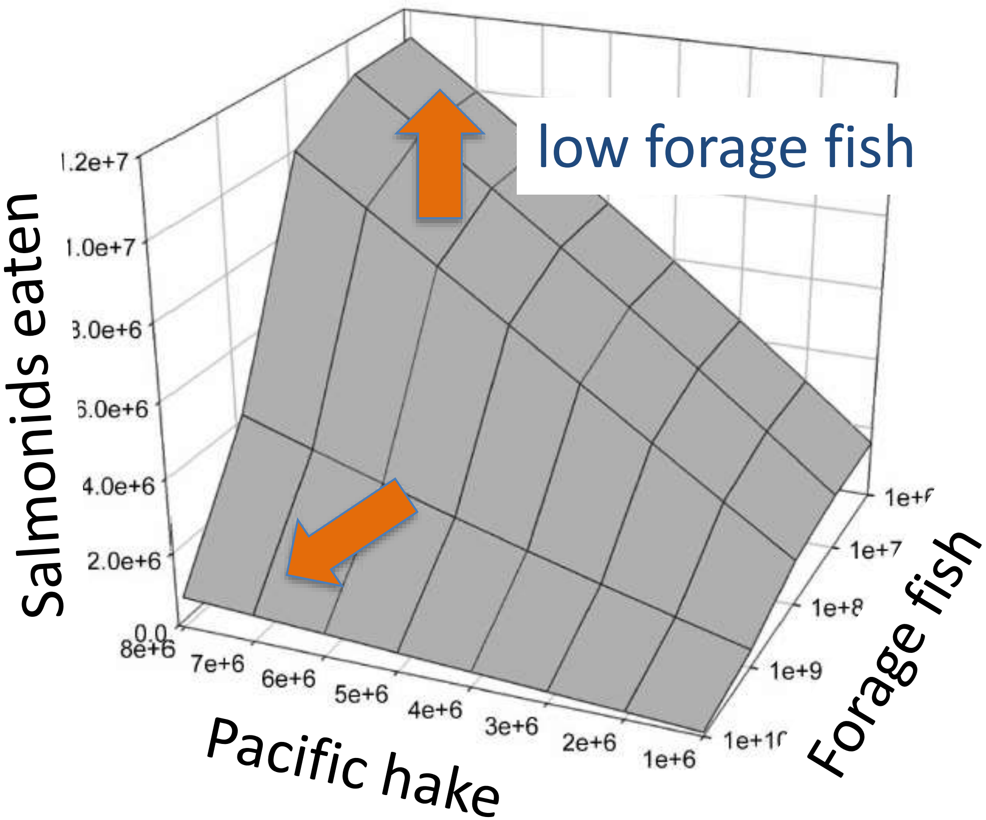
Forage fish can serve as a predation buffer



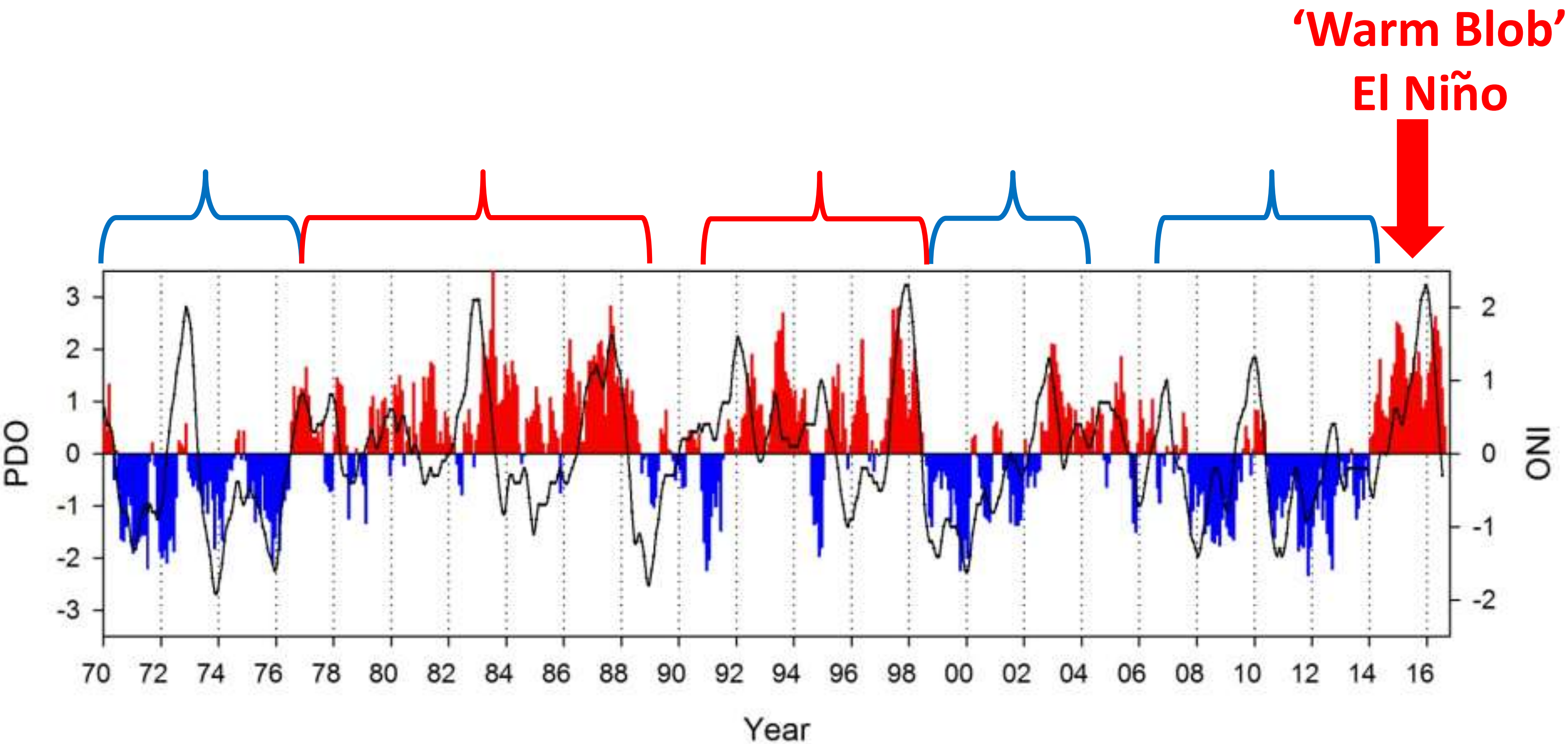
Number of salmon eaten by hake decreases as abundance of forage fish increases

R. Emmett Dissertation

Forage fish show large response to changes in oceanographic conditions

Inter-annual and decadal-scale variability in pop. sizes and distribution

Large-scale environmental drivers



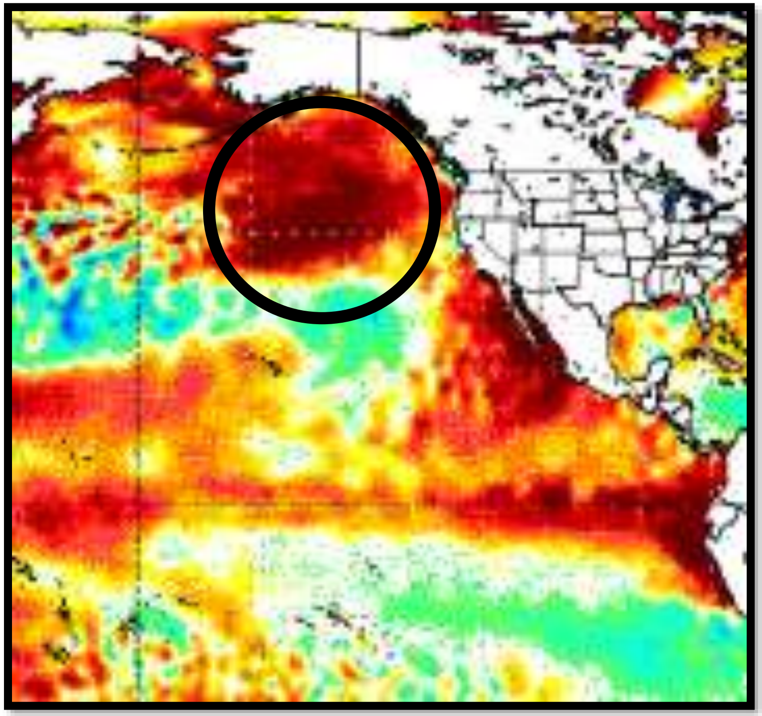
Bars = PDO (Pacific Decadal Oscillation Index)

Line = ONI (Oceanic Niño Index)

Auth et al. (2017) GCB

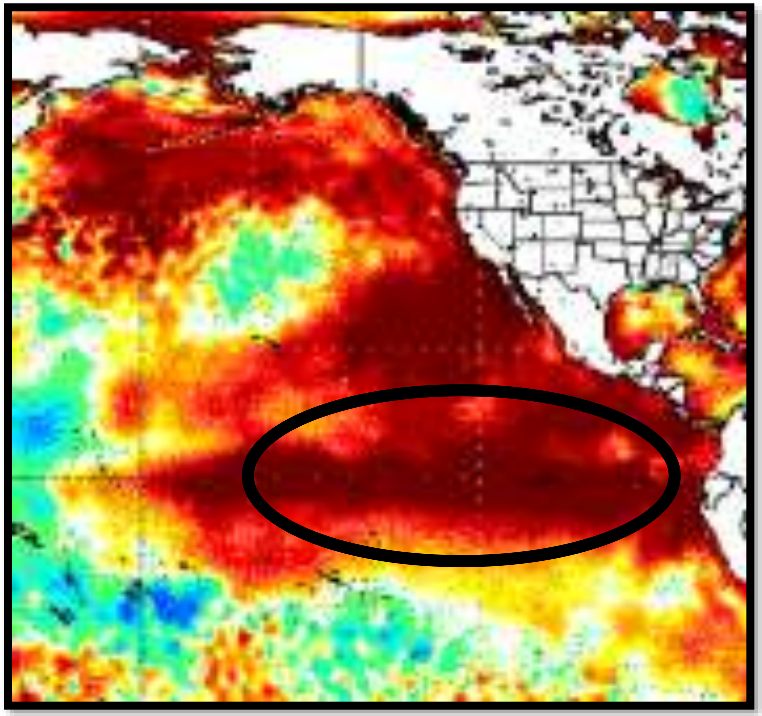
North Pacific surface temperature anomalies

July 2014



The Blob

October 2015



El Niño

How are warm ocean conditions affecting feeding ecology of small pelagic fishes in the NCC?

- Our understanding of how ocean conditions influence energy pathway is limited.

- Unique opportunity to better understand the connection between ocean conditions and forage fish feeding habits.

Northern Anchovy (*Engraulis mordax*)

Pacific Sardine (*Sardinops sagax*)

Image: Pew Trusts

Approach

- Analyze dominant small pelagic fish diets during warm anomaly and compare feeding habits to previous average and cooler periods in the NCC

- Hypothesis: Warming would have altered the prey availability, leading to changes in the diet composition

Northern anchovy

Pacific sardine

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Sampling during warm conditions

- Conducted in June of 2015 and May and June of 2016
- Forage fish were caught on the NOAA/BPA plume surveys and NOAA Pre-Recruit surveys using pelagic trawl nets

Ashley Hann, NOAA Hollings Scholar

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Dominant Forage Fish Species

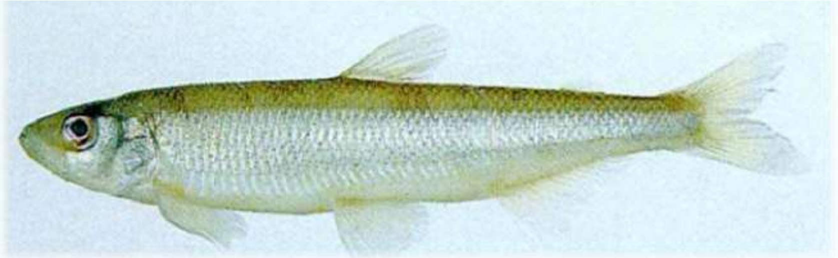
Northern anchovy (*Engraulis mordax*)

Pacific herring *(Clupea pallasii*)

Pacific sardine (*Sardinops sagax*)

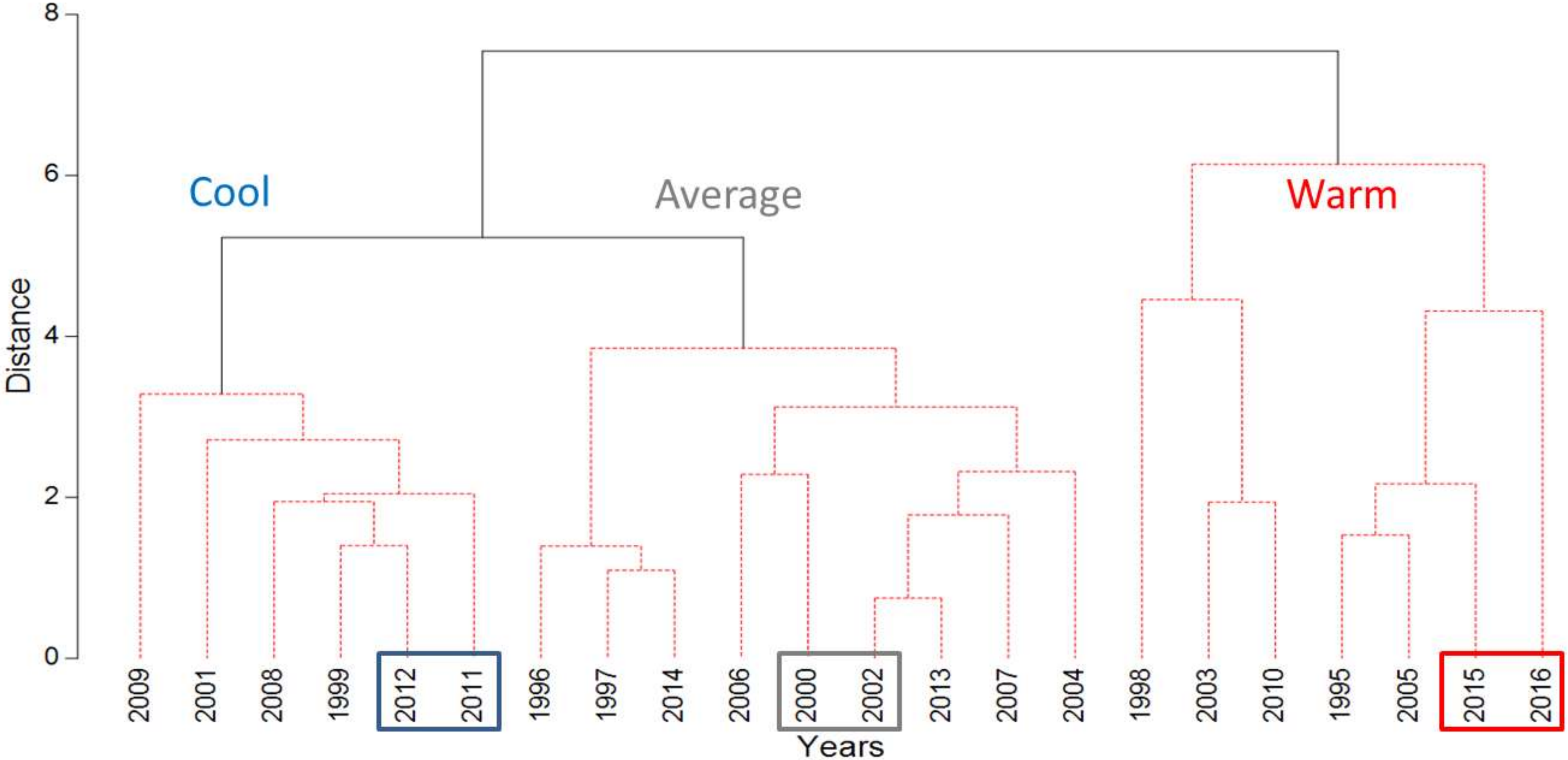
Surf smelt (*Hypomesus pretiosus*)

Jack mackerel (*Trachurus symmetricus*)



Whitebait smelt (*Allosmerus elongatus*)

Fish diets acquired from 2015-16 were compared to similar diet studies from cool and average regimes



Based on Standardized Monthly Values of SST, PDO, NPGO and ONI for Six Months

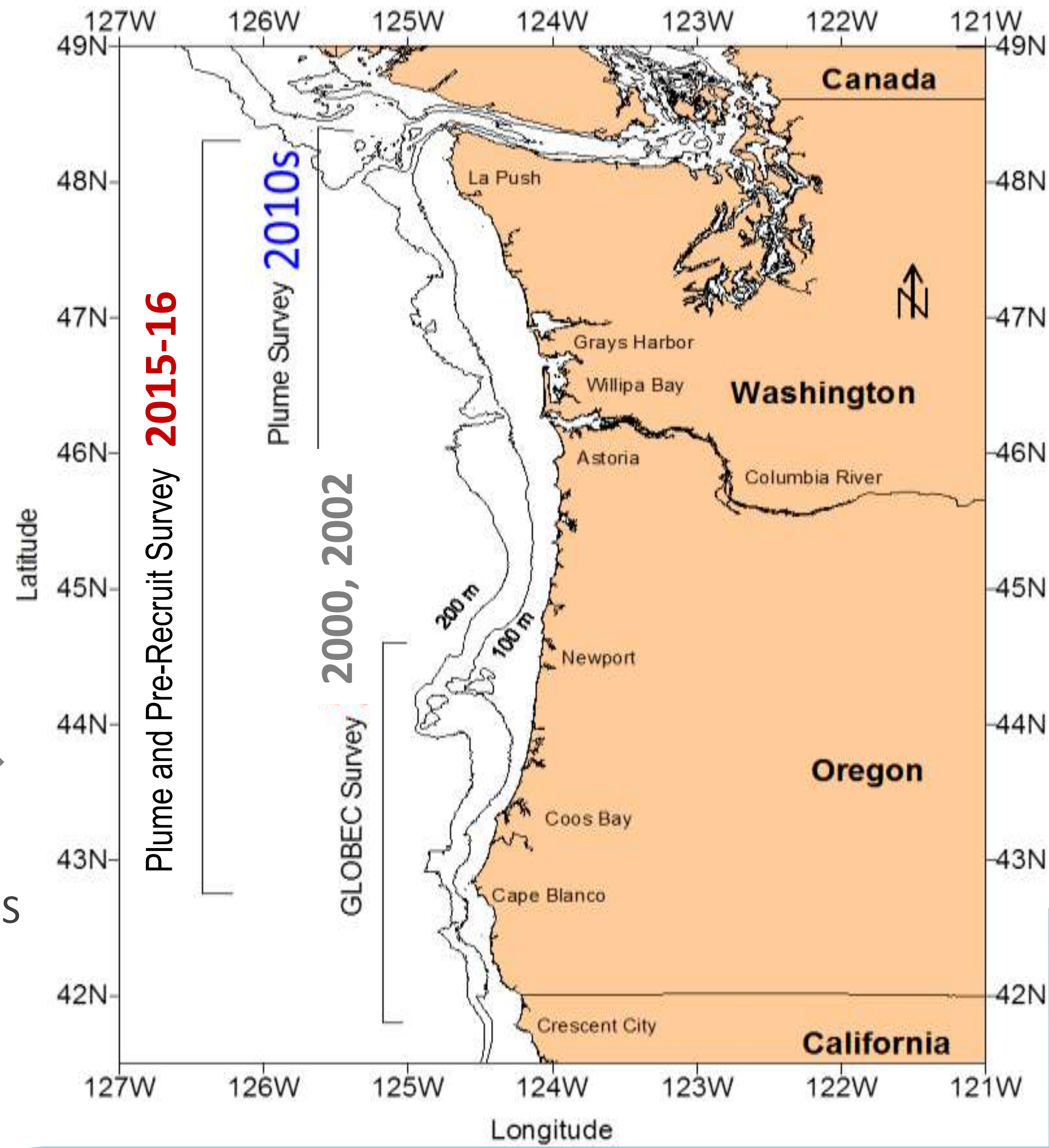
Dashed lines not significantly different (SIMPROF, p > 0.05)

Diet samples collected off Oregon and Washington

Cool Period

Warm Period

Average Period



- 2000 and 2002 Diet Data From Miller et al. (2010) MEPS
- 2011 and 2012 Diet Data From Hill et al. (2014) JMS

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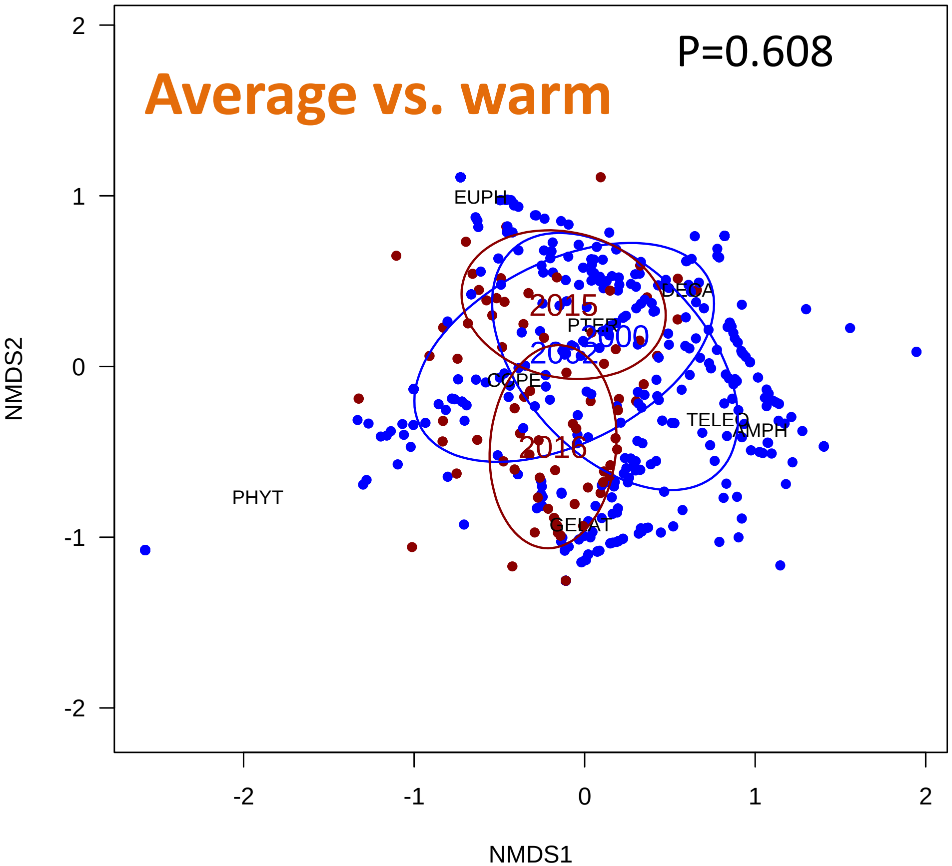
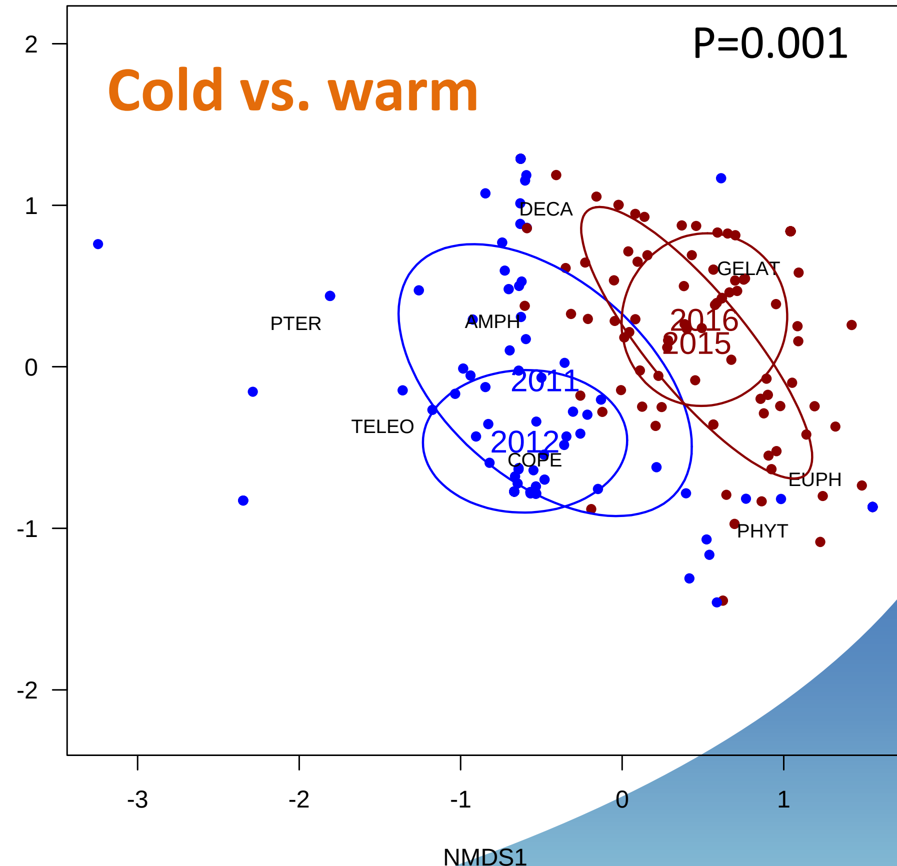
Community level diets varied between cold and warm periods

June 2000-2002 vs. June 2015-2016



June 2011-2012 vs. June 2015-2016



Dispersion ellipses show the standard deviation of the average spatial scores

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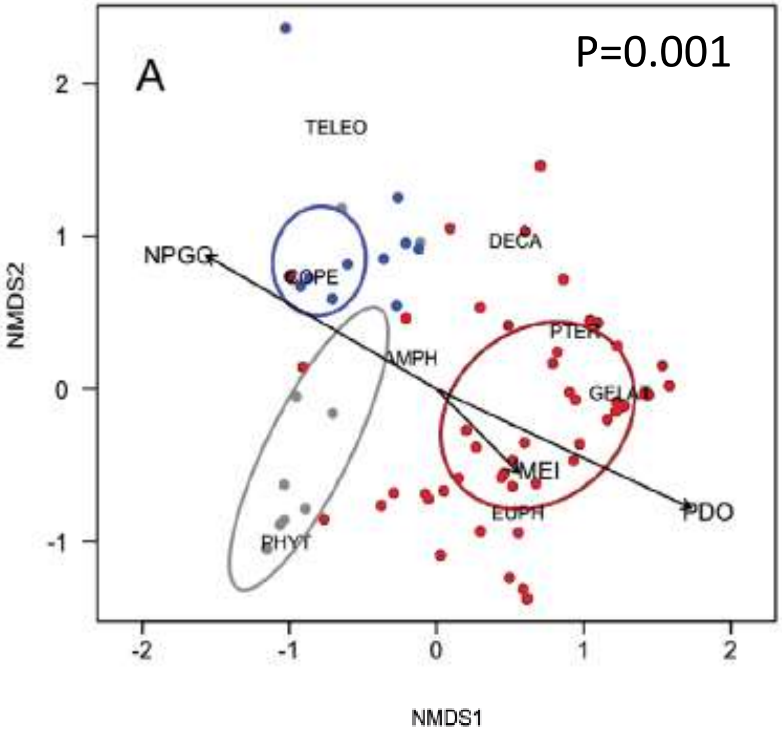
Species-level diets vary between warm and cold periods

Northern Anchovy



P-values based on Multi-Response Permutation Analysis

Dispersion ellipses show the standard deviation of the average spatial scores

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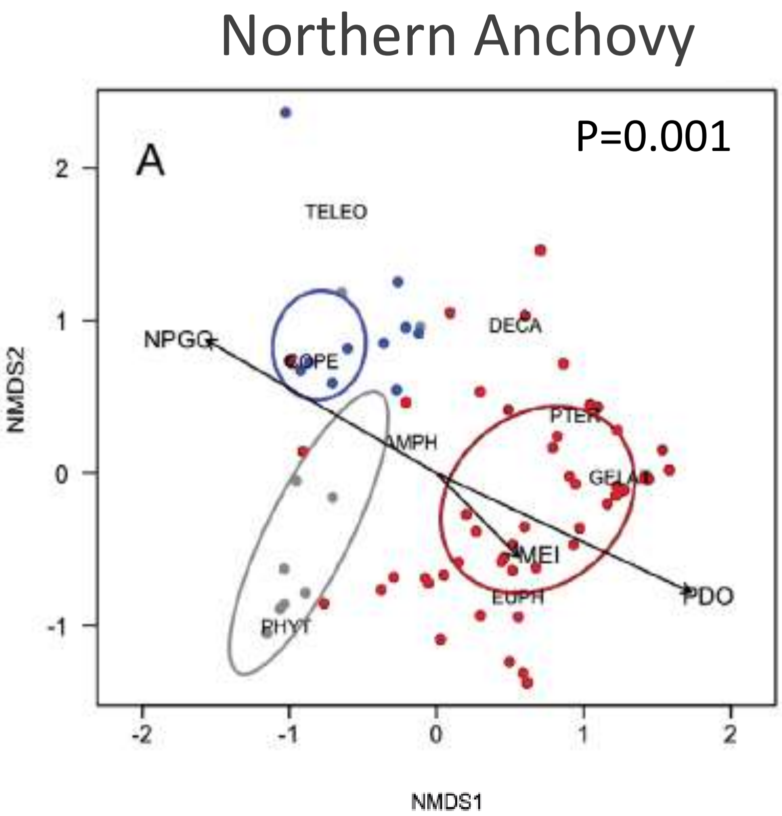
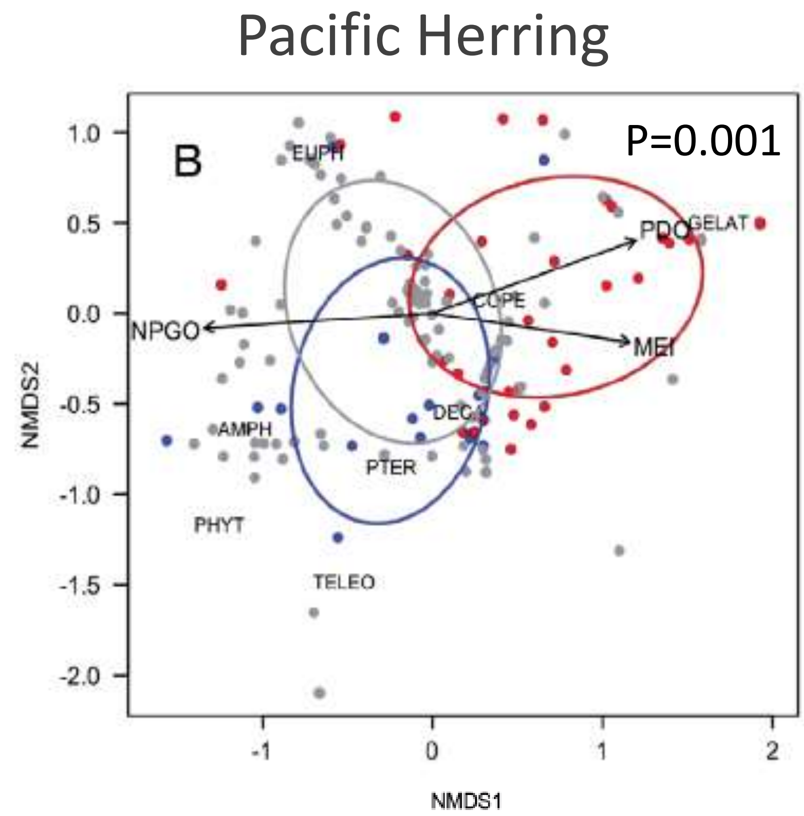
Diets are significantly different between warm and cold periods





P-values based on Multi-Response Permutation Analysis

Dispersion ellipses show the standard deviation of the average spatial scores

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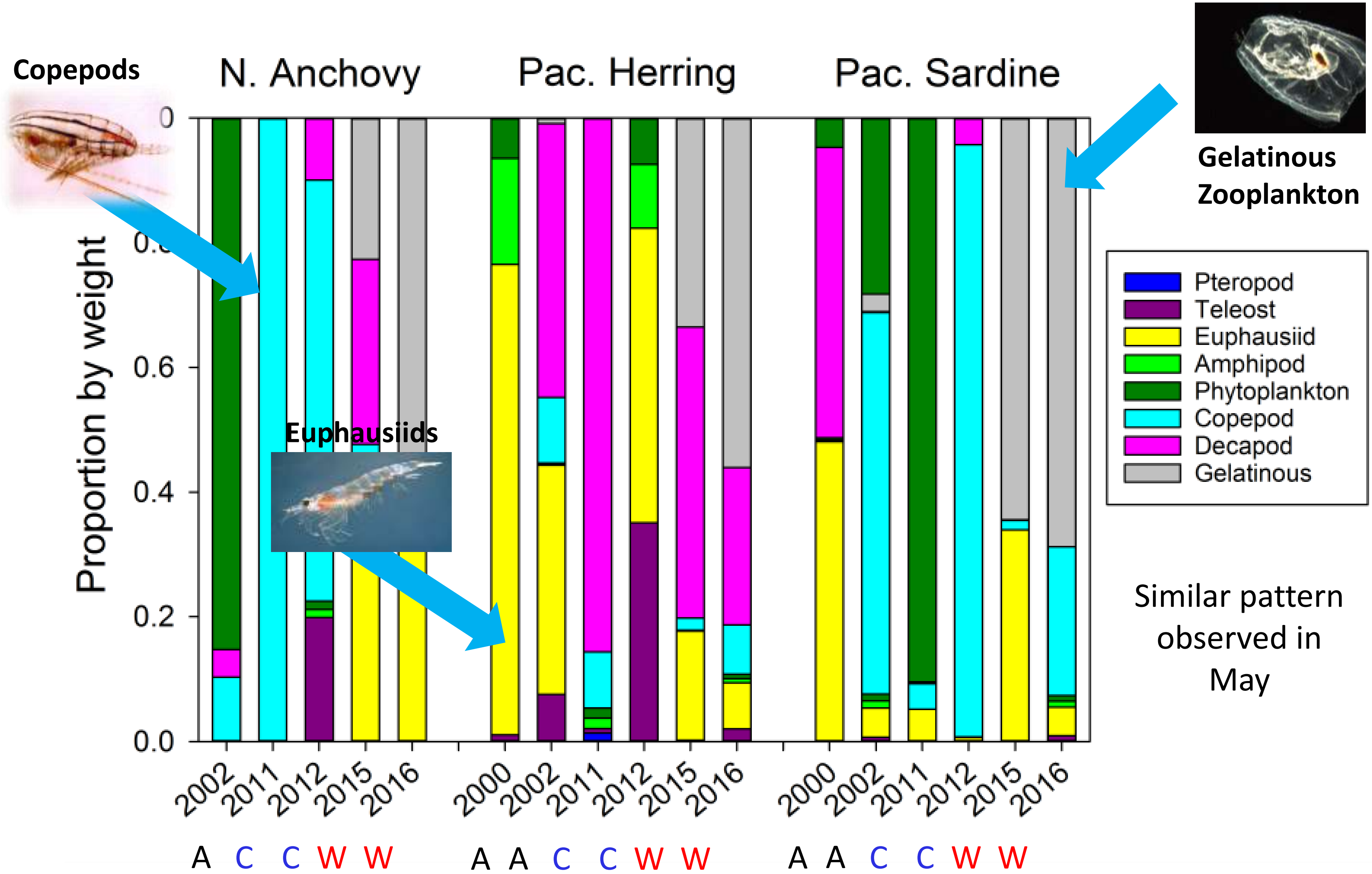
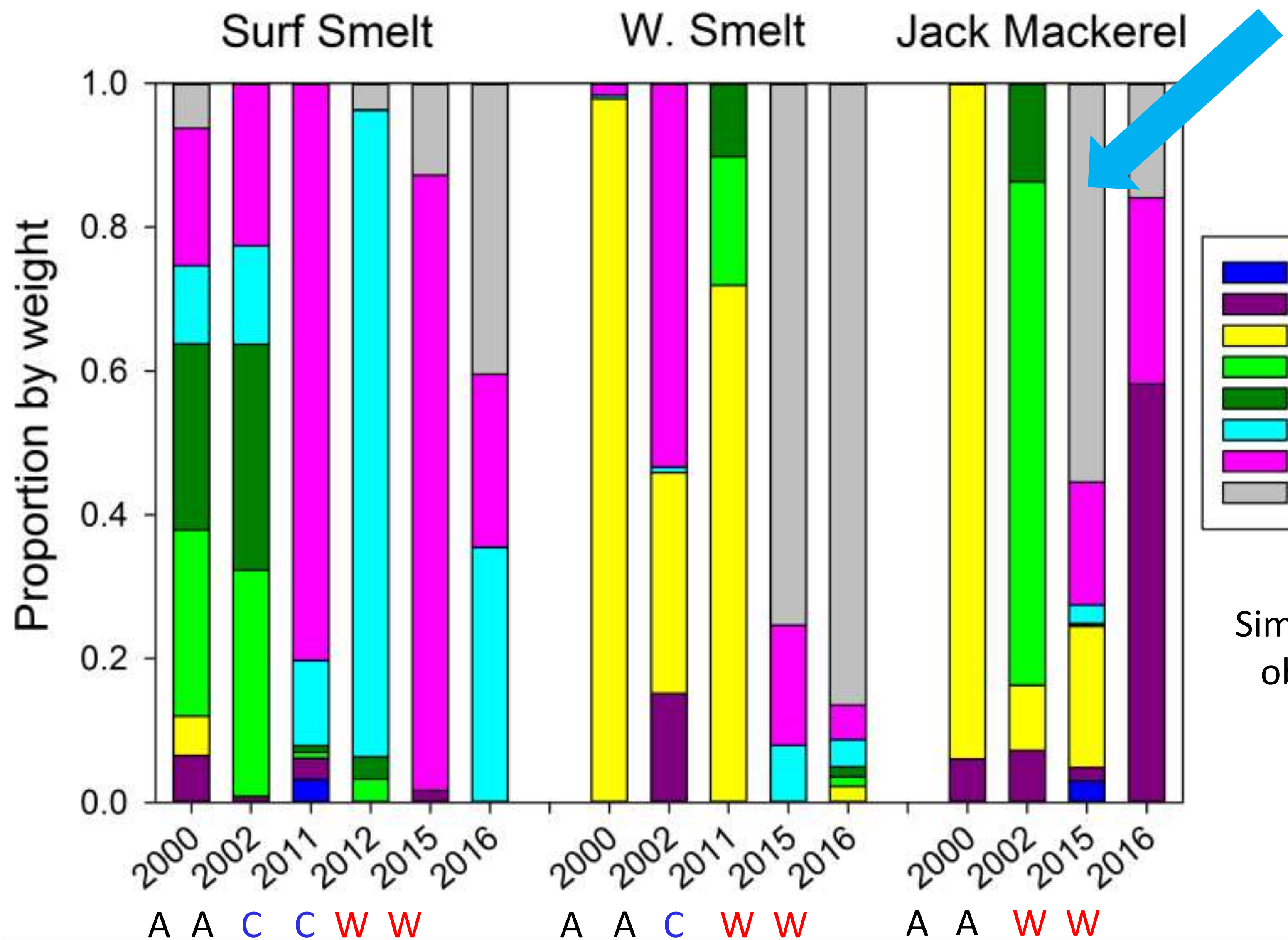
Diet composition in June by weight



Similar pattern observed in May

Diet composition in June by weight

Gelatinous Zooplankton



Similar pattern observed in May

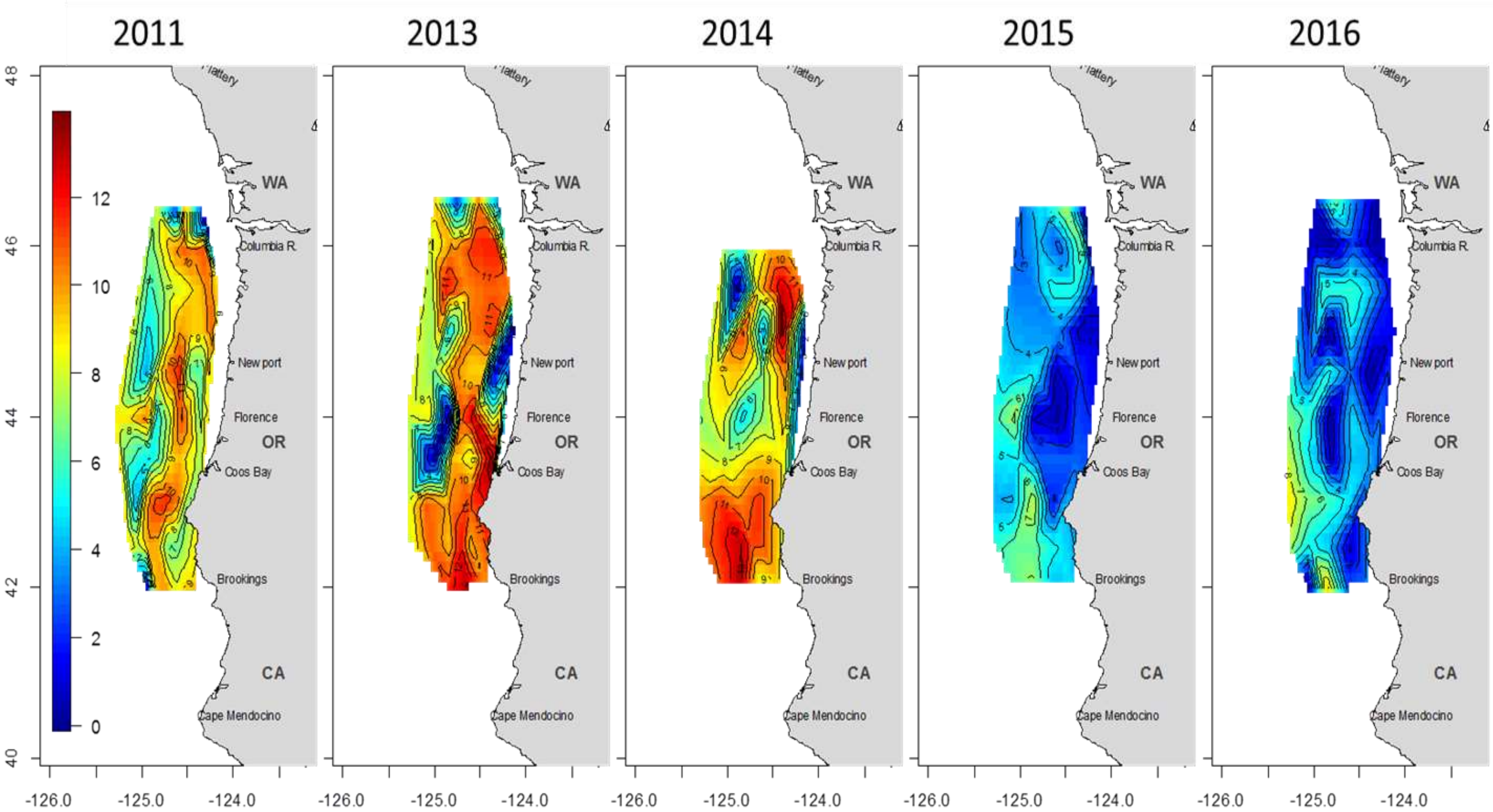
Occurrence of gelatinous material in stomachs (%)

	2000	2002	2011	2012	2015	2016
Northern anchovy	0	0	0	5.3		
Pacific herring	0	12.0	0	0		
Pacific sardine	16.7	45.7	0	0		
Jack mackerel	0	0	---	---		
Whitebait smelt	0	0	0	---		
Surf smelt	40.6	71.7	0	66.7		
Ocean conditions	Average	Average	Cool	Cool		

High occurrence of gelatinous material in warm years

	2000	2002	2011	2012	2015	2016
Northern anchovy	0	0	0	5.3	60.1	78.4
Pacific herring	0	12.0	0	0	64.3	51.4
Pacific sardine	16.7	45.7	0	0	92.3	39.5
Jack mackerel	0	0	---	---	60.0	33.3
Whitebait smelt	0	0	0	---	---	92.6
Surf smelt	40.6	71.7	0	66.7	---	100.0
Ocean conditions	Average	Average	Cool	Cool	Warm	Warm

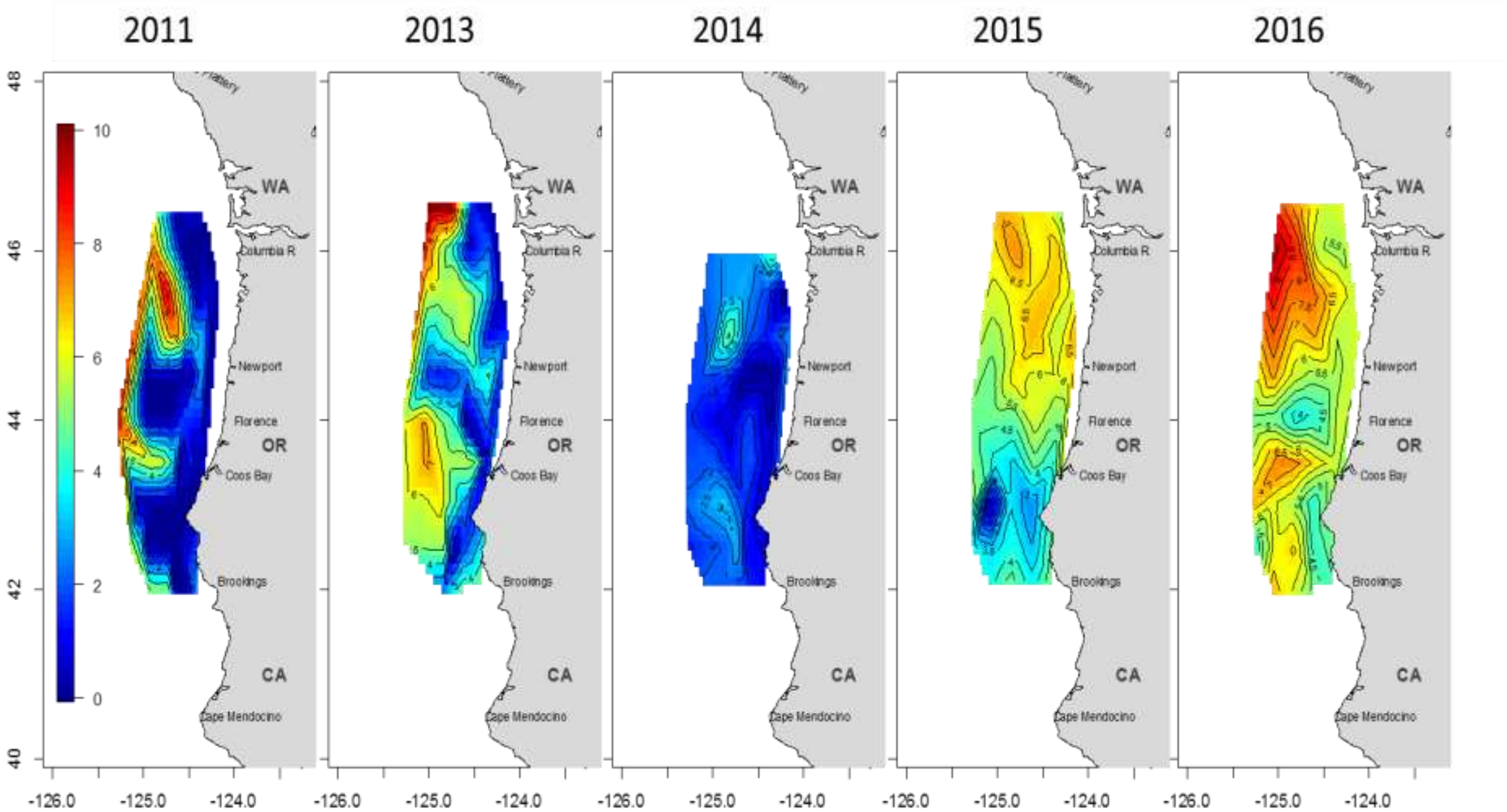
Total Crustacea



Number = mean abundance in thousands

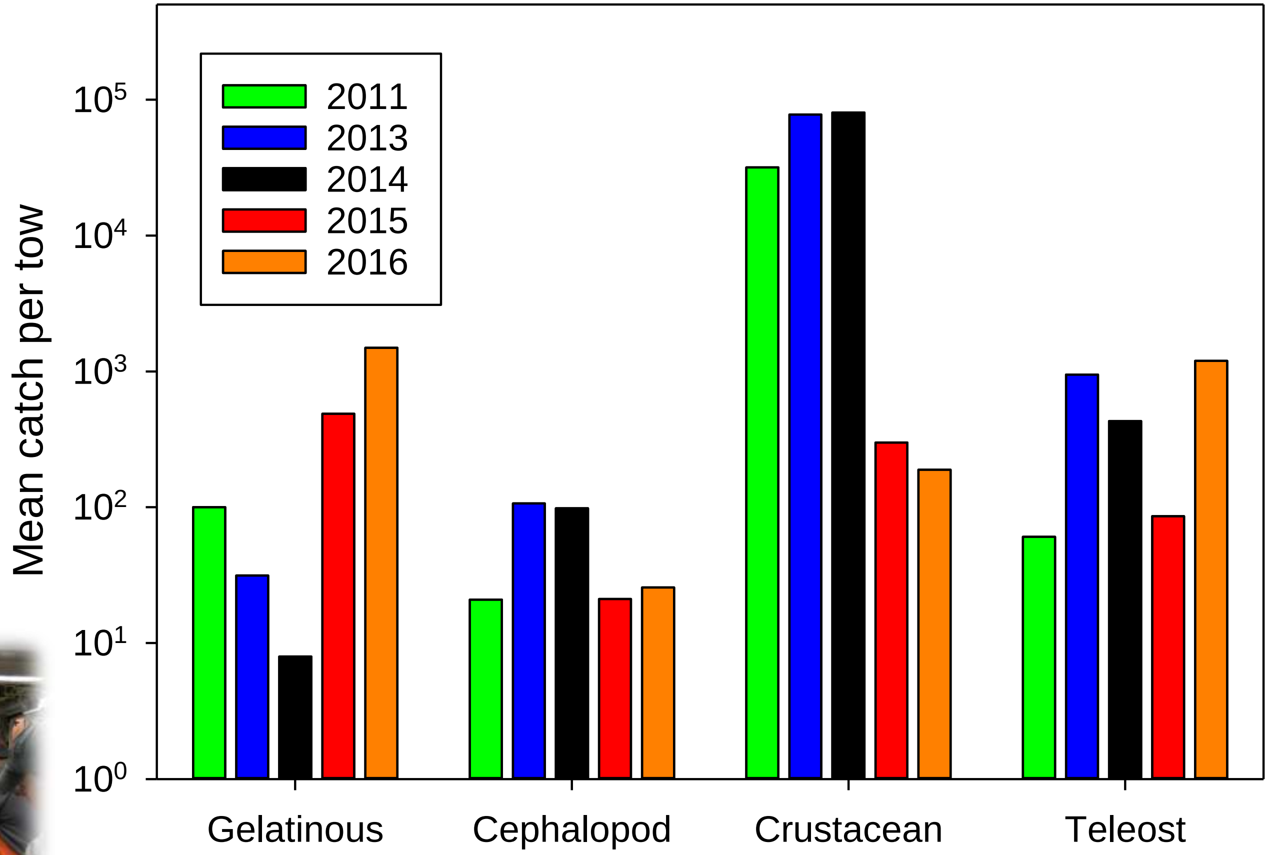
Brodeur et al. 2018

Total Gelatinous



Brodeur et al. 2018

Shift from crustacean-dominated to jellyfish-dominated ecosystem

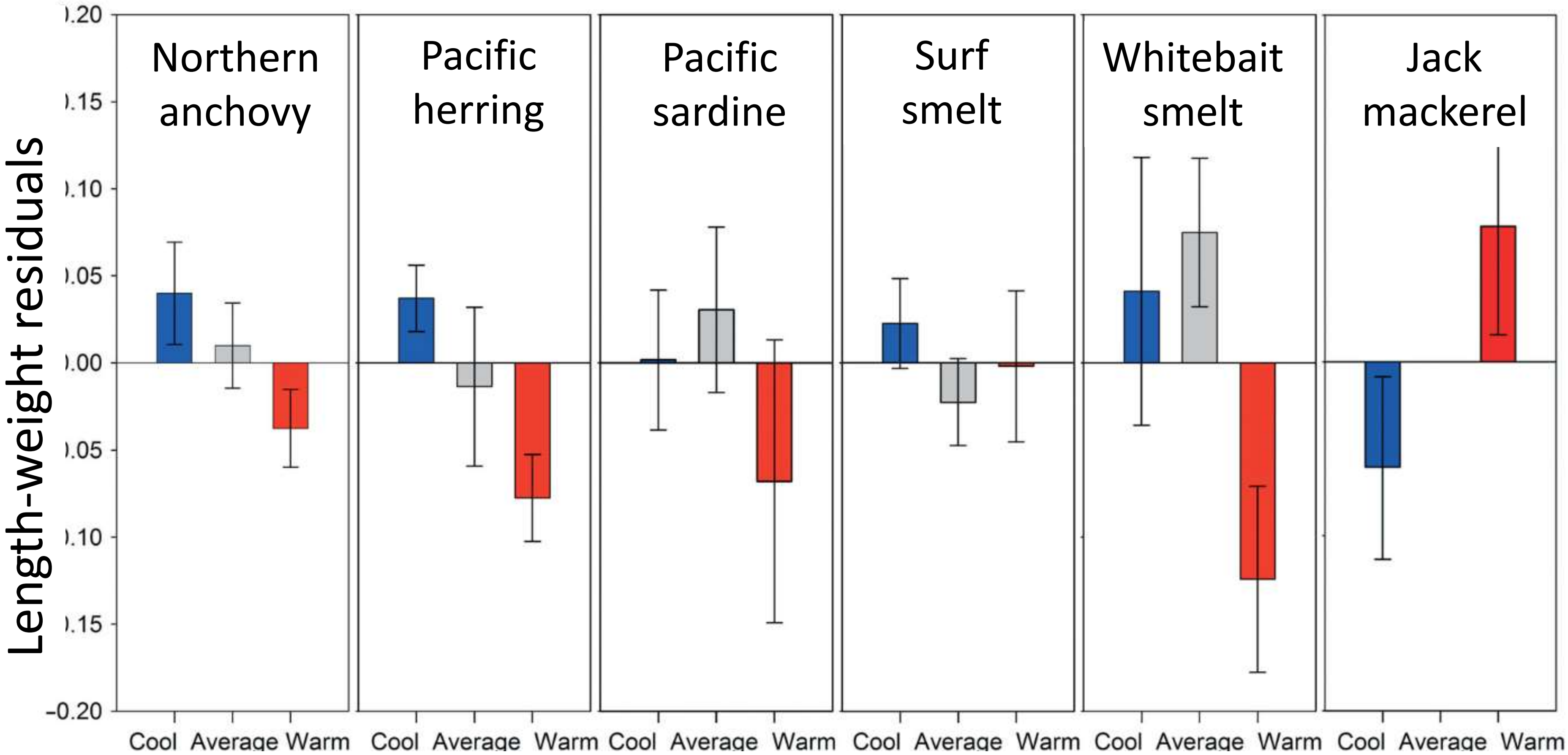


2014

2015

Brodeur et al. 2018

Possible negative effects on fish body condition



Conclusions and Implications

- Recent shift from mostly crustacean diet to gelatinous diets in many species related to changes in prey availability resulting from warm ocean conditions
- Uncertain how the switch a more gelatinous diet will affect growth and survival of these fish
- Glimpse of expected changes in the prey community and feeding conditions with rising ocean temps and changes in productivity due to climate change

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Next steps…

- Continue diet analysis in future looking at more species in the NCC
- Stable isotope ratios of carbon and nitrogen of predators and prey to compare to previous studies (Miller et al. 2010, MEPS)

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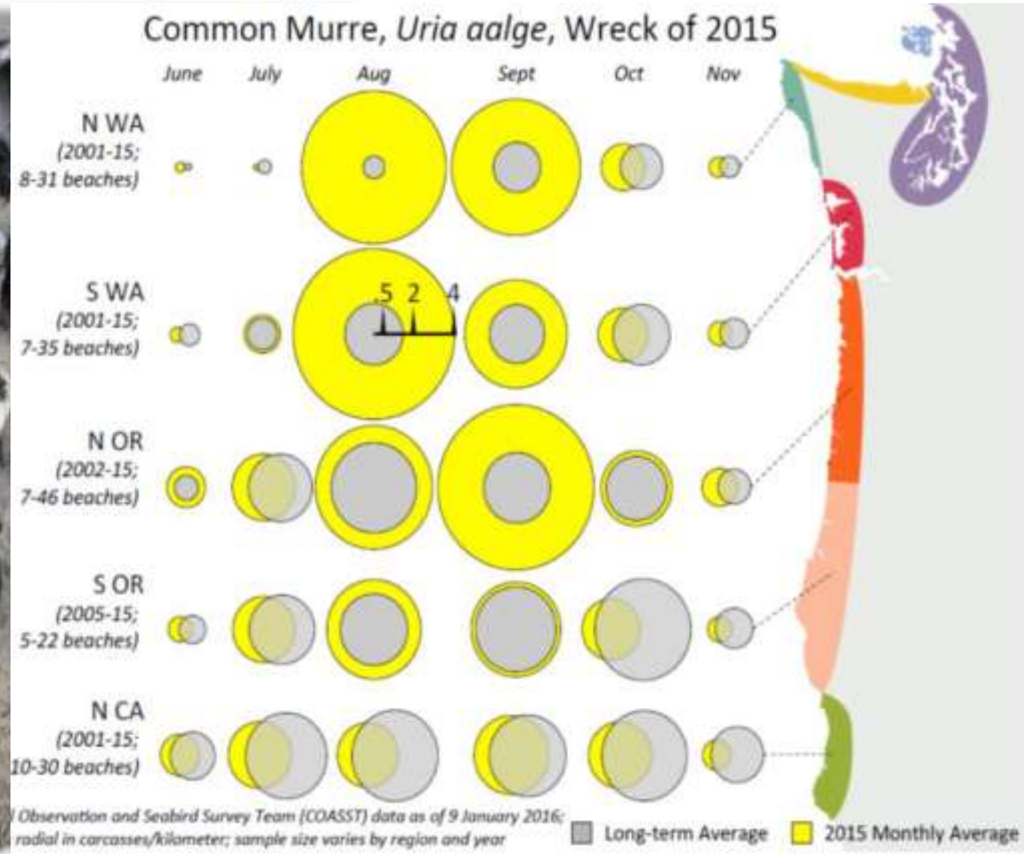
Implications for higher trophic levels

Cassin's auklets



Common murres

Unusual mortality events seen during the blob

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Acknowledgements

- Drew Hill, Ashley Yarbrough and Morgan Kroeger
- The crew and scientists of the NOAA Ship Bell M. Shimada, R/V Ocean Starr and F/V Frosti
- NOAA and Bonneville Power Administration for funding

Bonneville Power Administration

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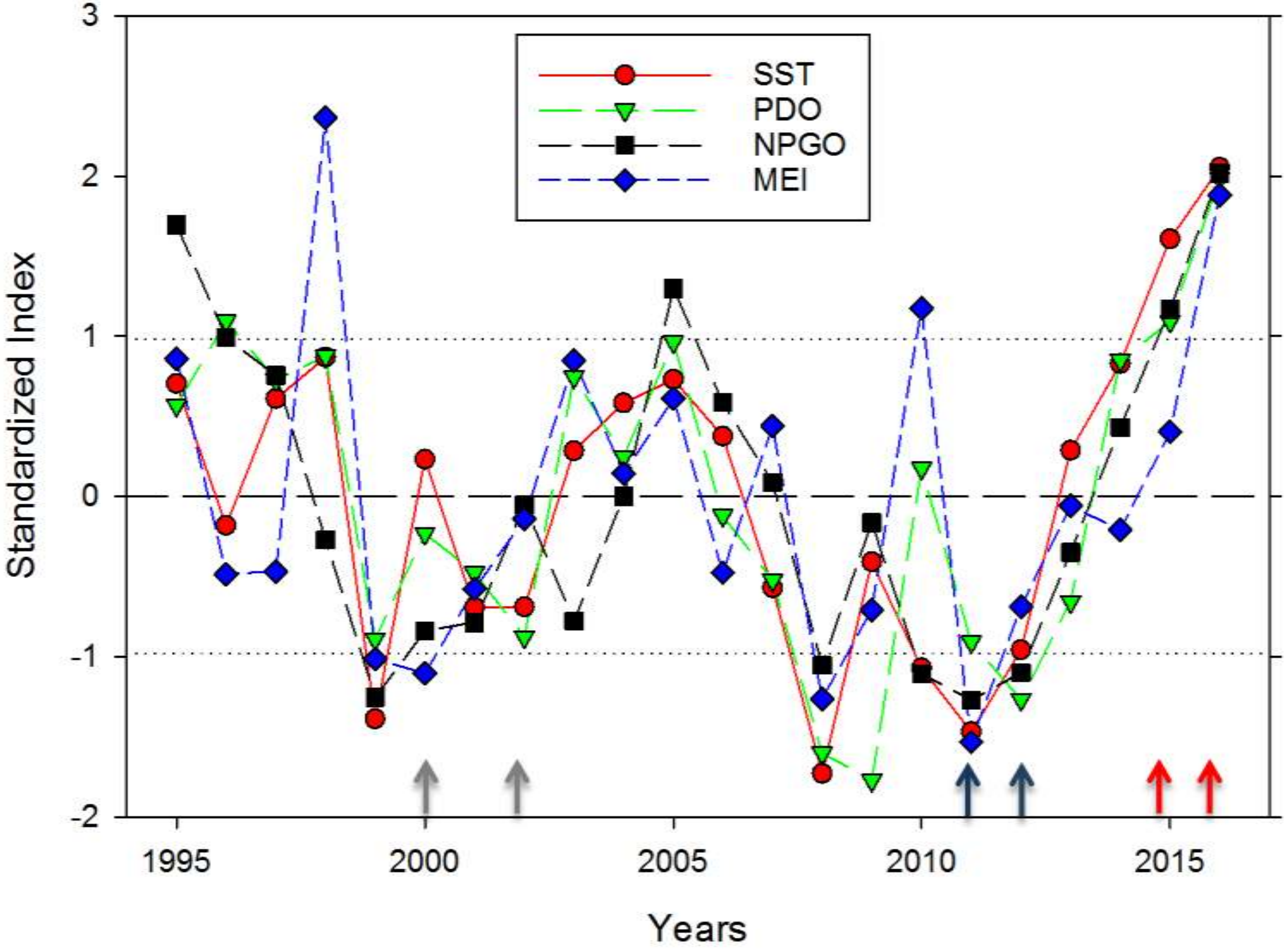
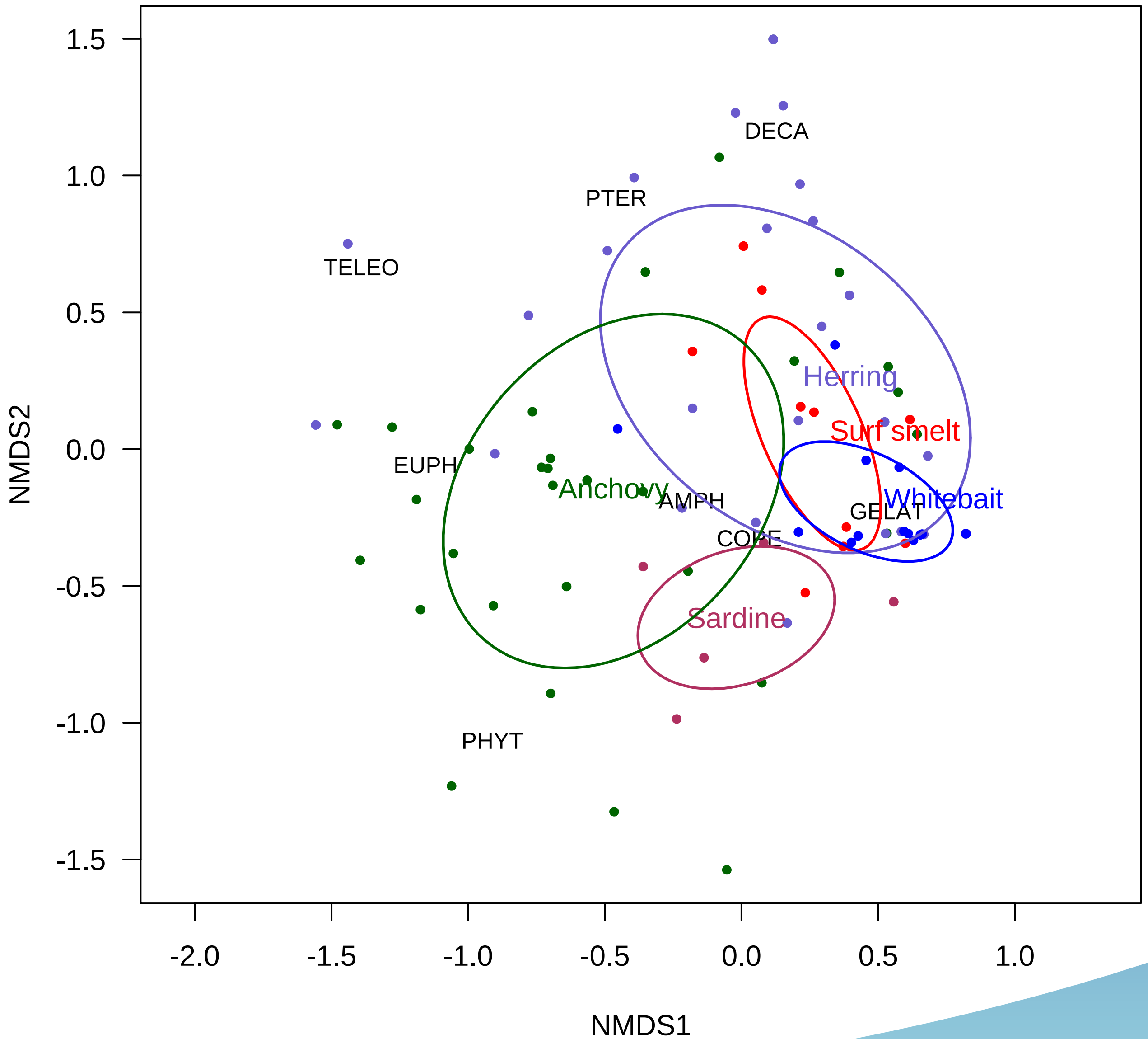
Thank you!

Mary.Hunsicker@noaa.gov



SST
PDO
NPGO
MEI
Standardized Index
Years
3
2
1
0
-1
-2
1995
2000
2005
2010
2015

Forage fish from June 2015 and 2016 with common prey items



Sample size

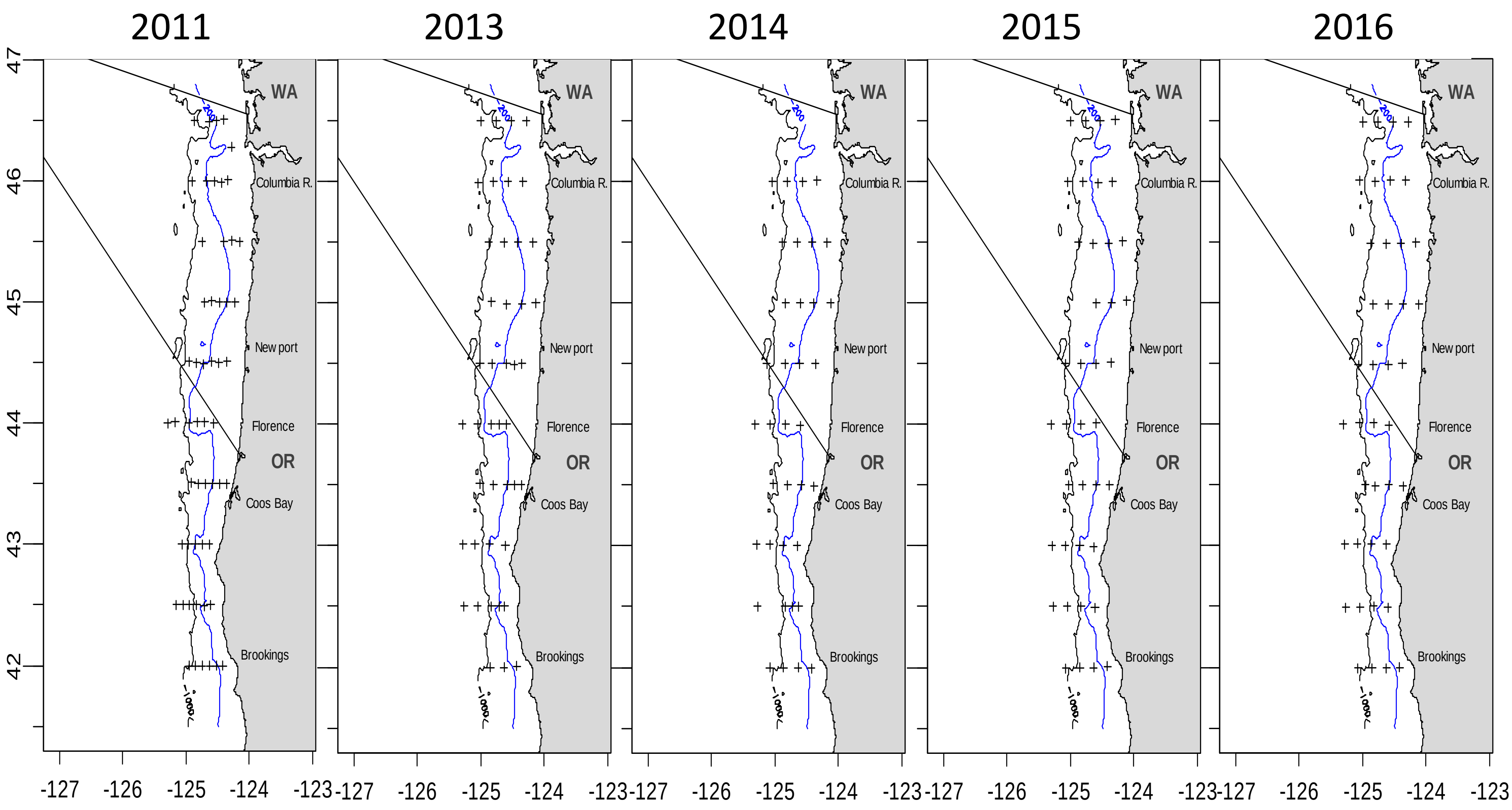
Anchovy	**78**
Sardine	**74**
Whitebait	**221**
Herring	**188**
Surf Smelt	**78**

dispersion ellipses show the standard deviation of the average spatial scores

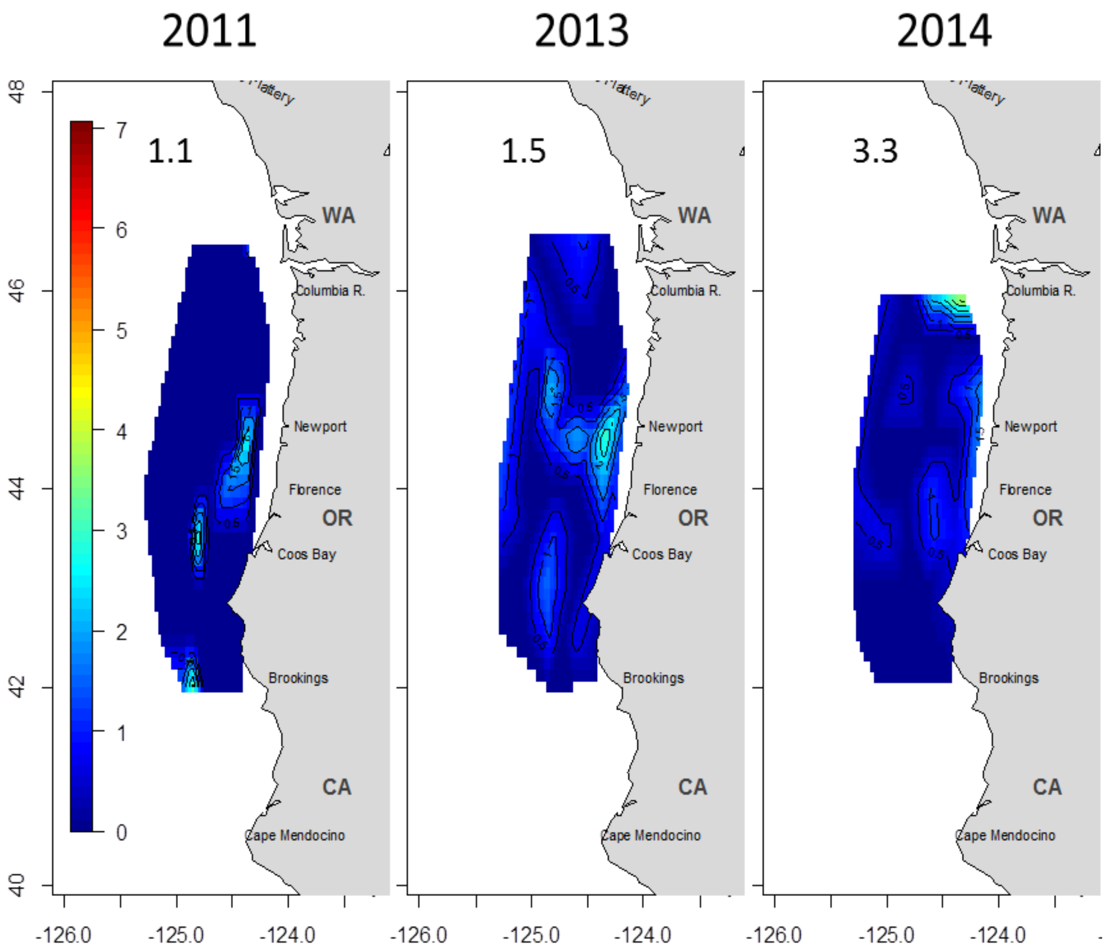
Prerecruit surveys

- **Sampling dates:** June 2011, 2013-16
- **Net:** modified-Cobb midwater trawl with a 26-m headrope and a 9.5-mm codend liner
- **Headrope depth:** 30 m
- Sampled 10 transects off Oregon and southern Washington

Sampling Locations



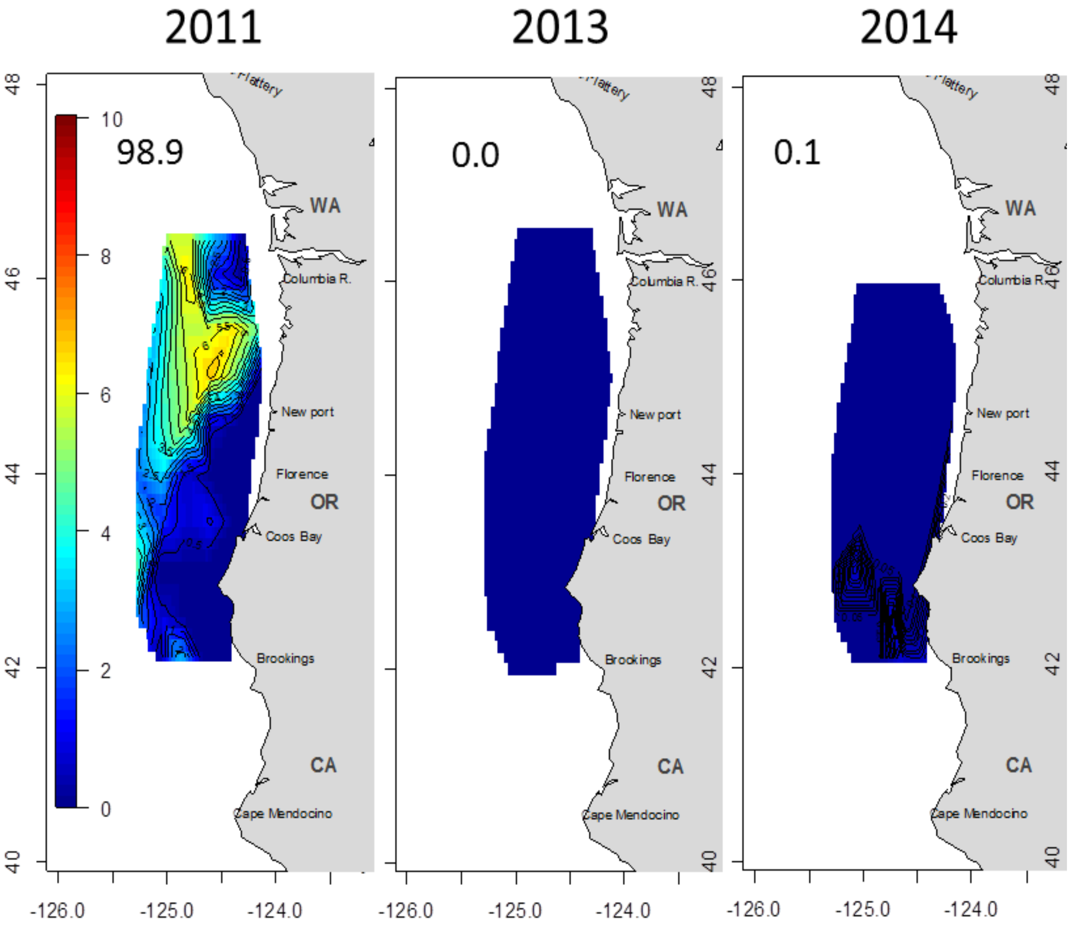
Water Jellies
Aequorea victoria



Scale bar = log (abundance)
Number = Geometric mean abundance

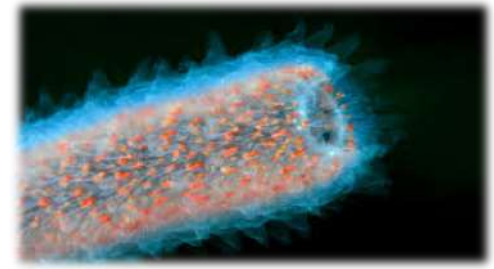
Brodeur et al. (MS)

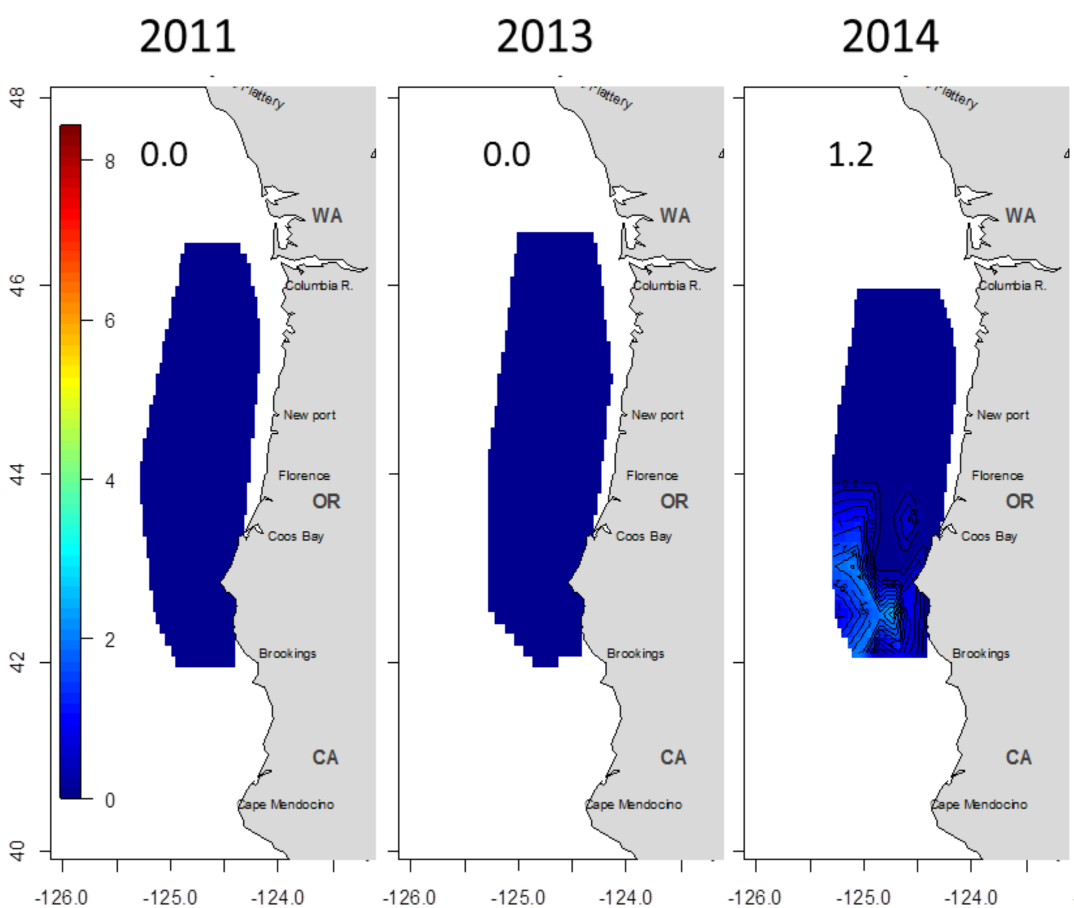
Total Salps
Salpa fusiformis



Brodeur et al. (MS)

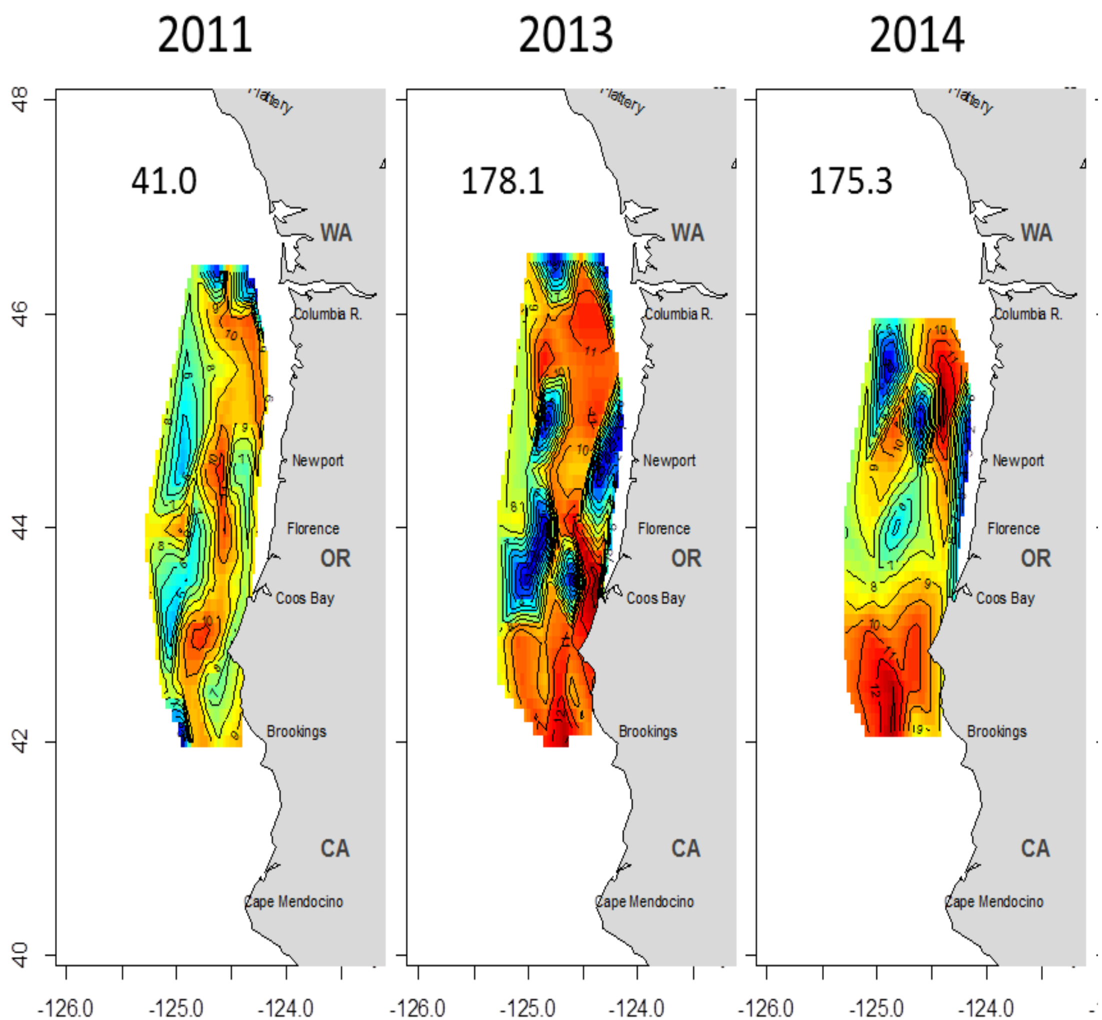
Pyrosoma atlanticum





Brodeur et al. (MS)

Total Euphausiidae



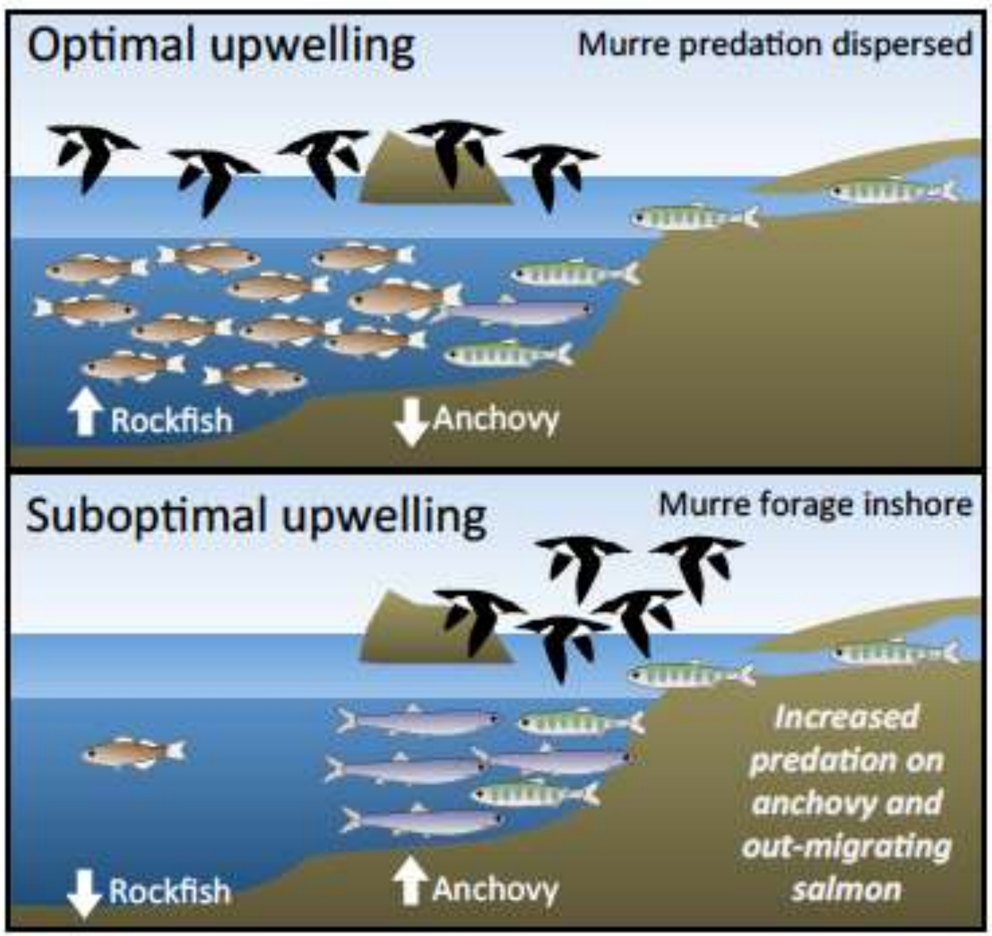
Number = mean abundance in thousands

Brodeur et al. (MS)

Table 2. Results of the Multi-Response Permutation Procedure (MRPP) for June diet differences by species for the various regimes examined. Shown is the value for the MRPP *A*-statistic which is the chance-corrected within-group assignment. Also shown is the significance of the *A*-statistic (***$p \leq 0.001$; **$p \leq 0.01$; *$p \leq 0.05$; ns: not significant)

Species	Warm vs.	Warm vs. Average	Cool vs. Average
Northern anchovy	0.20***	0.18***	0.35***
Pacific herring	0.09***	0.06***	0.02*
Pacific sardine	0.12***	–0.01 ns	–0.01 ns
Surf smelt	0.10***	0.0 ns	0.36***
Whitebait smelt	0.44***	0.19***	0.03 ns
Jack mackerel	–	0.17***	–
All species combined	0.14***	0.01***	0.02***

Predation dynamics influenced by ocean conditions



Wells et al. 2017