Columbia River Plume and California Current Ecosystem: Role in Salmon Productivity

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Northwest Fisheries Science Center

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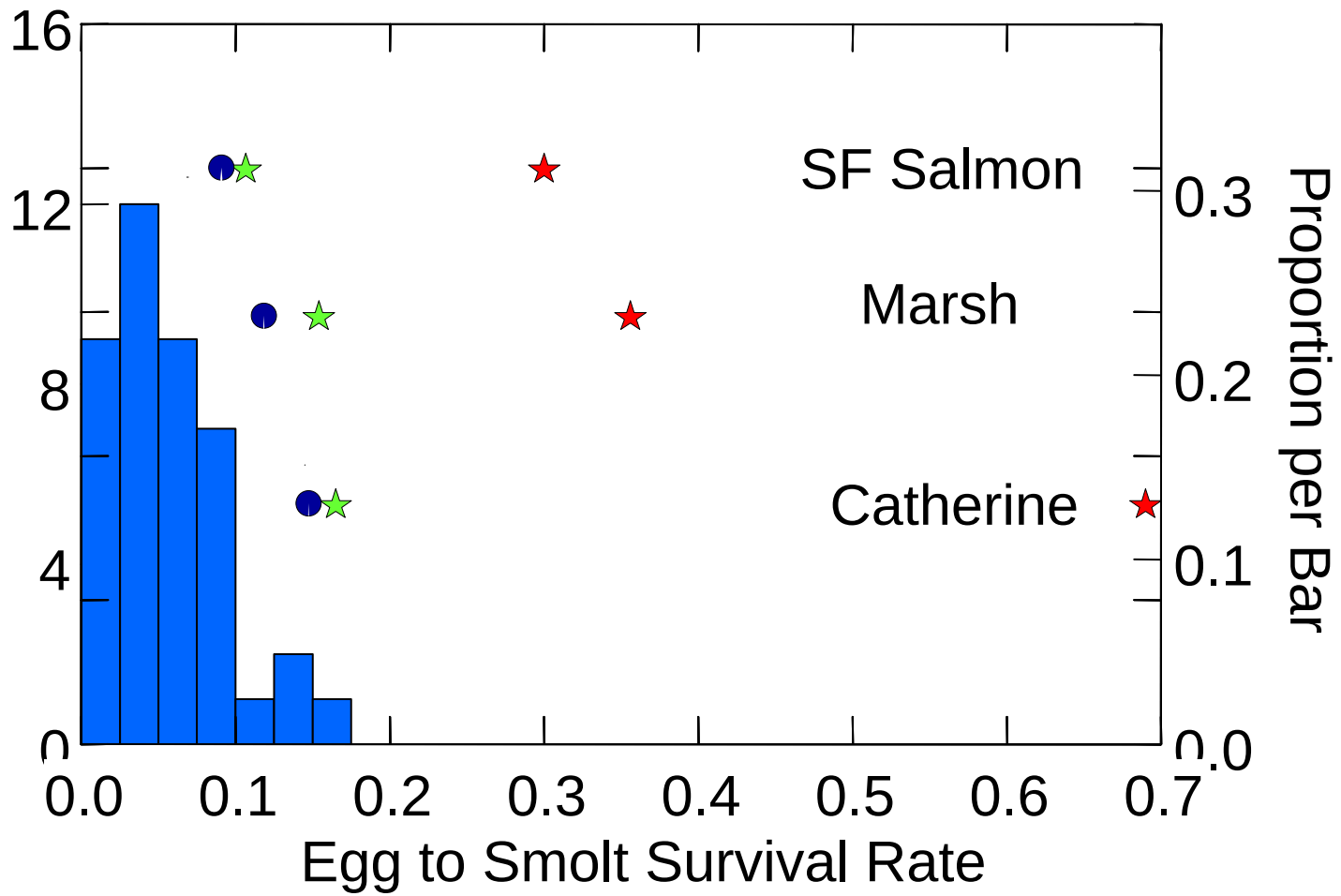
Why study the ocean?

- Ocean productivity sets salmon recruitment levels - return rates can vary >10x with similar freshwater conditions/survival

- The coastal pelagic ecosystem is dynamic and the variability seems to be increasing – need to put FW actions in this context

- Objective – Understand processes and develop tools (models and ocean indices) for forecasting salmonid survival and returns

Egg-smolt Potential- Snake River Spring Chinook



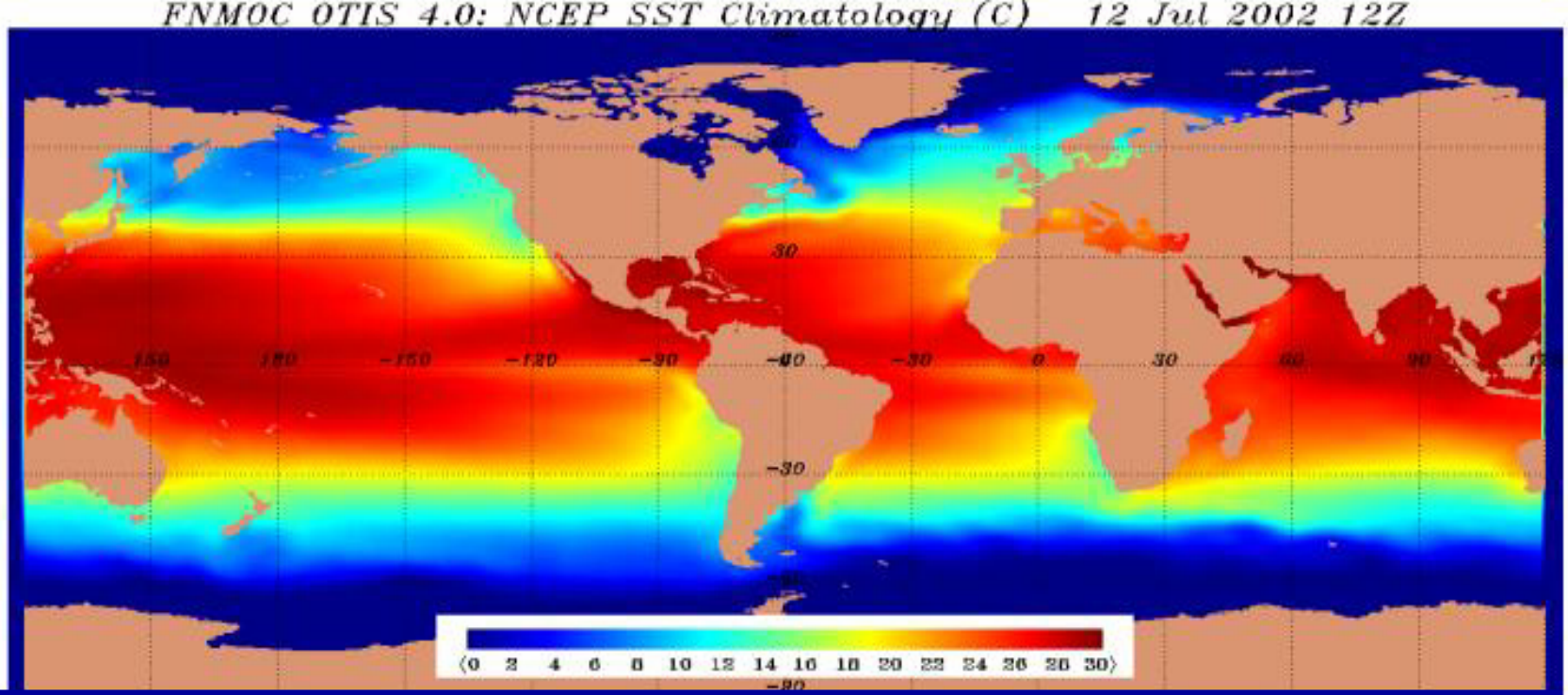
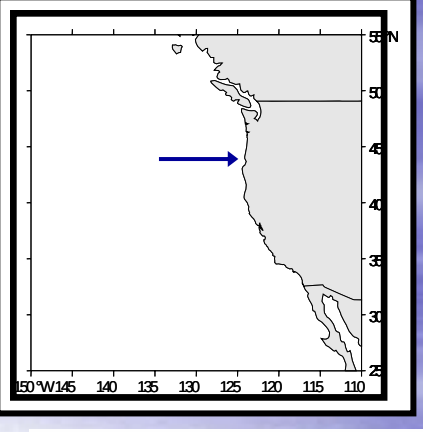
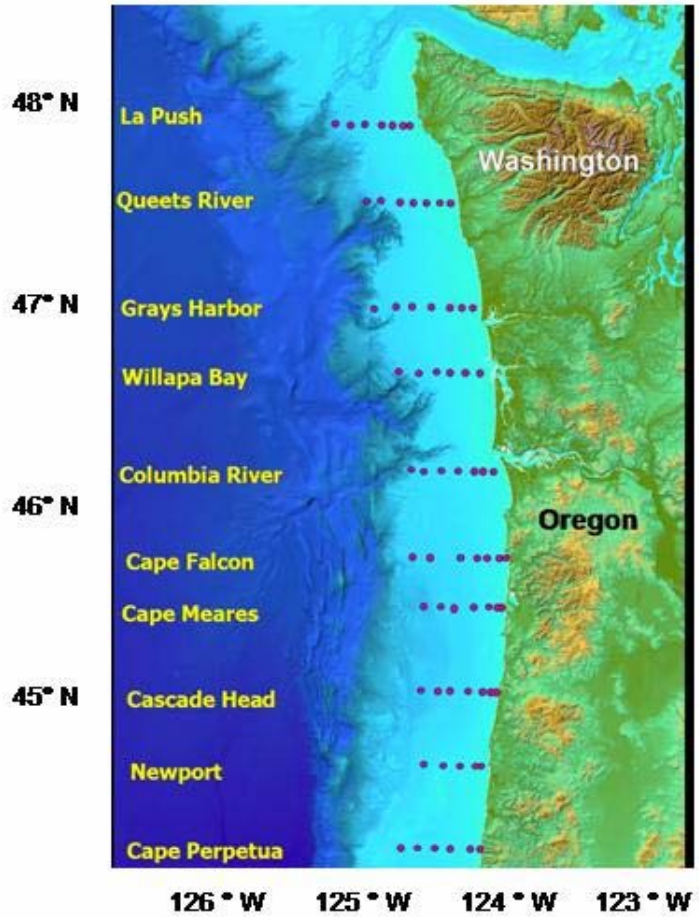


CHART OF SEA SURFACE TEMPERATURE

- Note: warm water between the equator and ~ 30 N
- Because of upwelling off North America, S. America N. Africa and S. Africa, cool water is found at the coast. Without upwelling, the coasts would be ~ 5-10 °C warmer during summer because offshore waters would move shoreward.



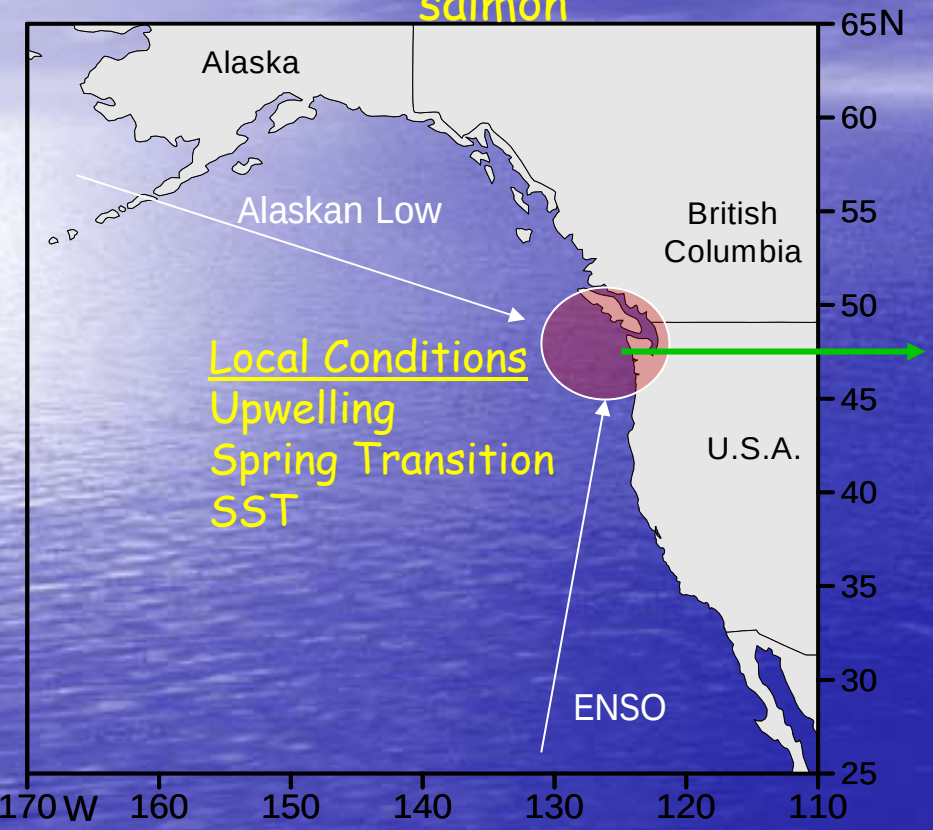
Plankton, Salmon and Pelagic Fish Sampling

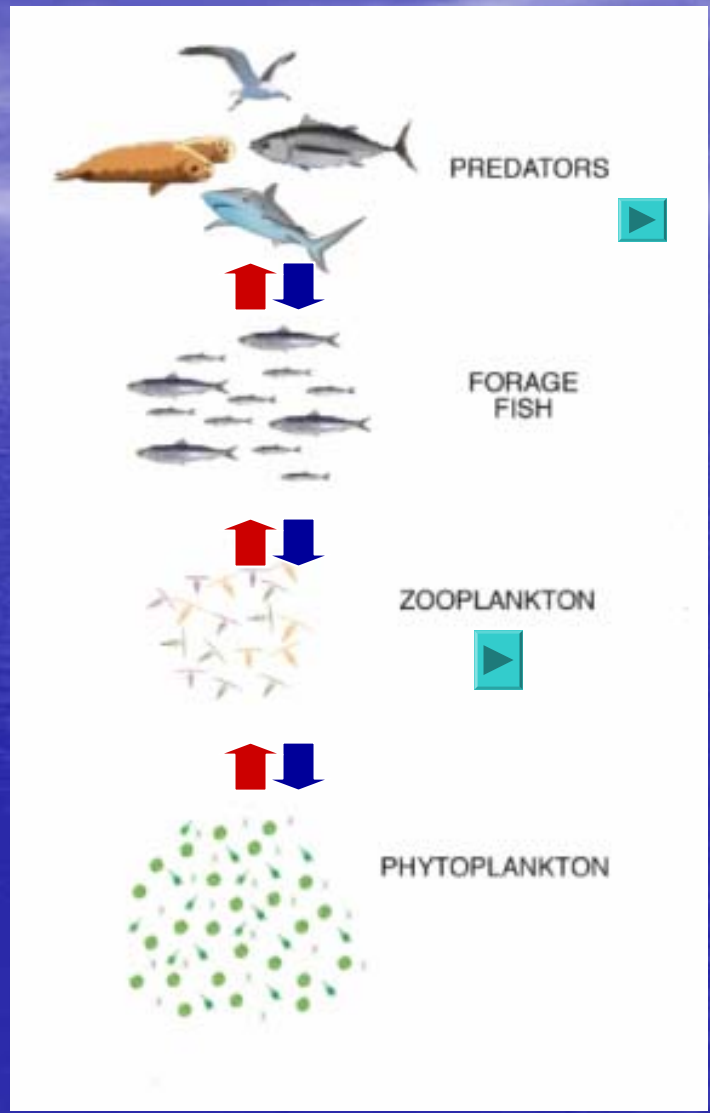


- Sample in May, June and September (50 stations) since 1998
- Sample Columbia River and Willapa Bay every 10 days from April through July (AT NIGHT) at ~ 10 stations; since 1998
- Sample off Newport every two weeks, since 1996
- Have historical data on hydrography and zooplankton from 1970s and 1983; salmon abundance data from 1981-1985 but only some of these data are part of this talk

State of the Northern California Current Ecosystem

Influenced by large scale forces acting at the local scale to affect biological process important for salmon





Local Biological Conditions

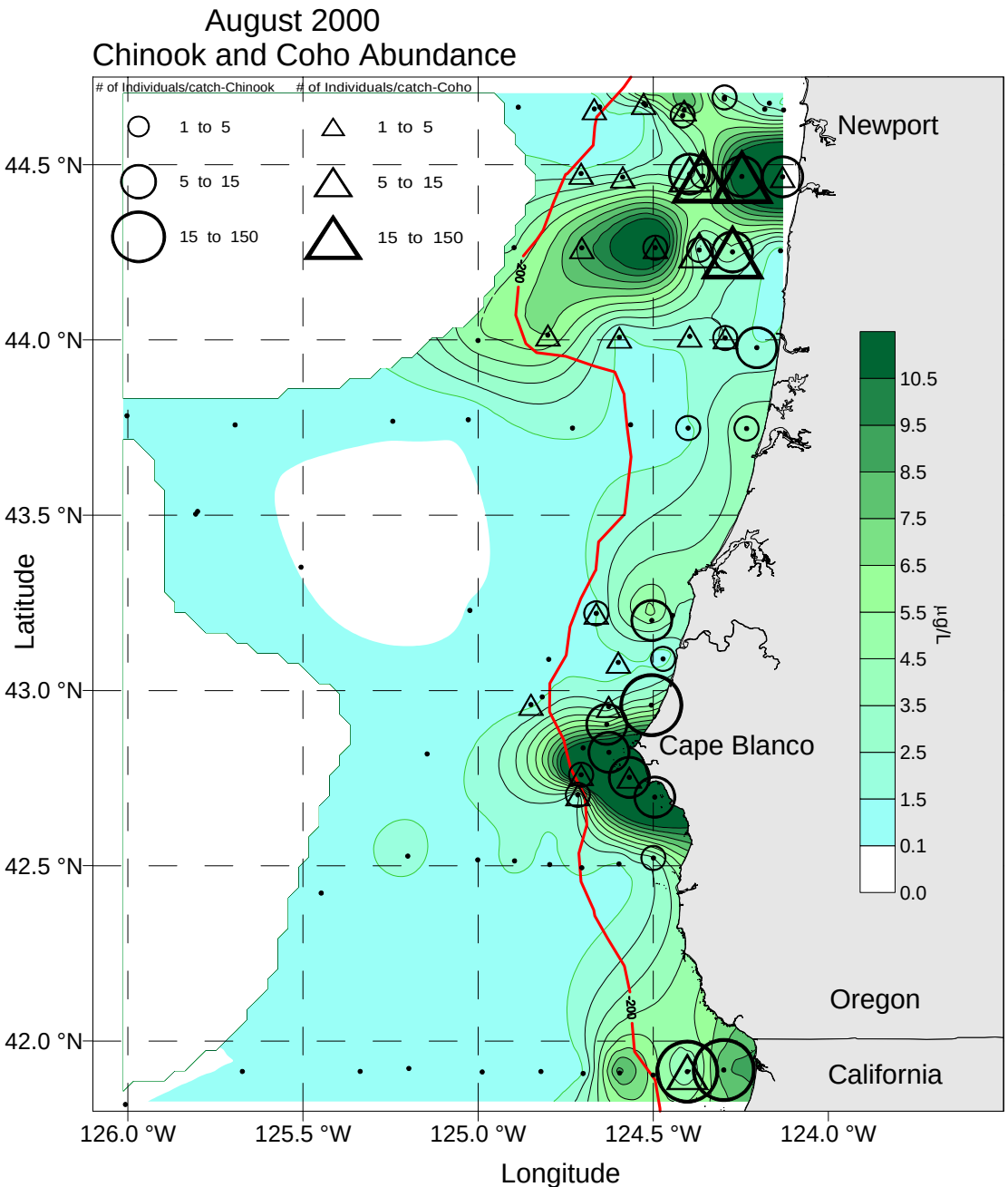
My Task

- Ocean entry timing and plume research
- Ocean productivity, variability, and PDO

Overview – Ocean Factors

- Growth – bottom up process
- Predation – Top down process
- Development of ocean condition indices
- Plume and salmon survival
- Ocean habitat, variable ecosystem, forecasting

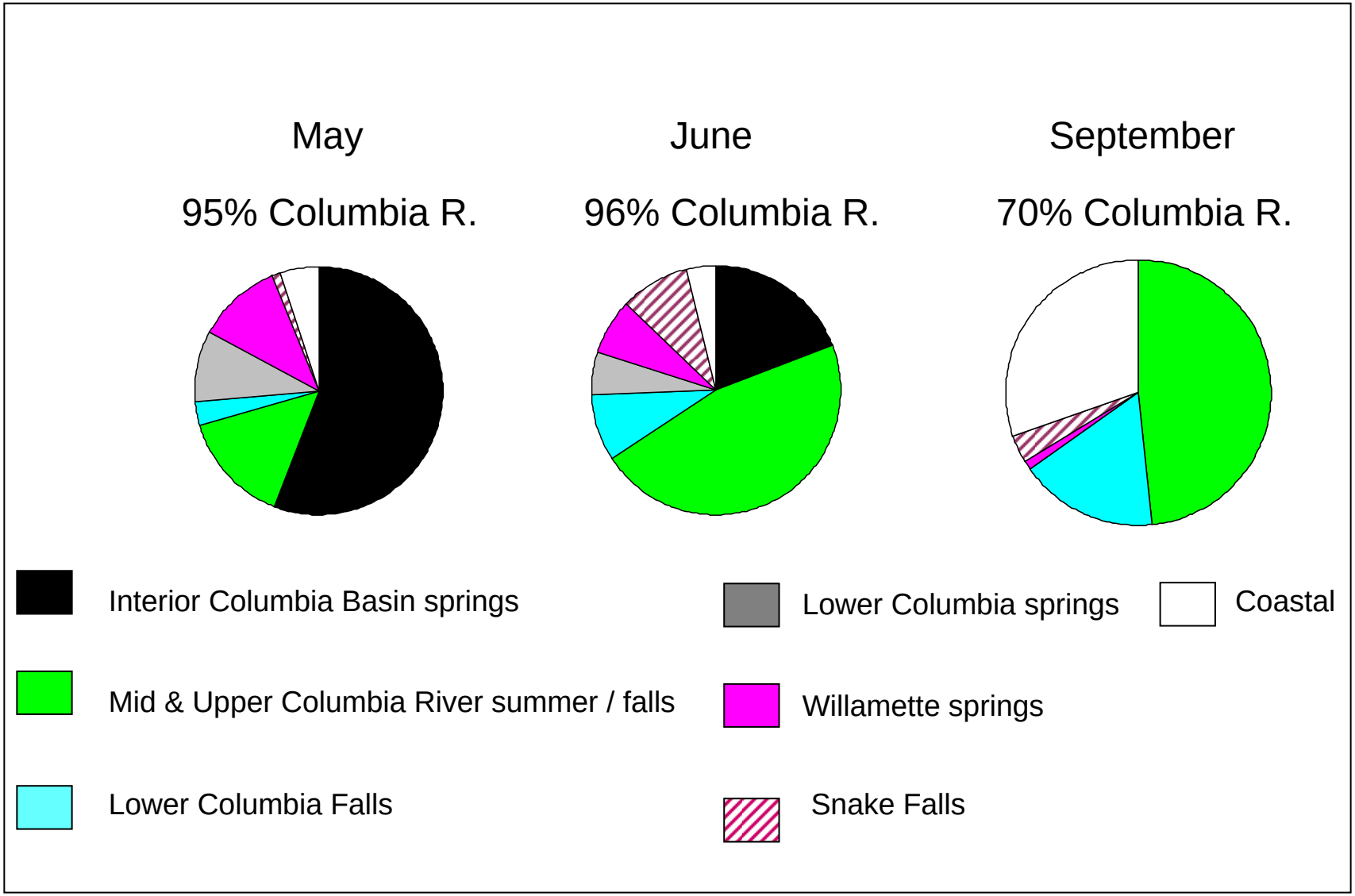
Where Are Juvenile Salmon in the Coastal Ocean?



Salmon - Habitat Linkages: Salmon are not everywhere in the coastal ocean!

Salmon Associated with ‘Hot Zones’ of Ocean Productivity

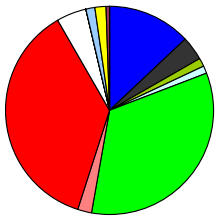
Juvenile Chinook Stock Compositions off Oregon and Washington from analysis of microsatellite DNA variation



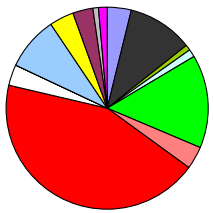
Genetic Stock Identification of Juvenile Chinook Salmon
Columbia River Plume Study Area

September Cruises 1998 - 2006

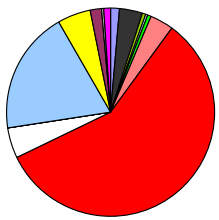
Grays Harbor to LaPush



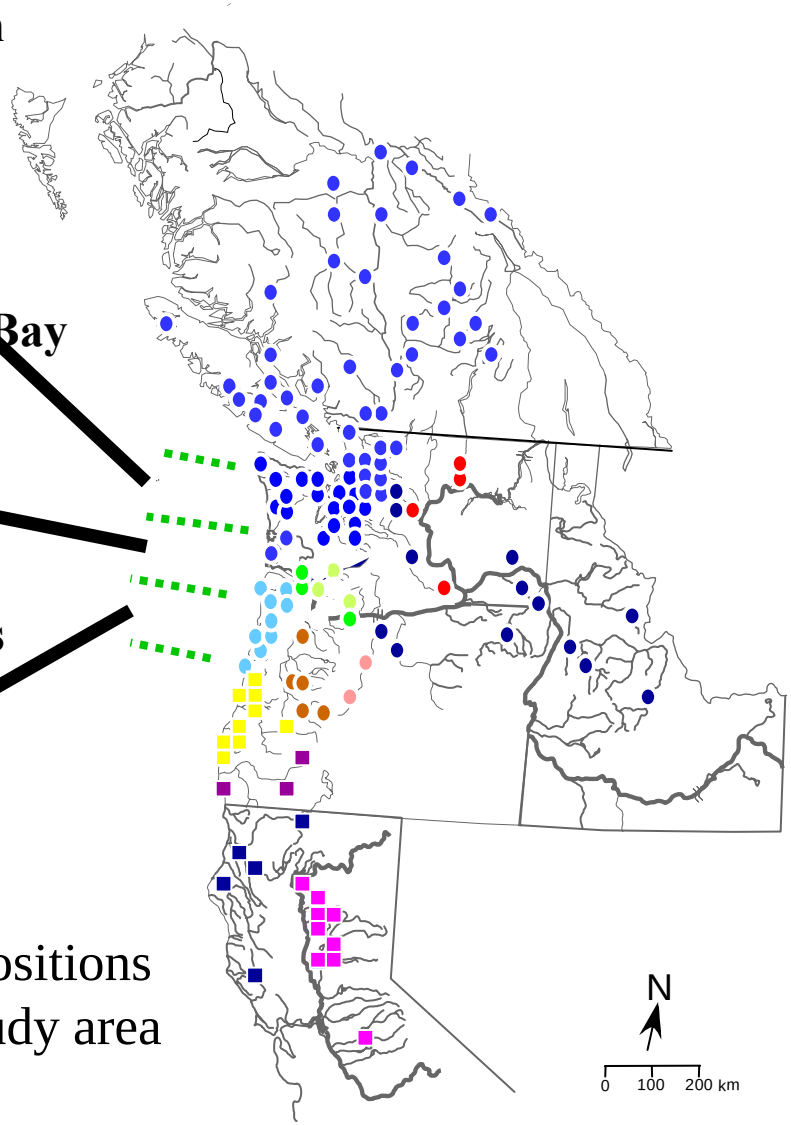
Cape Falcon to Willapa Bay



Newport to Cape Meares



Charts show stock compositions in three regions of the study area



Source Populations

- North of Columbia River
- Lower Columbia Fall
- Lower Columbia Spring
- Upper Willamette Spring
- Spring Creek Group Fall
- Deschutes Fall
- Upper Columbia Summer/Fall
- Snake Fall
- Interior Columbia Basin Spring
- North Oregon Coast
- Mid Oregon Coast
- South Oregon Coast
- Klamath / California Coast
- Central Valley

Overview – Ocean Factors

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- Predation – Top down process
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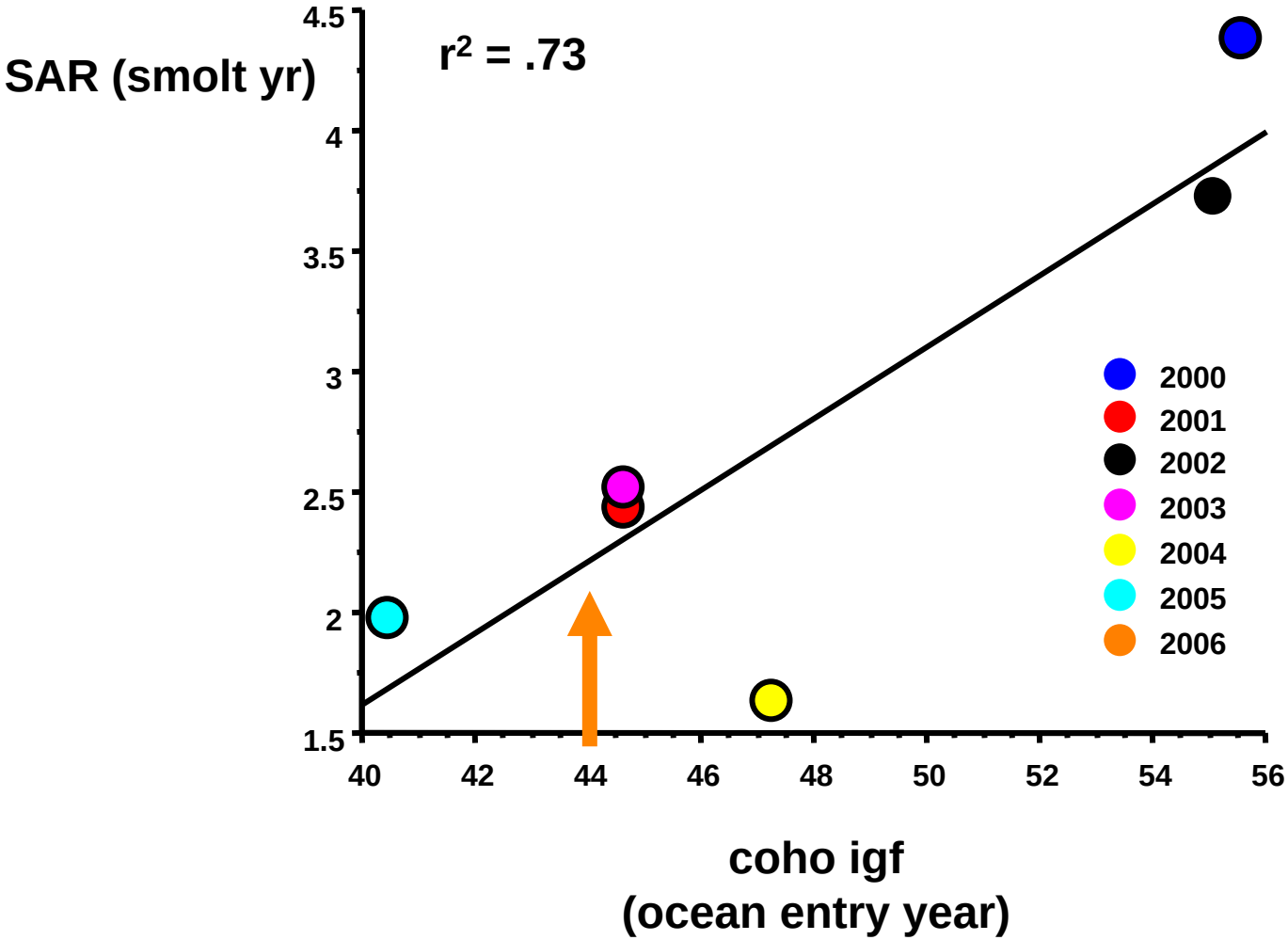
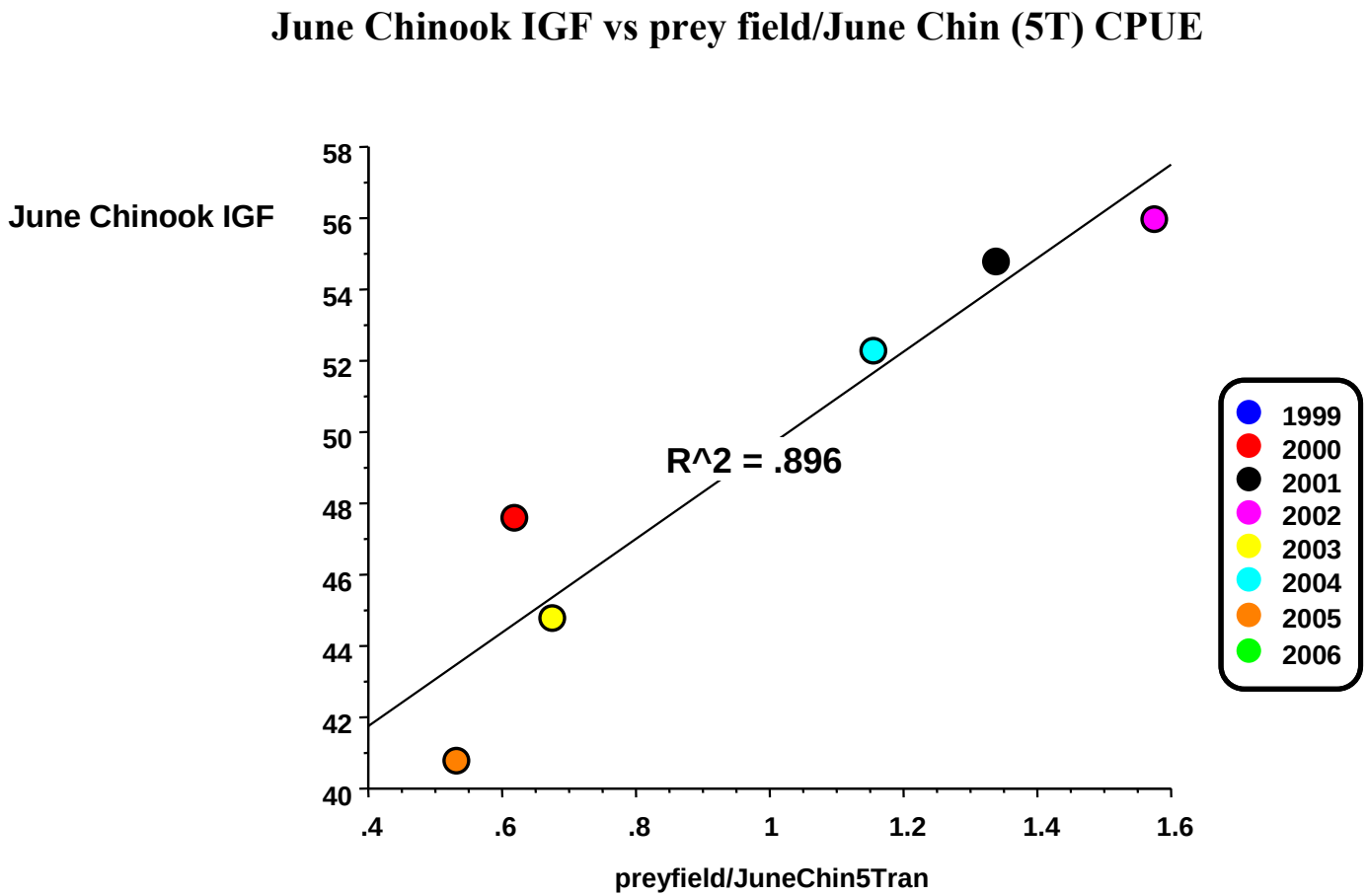
IGF in ocean caught juvenile salmon is related to adult returns



IGF is a critical growth related hormone reflecting recent (2 wk) ocean conditions

IGF in ocean caught juvenile salmon related to available food supply

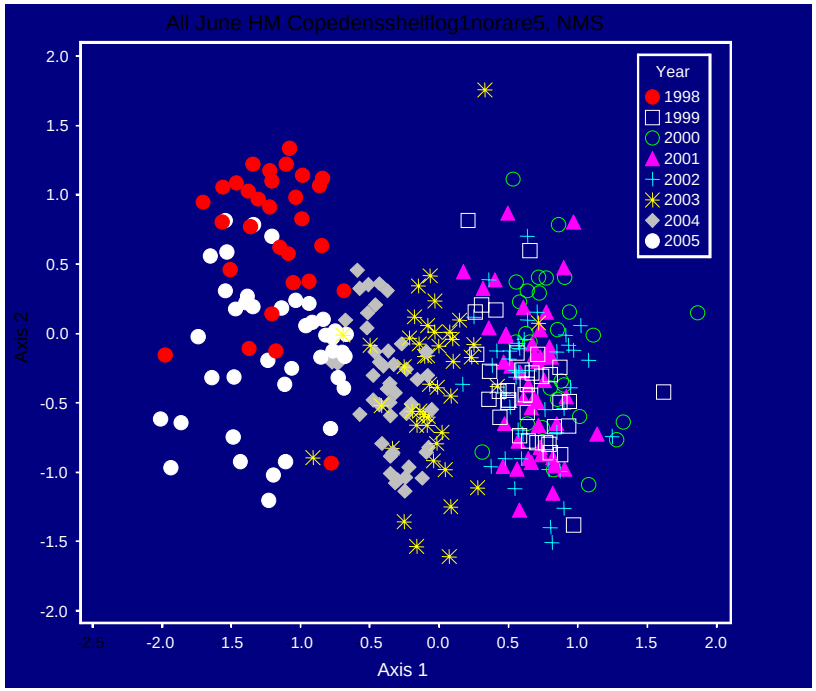
Chinook IGF relates to food and abundance similarly to relations found with coho



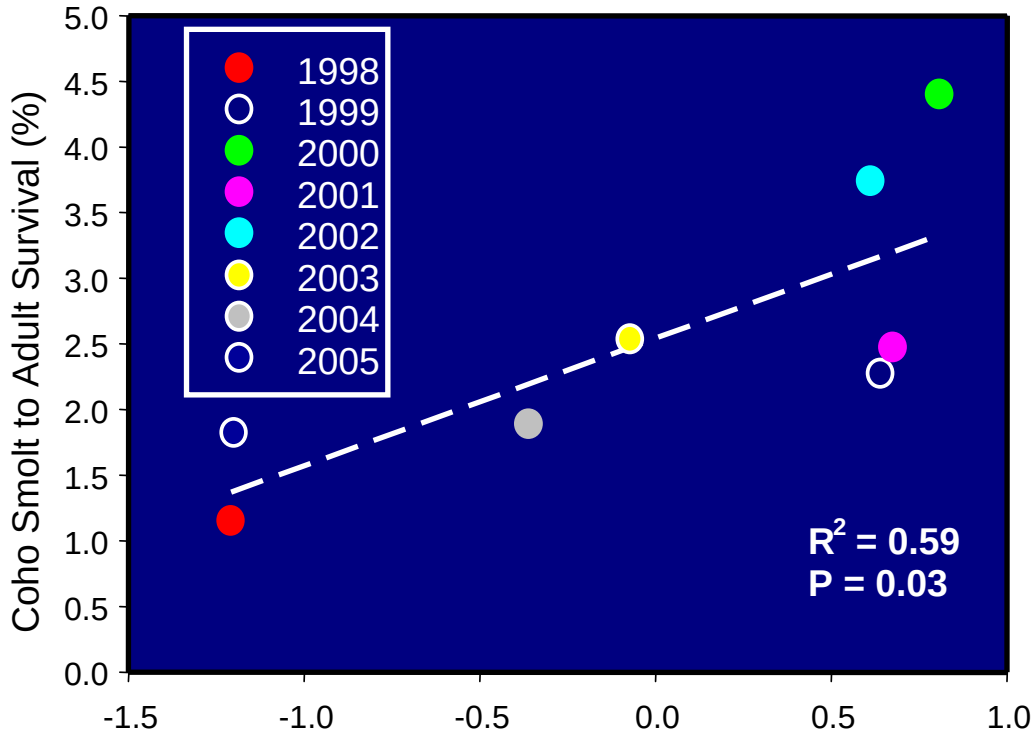
Variation influenced by temperature

Half Meter Vertical Net – Copepods & Coho

Copepod Community Composition in June related to Coho Survival
• 2005 Added since meeting (white dots to the left with 1998)

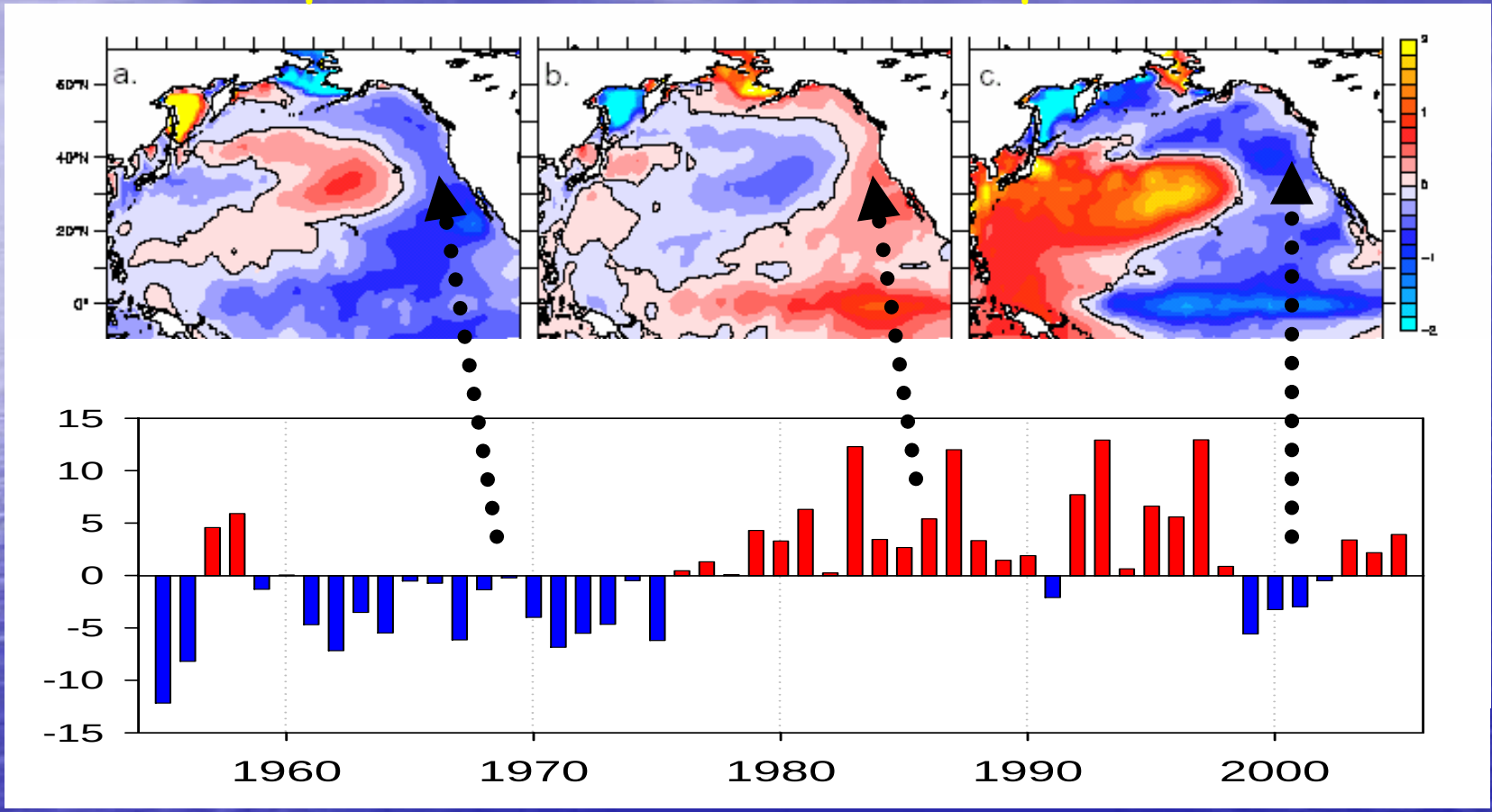


NMS Ordination Median Axis-1 Score (98-05)



NMS Ordination Median Axis-1 Score (98-05)

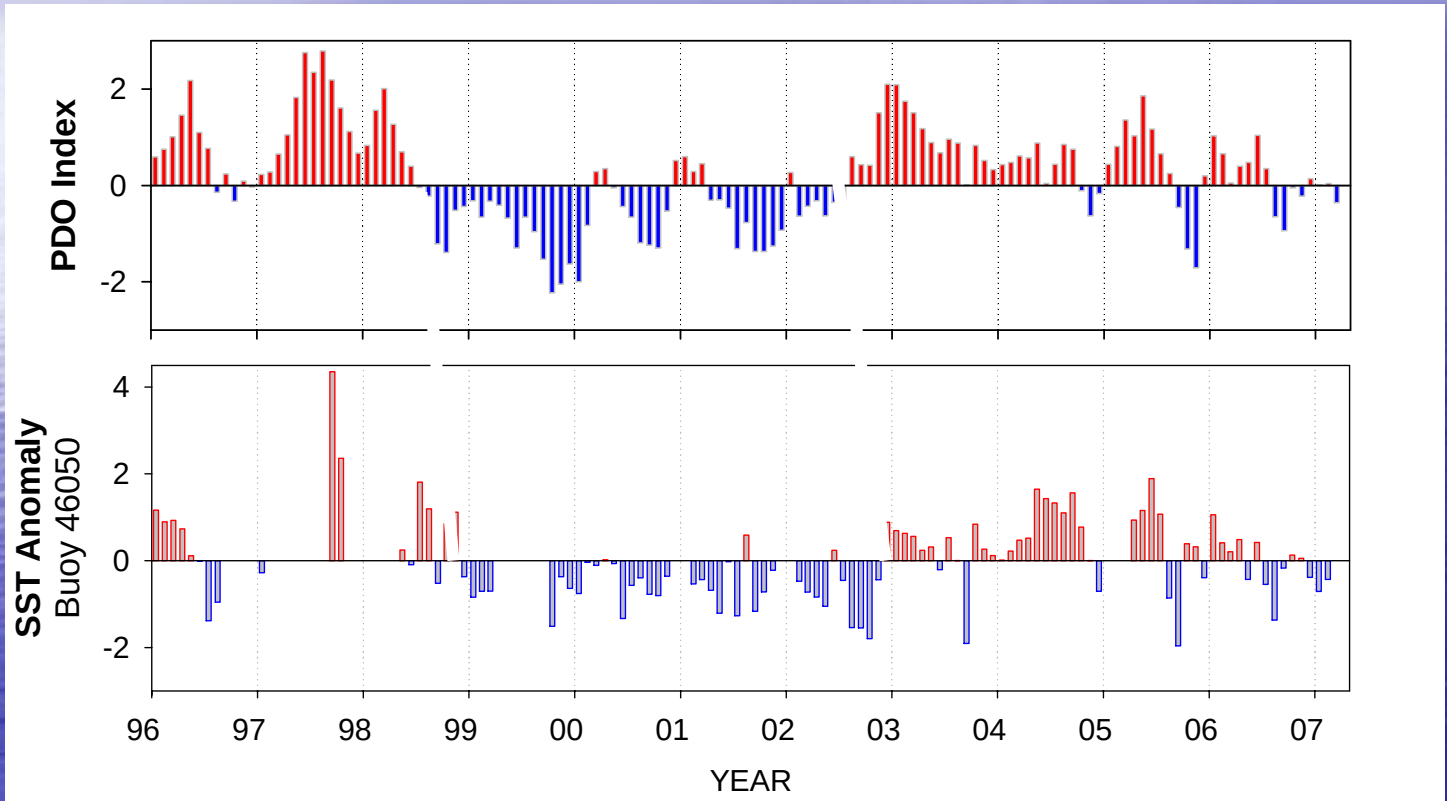
Phase shifts are tracked by the Pacific Decadal Oscillation (PDO): negative values = cool phase; positive values = warm phase.



- Cool phase 1947-1976
- Cool phase 1999-2002
- Cool phase 2006 ??

- Warm phase 1977-1998
- Warm phase 2002-2005

Sea surface temperature (SST) data from weather buoy off Newport shows similar patterns & shows that SST off Newport is related to the PDO = downscaling



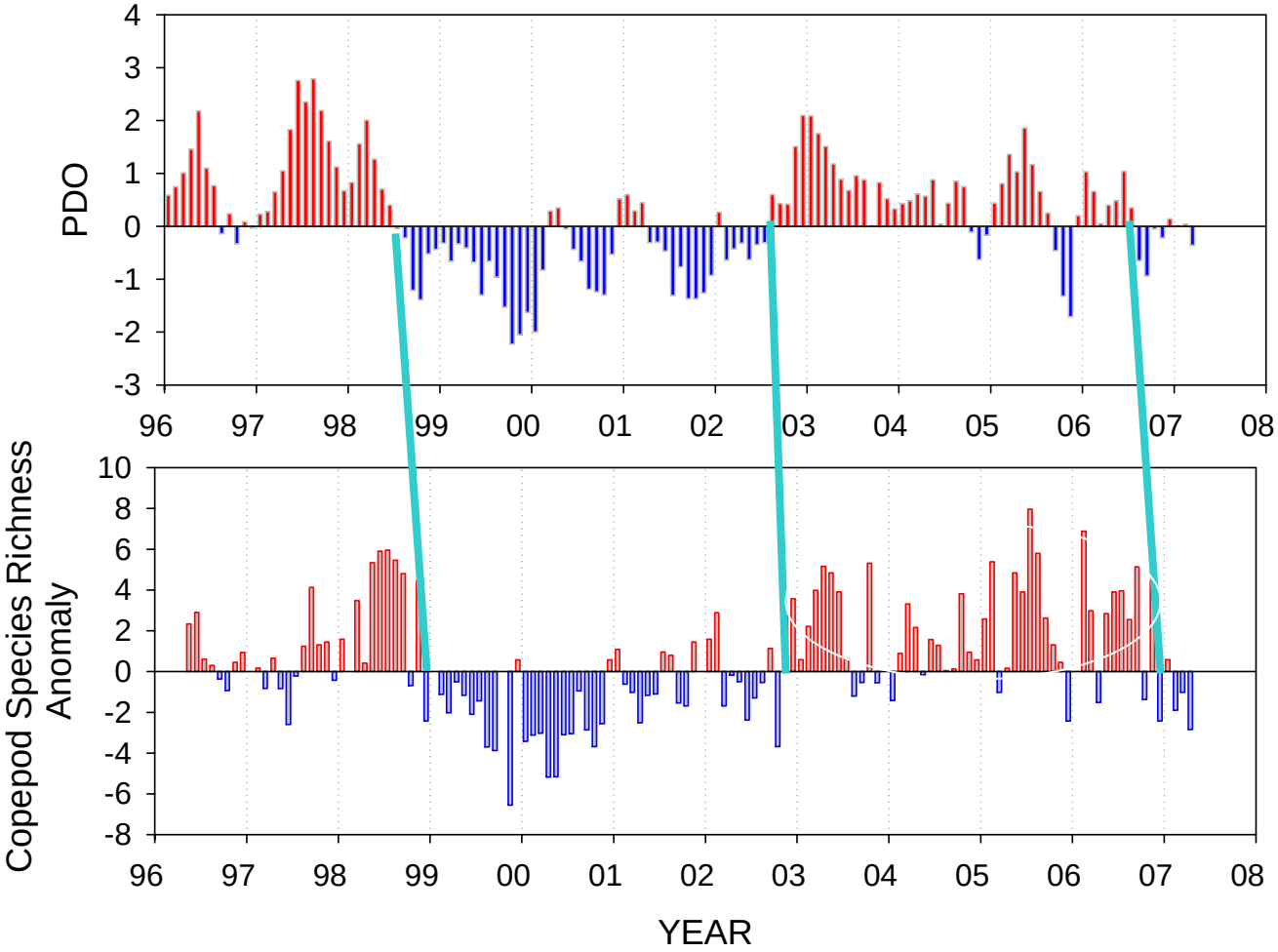
Cooler water in late 1998 associated with PDO change.

Warmer water in late 2002 associated with PDO change.

Most months cooler since late 2005

Note: time lags between PDO and SST change, associated with advection of different water types to Oregon.

Copepod species richness anomaly and the PDO



Species richness reflects origins of the animals. Low = subarctic; high = subtropical

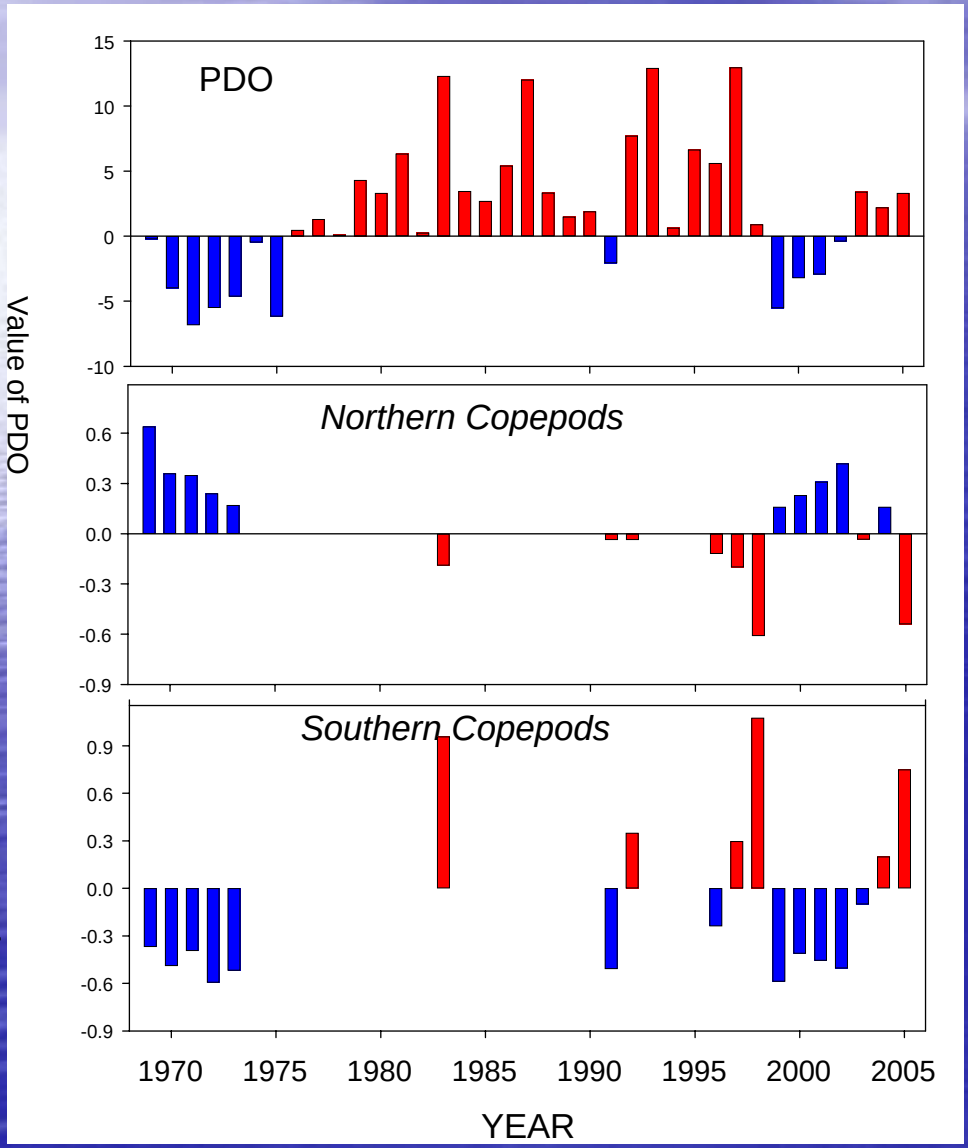
Species richness declined in fall 1998 but began to increase in Nov 02 due to phase shift of PDO

Richness in 2003-2006 similar to the 1997-98 El Niño event

As with SST, 3-5 months following PDO change, copepod species richness switches.

- Suggests different water types appear off Oregon with persistent changes in PDO.
- Now, changing again,

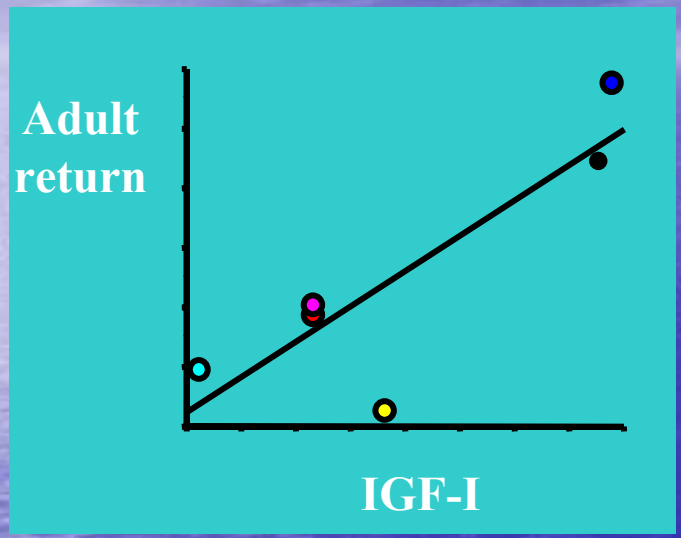
PDO v Northern and Southern copepod biomass anomalies



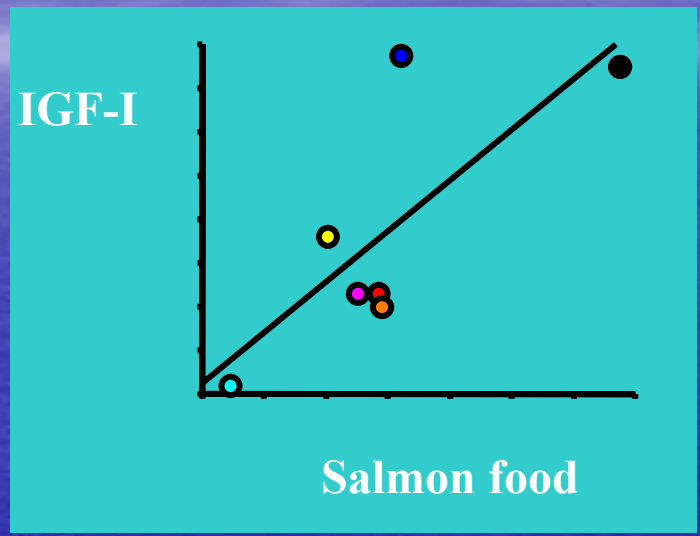
- Strong positive anomalies of Northern species when PDO is negative;
- Strong positive anomalies of southern species when PDO positive and during El Niño events (83, 97/98);
- 2005 especially anomalous with regards to copepod species, looking very "El Niño like"!

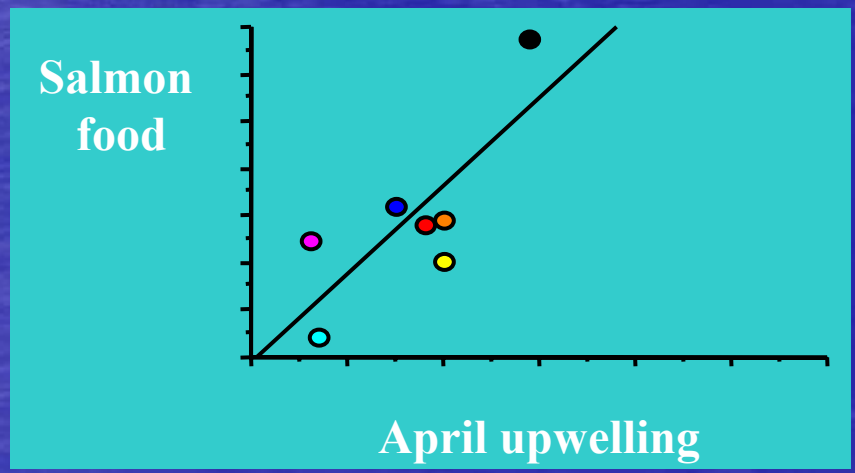
Summary

Survival relates to growth



Growth relates to food

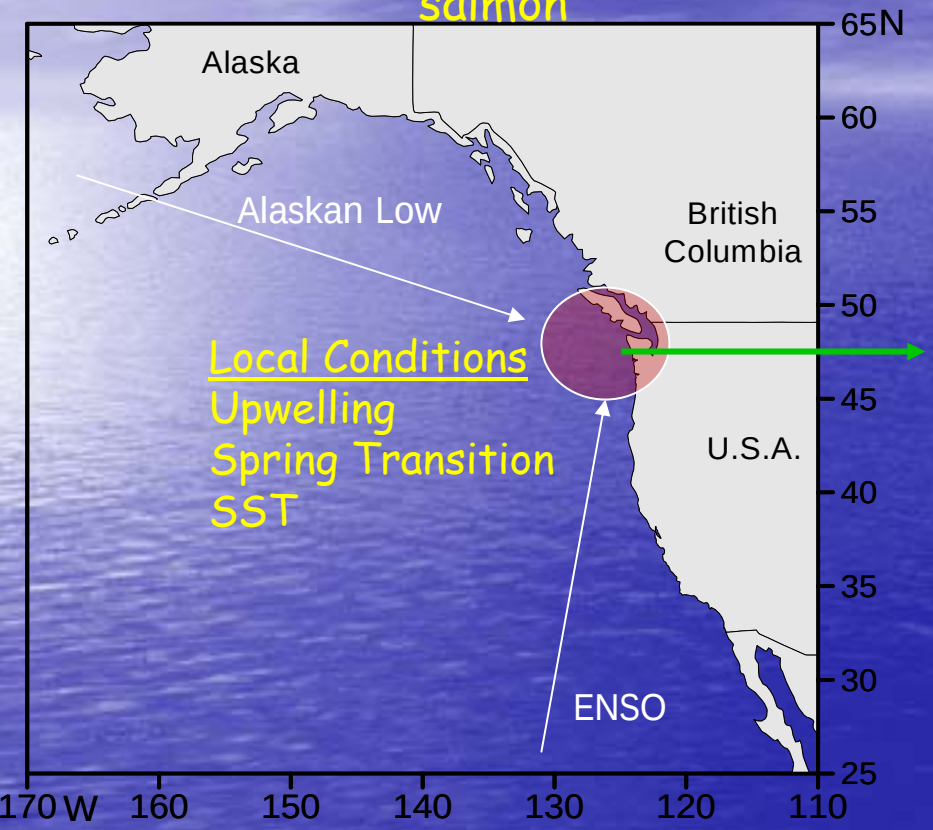


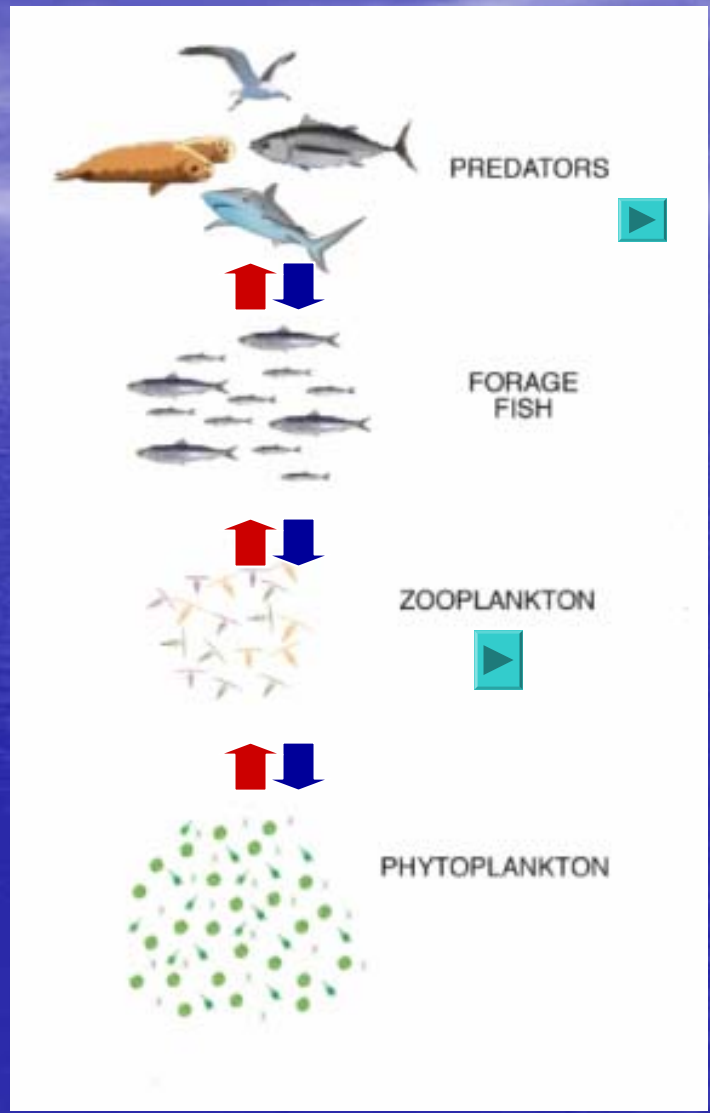


Food relates to ocean conditions

State of the Northern California Current Ecosystem

Influenced by large scale forces acting at the local scale to affect biological process important for salmon





Local Biological Conditions

Overview – Ocean Factors

- Growth – bottom up process
- Predation – Top down process (Fish, Bird and Disease)
- Development of ocean condition indices
- Plume and salmon survival
- Ocean habitat, variable ecosystem, forecasting

Predatory Fishes

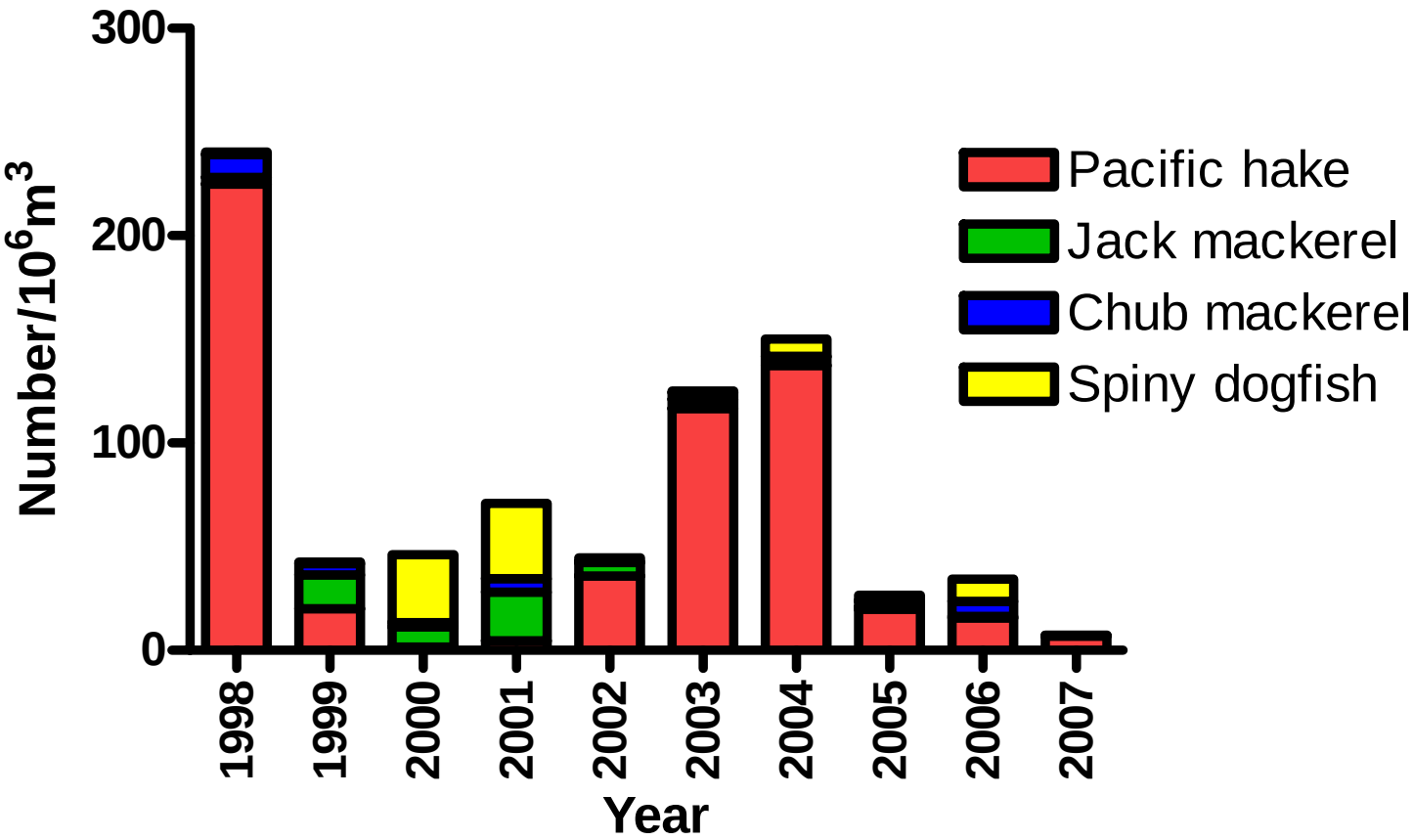
Jack mackerel (*Trachurus symmetricus*)

Pacific mackerel (*Scombrus japonicus*)

Pacific hake (*Merluccius productus*)

Spiny dogfish (*Squalus acanthias*)

Predator Densities off the Columbia River



Important Forage Fishes

Pacific herring (*Clupea pallasi*)

Whitebait smelt (*Allosmerus elongatus*)

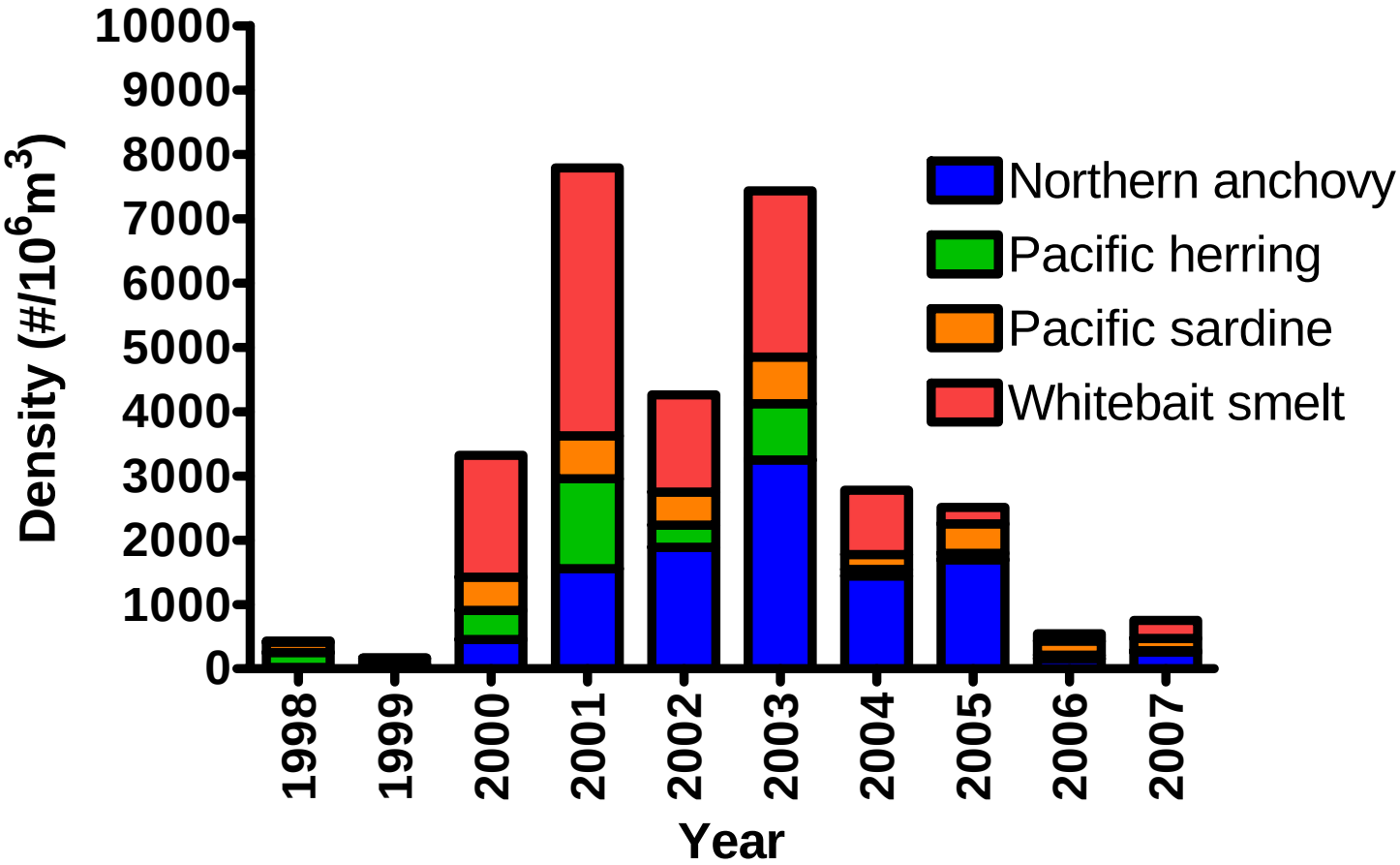
Eulachon (*Thalichthys pacificus*)

Chinook salmon (*Oncorhynchus tshawytscha*)

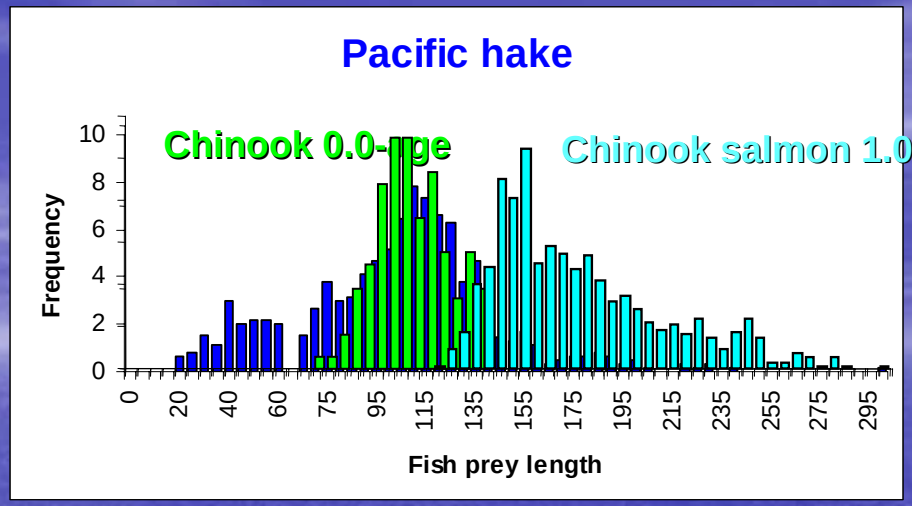
Northern anchovy (*Engraulis mordax*)

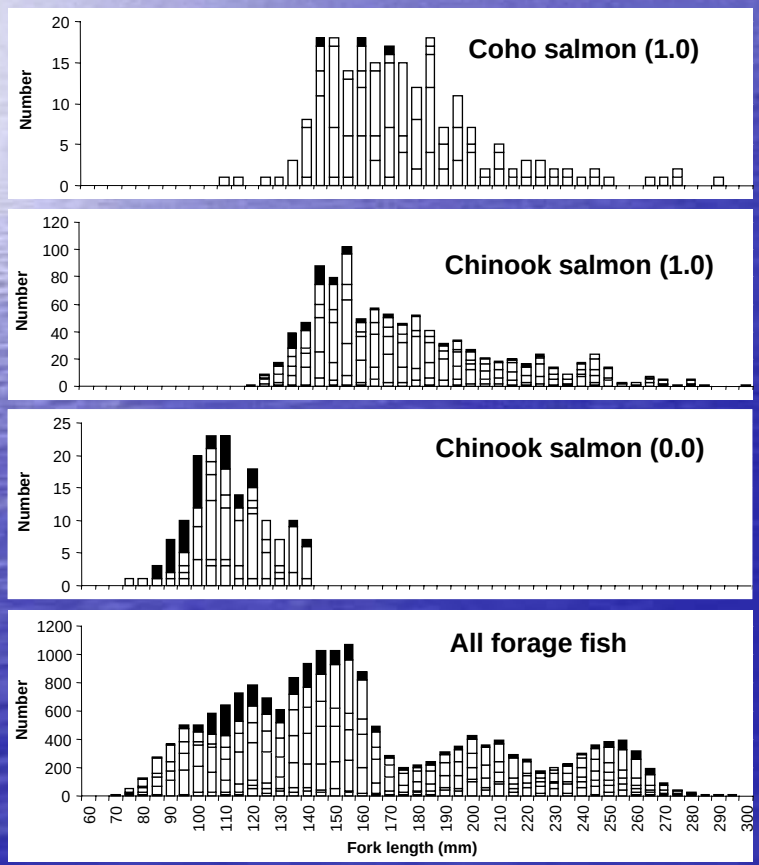
Pacific sardine (*Sardinops sagax*)

Forage Fish Densities off the Columbia River

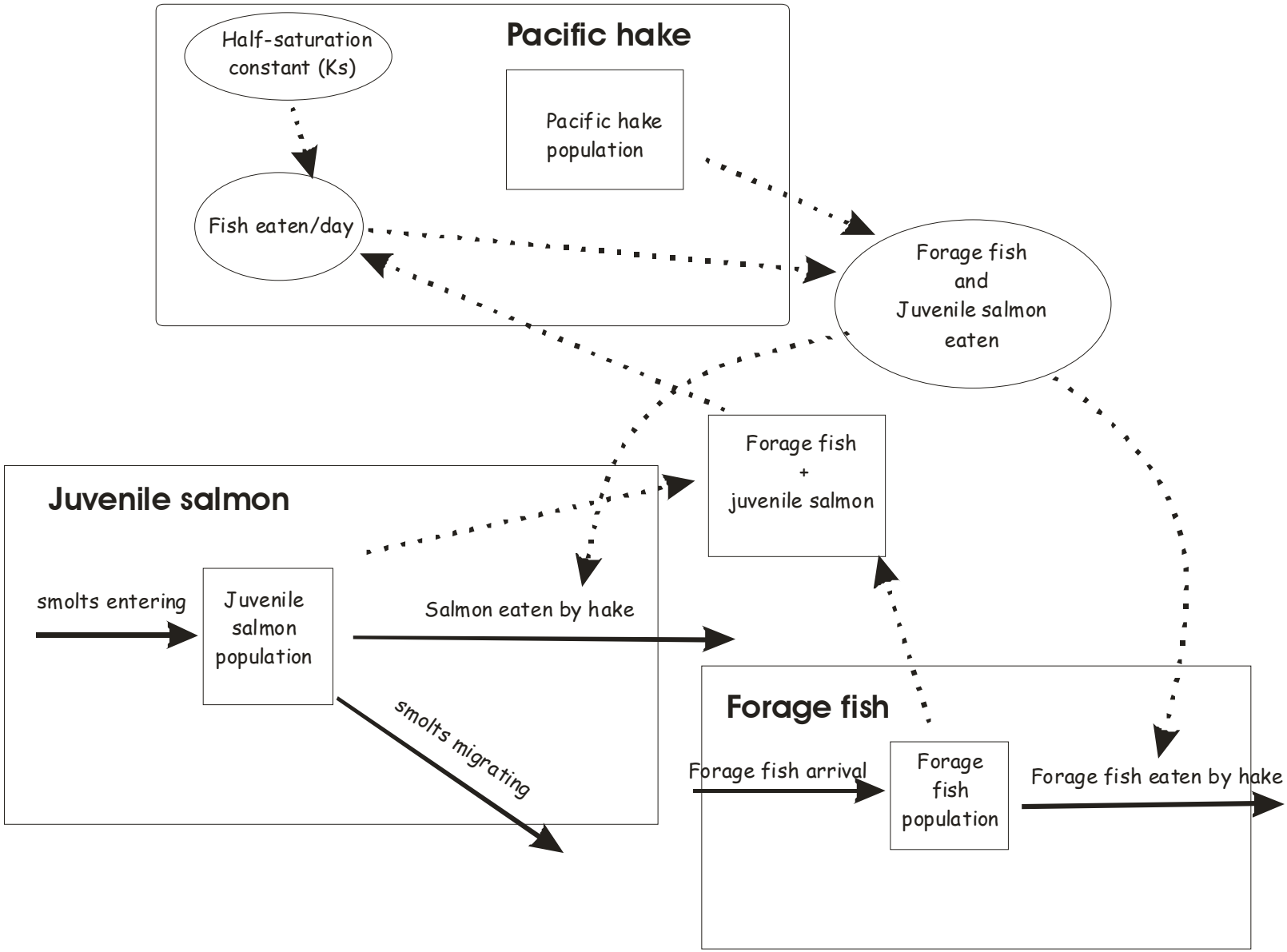


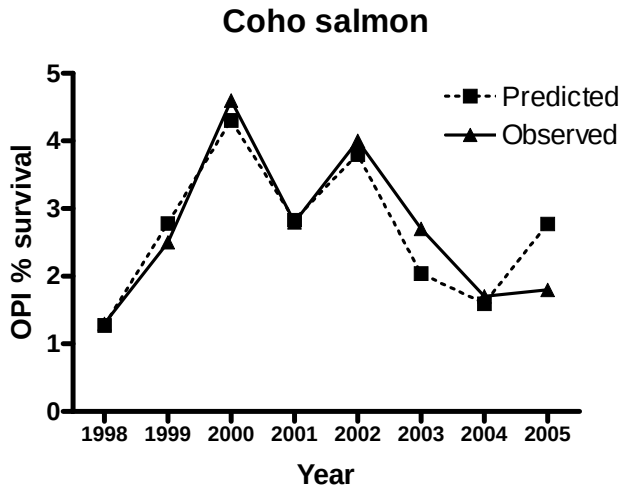
Predator/Prey Interactions – Top Down Forces

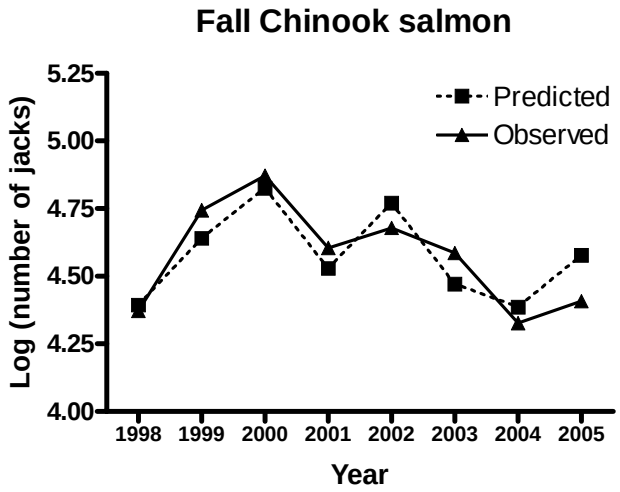


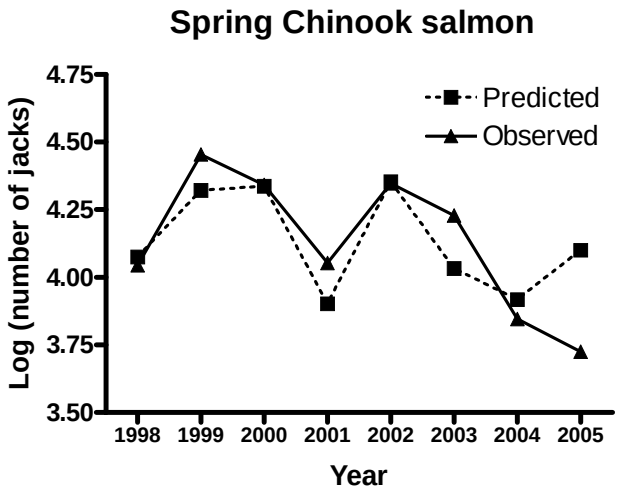


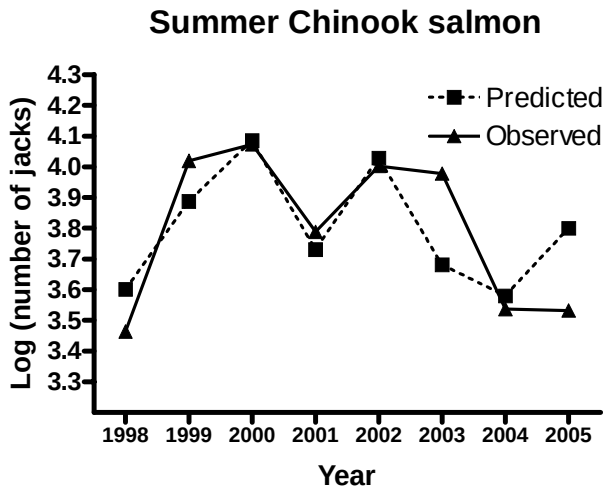
Model the Impact of Piscine Predation on Juvenile Salmon




Coho salmon
OPI % survival
5
4
3
2
1
0
Predicted
Observed
1998 1999 2000 2001 2002 2003 2004 2005
Year

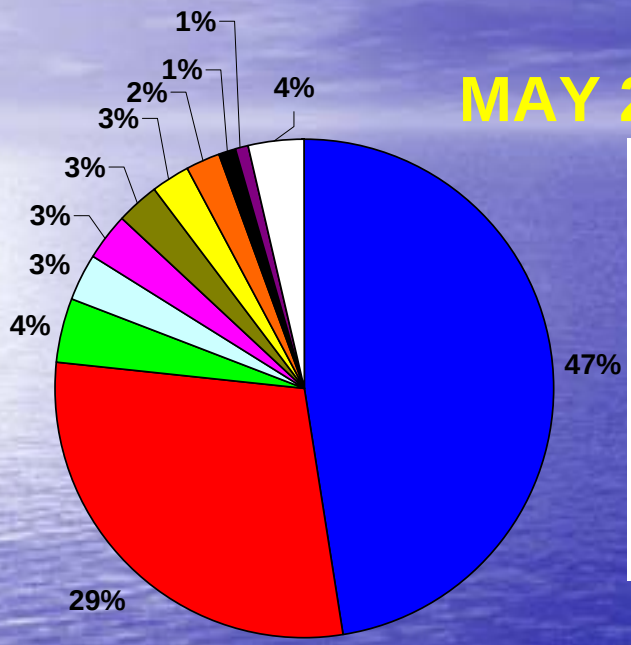

Fall Chinook salmon
Log (number of jacks)
5.25
5.00
4.75
4.50
4.25
4.00
Predicted
Observed
1998 1999 2000 2001 2002 2003 2004 2005
Year


Spring Chinook salmon
Log (number of jacks)
4.75
4.50
4.25
4.00
3.75
3.50
Predicted
Observed
1998 1999 2000 2001 2002 2003 2004 2005
Year


Summer Chinook salmon
Log (number of jacks)
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
Predicted
Observed
1998 1999 2000 2001 2002 2003 2004 2005
Year

May-June coastal ocean dominated by shearwaters, murres

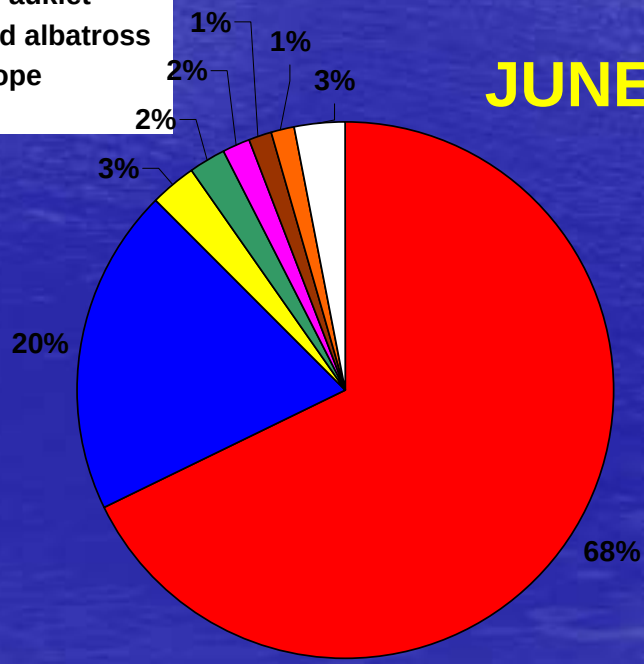
MAY 2003



- Common murre
- Sooty shearwater
- Sabine's gull
- Unidentified phalarope
- Western gull
- Unidentified gull
- Immature gull
- Rhinoceros auklet
- Black-footed albatross
- Red phalarope
- Other

common murre

JUNE 2003



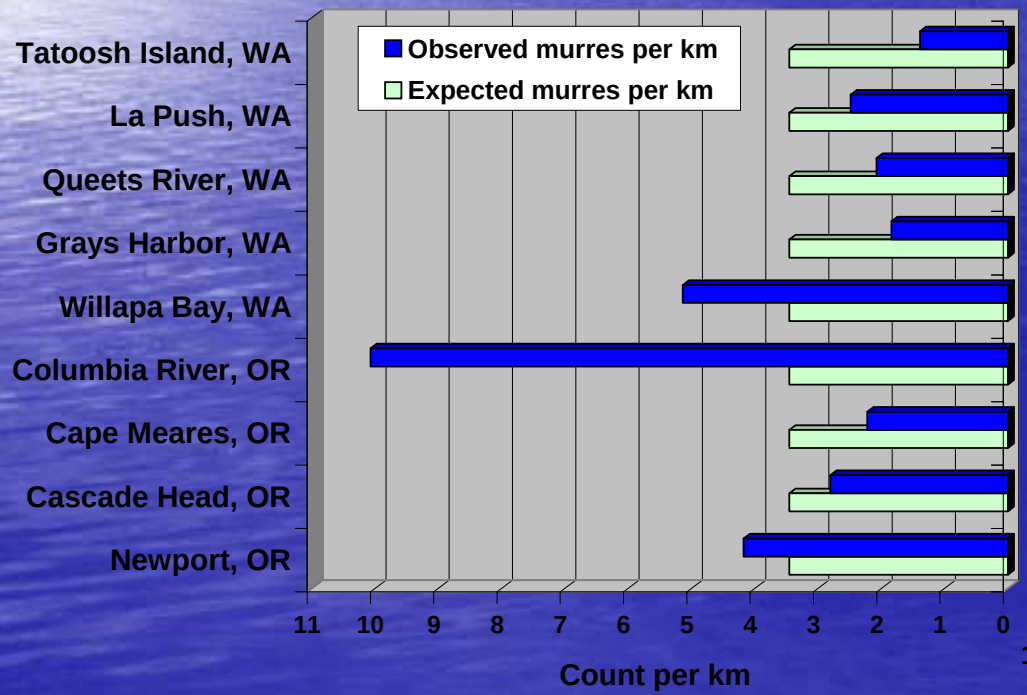
- Sooty shearwater
- Common murre
- Immature gull
- Pink-footed shearwater
- Western gull
- Northern fulmar
- Rhinoceros auklet
- Other

sooty shearwater

Predation concentrated in Plume Region

- Predation directly in salmon migration path along continental shelf

Common murre



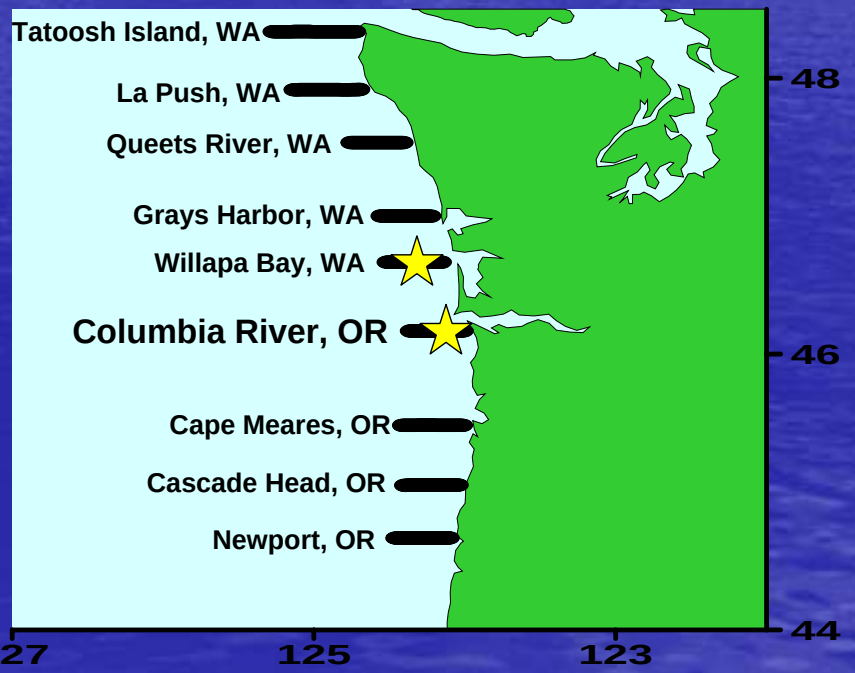
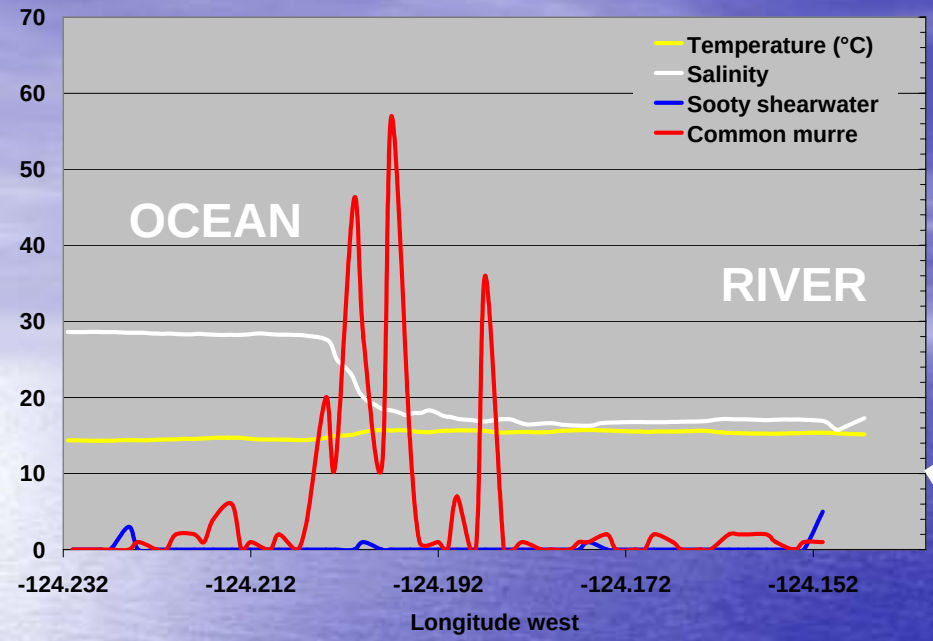
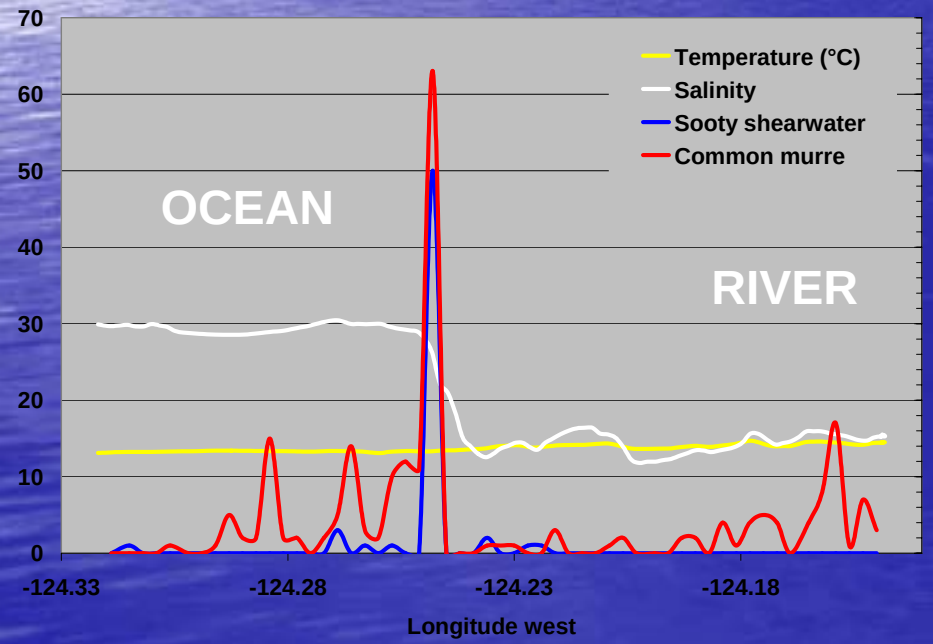
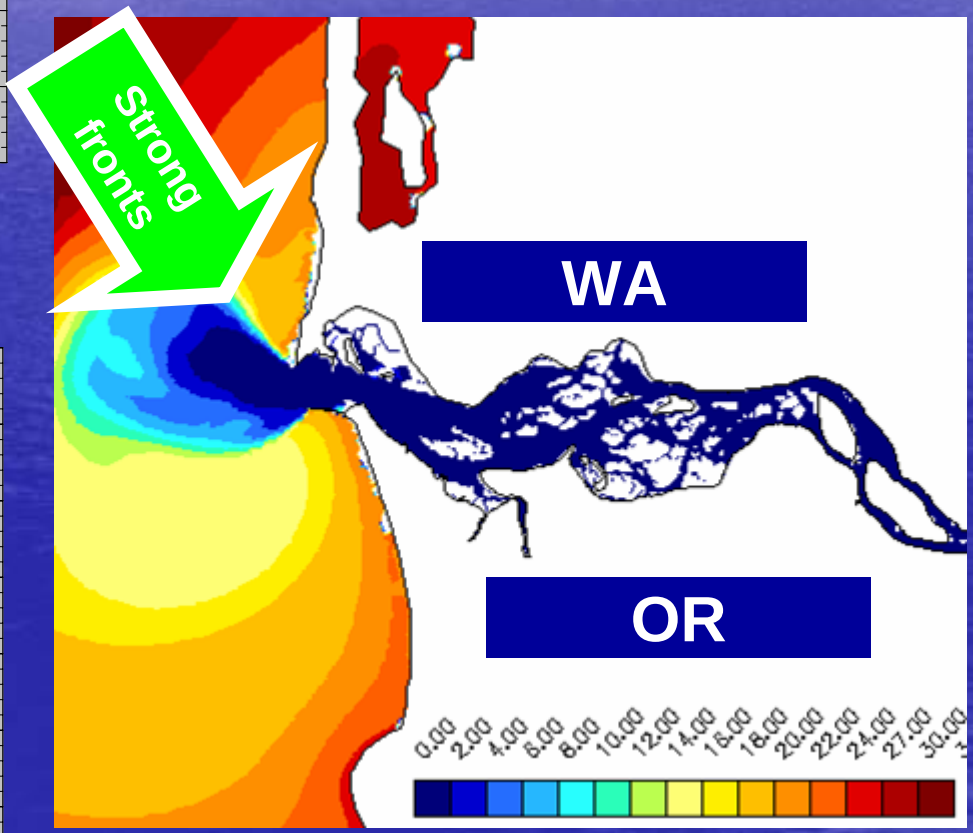


Photo credit – Peter LaTourrette, www.birdphotography.com

Birds aggregate at strong fronts



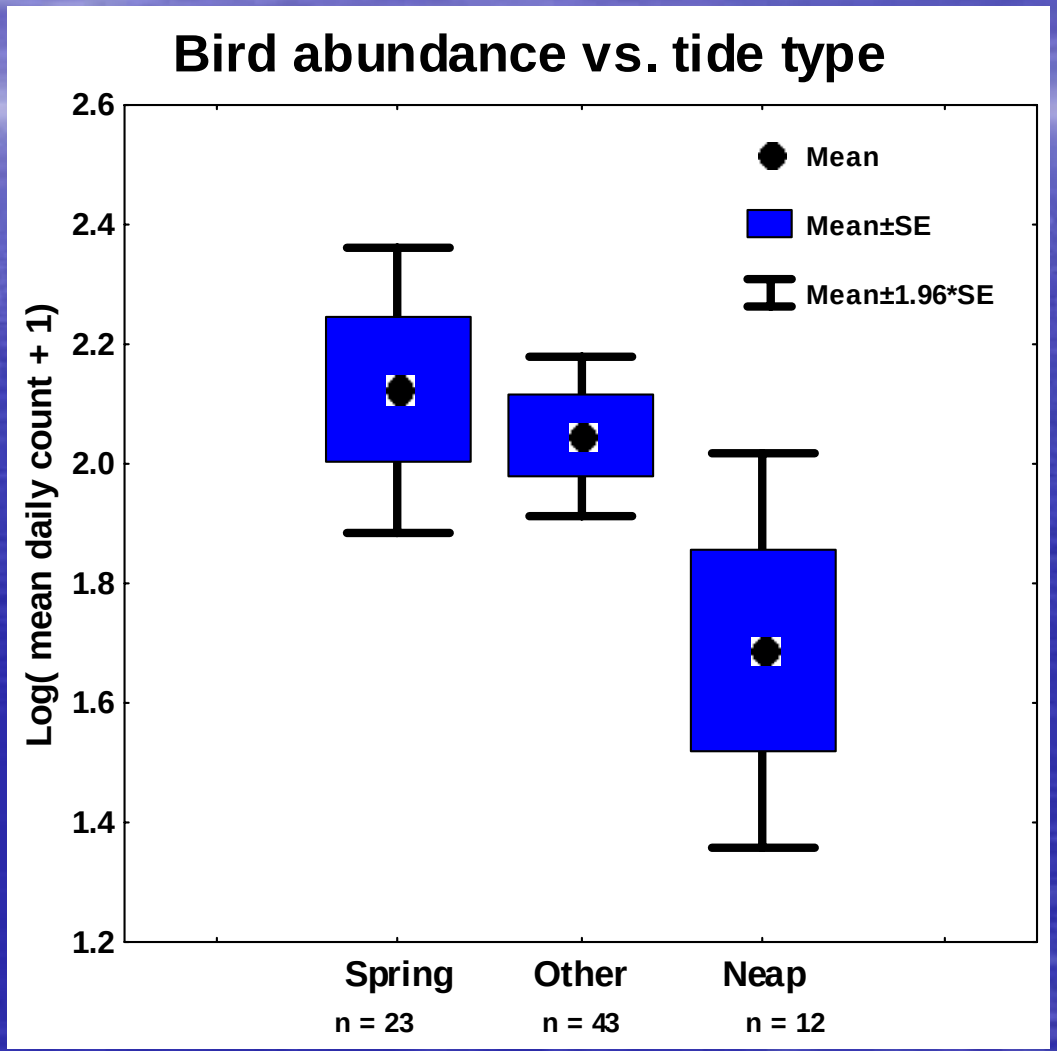




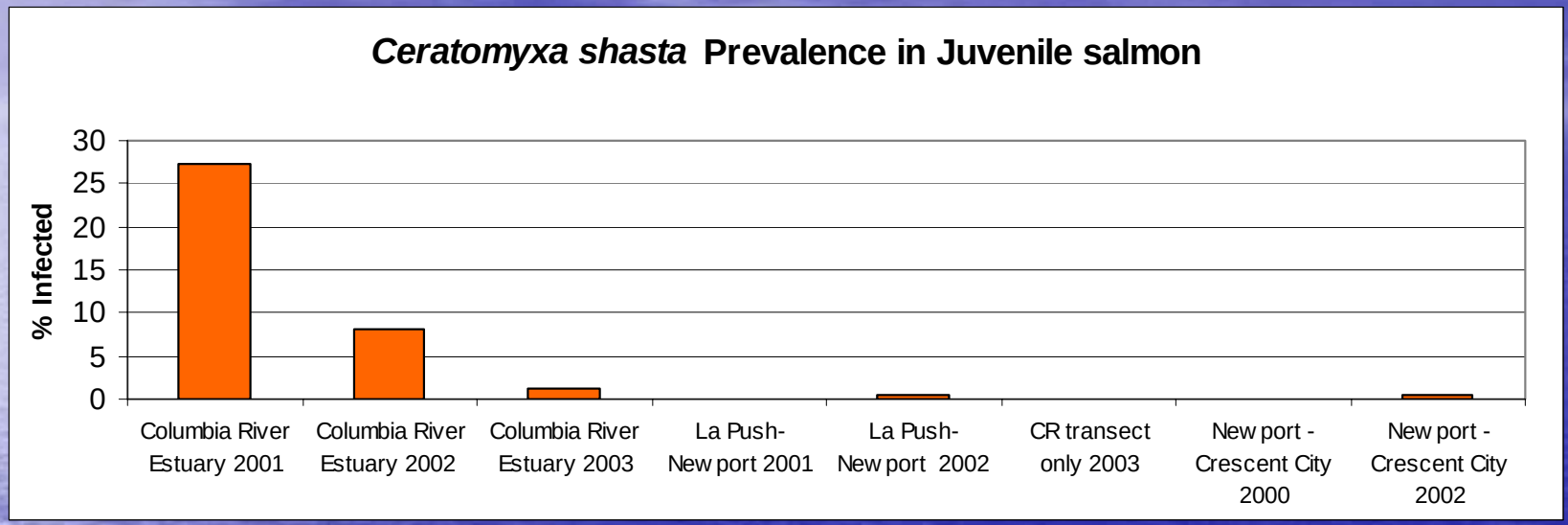
Surface salinity

Birds abundant, but vary with tide

- 3X as many birds on spring vs. neap
  - 73 vs. 25 birds per km^2
- Two-tailed t-test, log (x+1) transform:
  p = 0.043



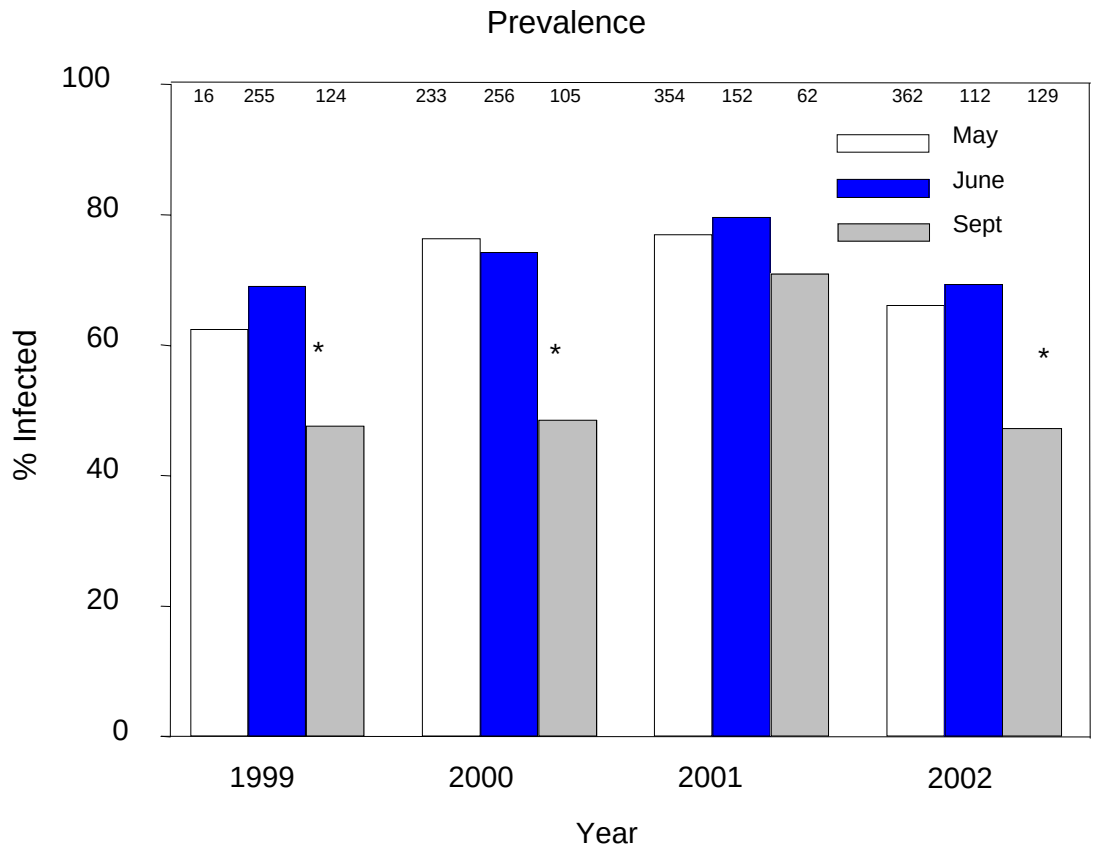
Disease as a Mortality Agent



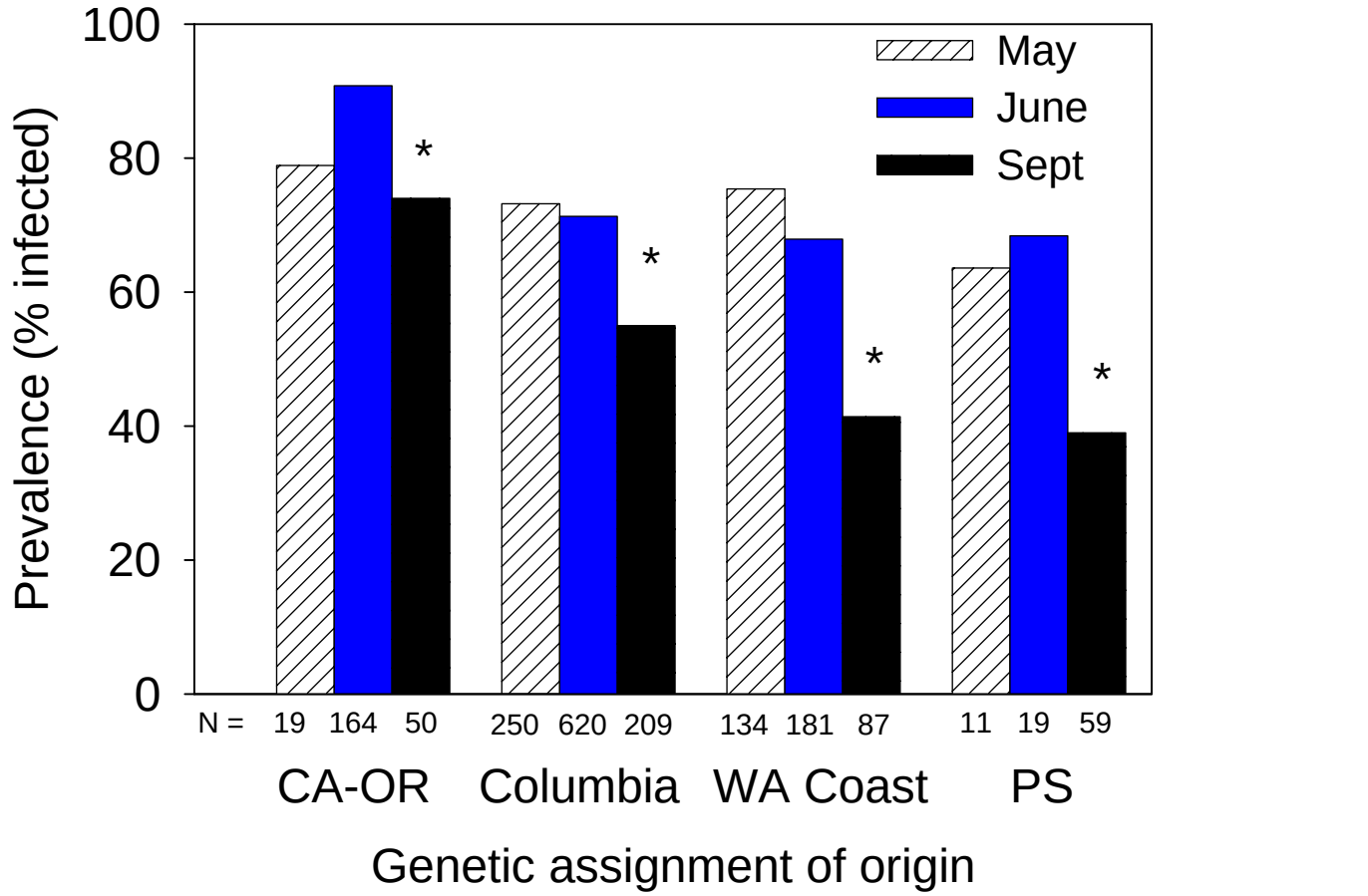
Estuary — Ocean

Juvenile salmon tested included a total of 662 yearling coho salmon, 495 yearling Chinook salmon, and 657 subyearling Chinook salmon

Prevalence and Intensity of *Nanophyetus salmincola* in juvenile coho salmon caught off Oregon and Washington

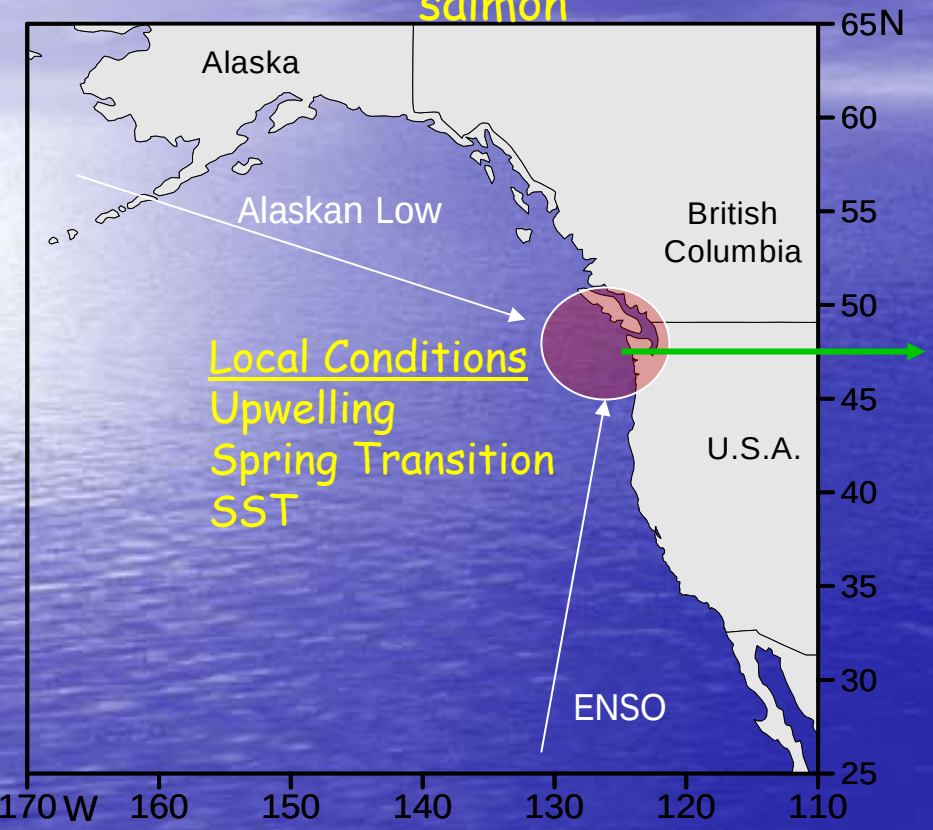


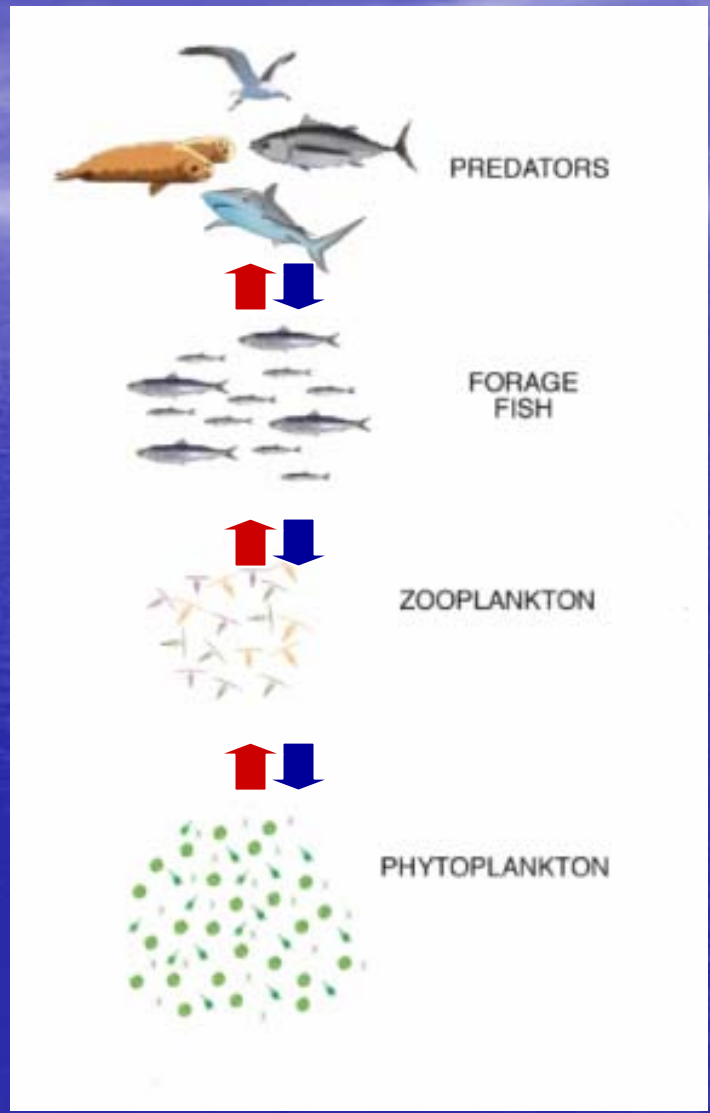
Prevalence of *Nanophyetus salmincola* in juvenile coho salmon during first summer in Pacific Ocean (1999-2002)

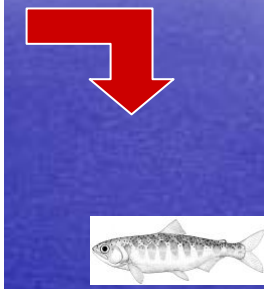


State of the Northern California Current Ecosystem

Influenced by large scale forces acting at the local scale to affect biological process important for salmon





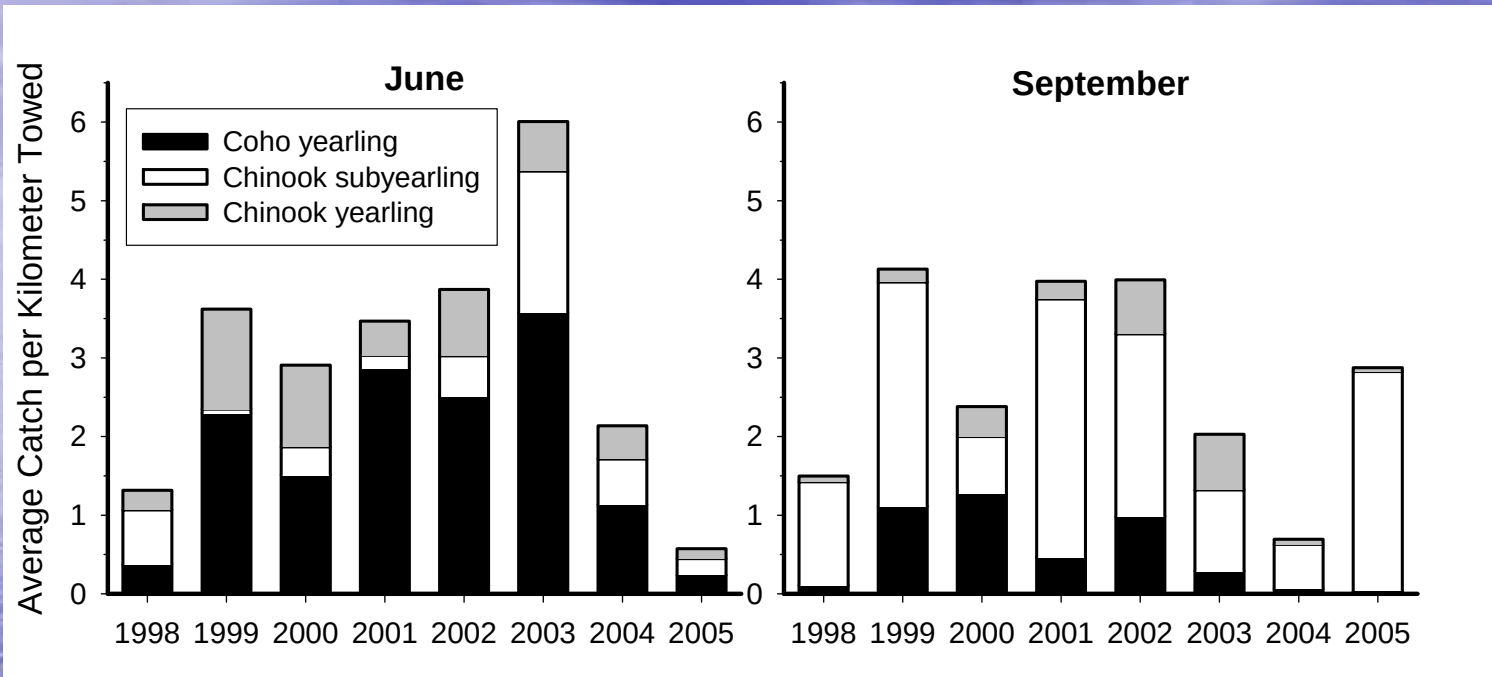


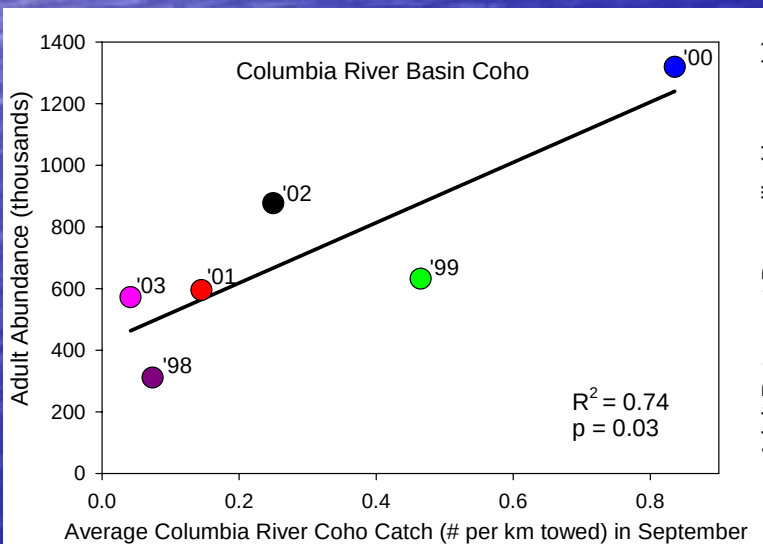
Local Biological Conditions

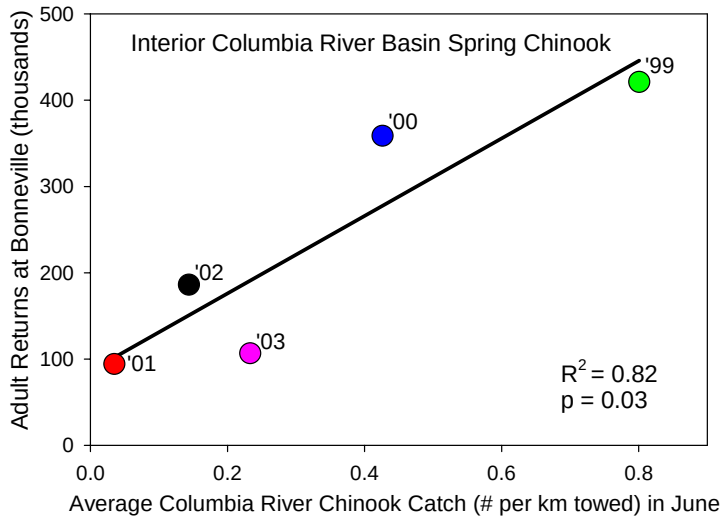
Overview – Ocean Factors

- Growth – bottom up process
- Predation – Top down process (Fish, Bird and Disease)
- Development of ocean condition indices
- Plume and salmon survival
- Ocean habitat, variable ecosystem, forecasting

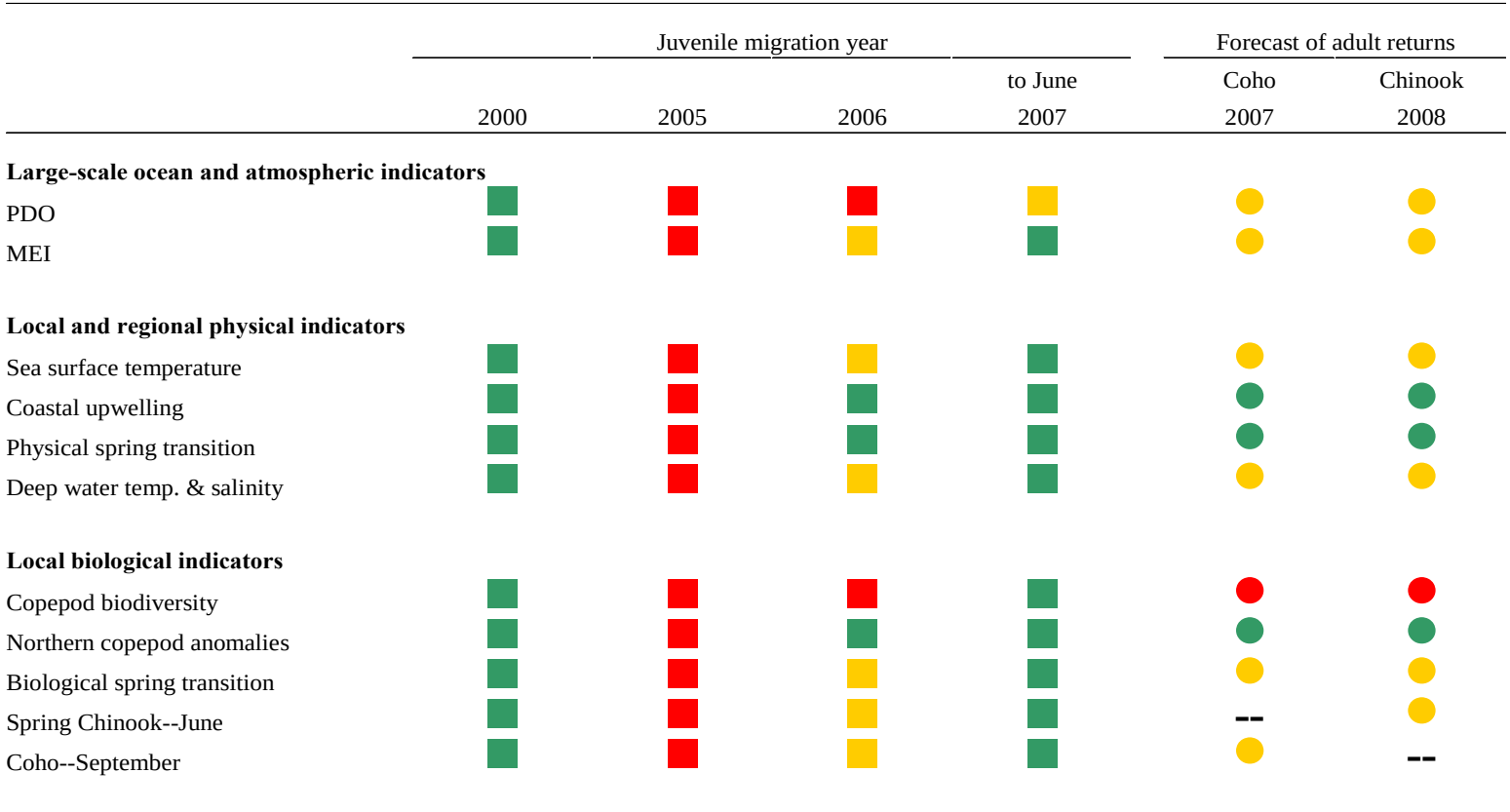
Juvenile salmon catches off Oregon and Washington directly relate to number of returning adult salmon:



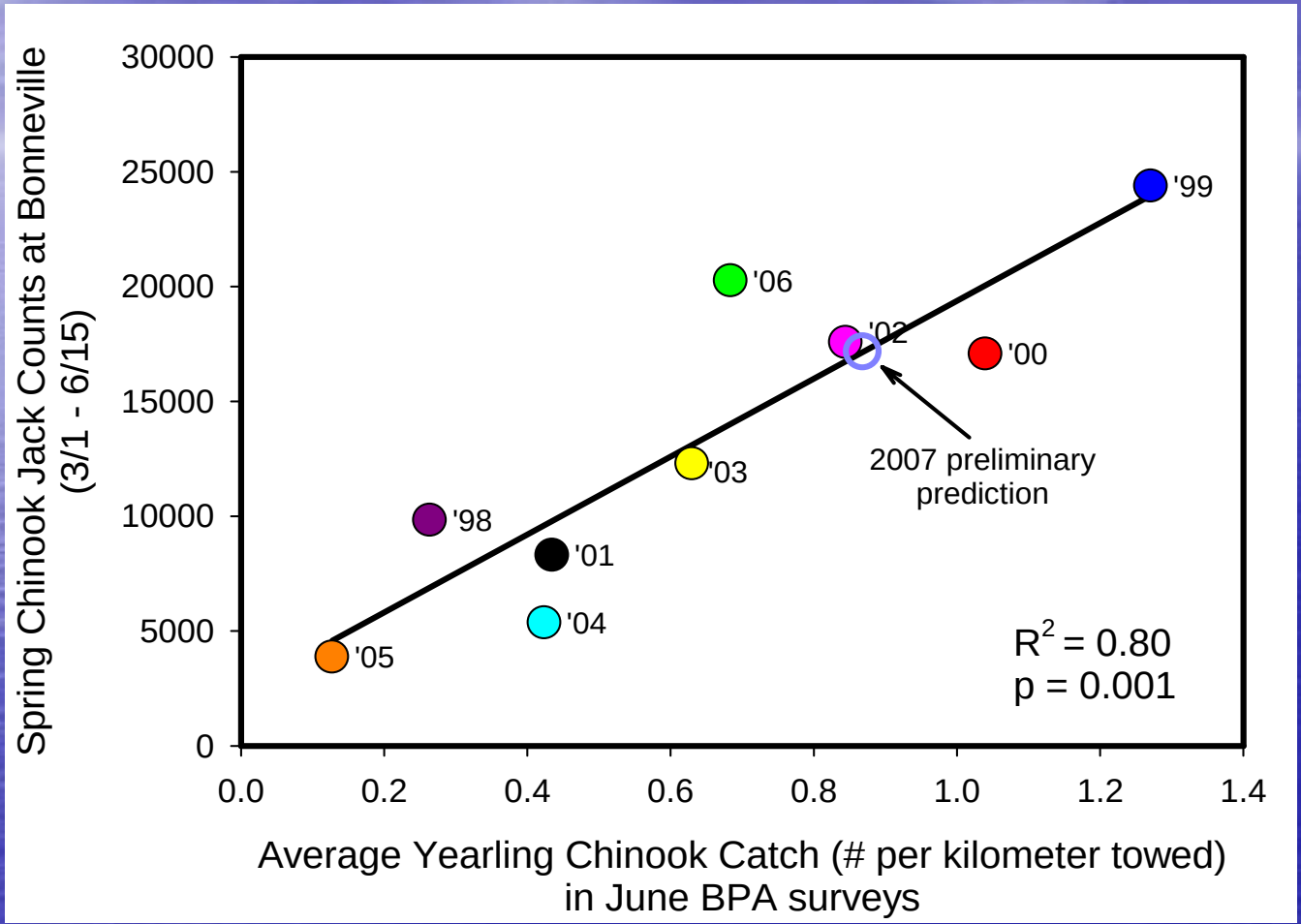




Ocean Index – Forecasting Future Salmon Returns



Current Forecast – Yearling Chinook



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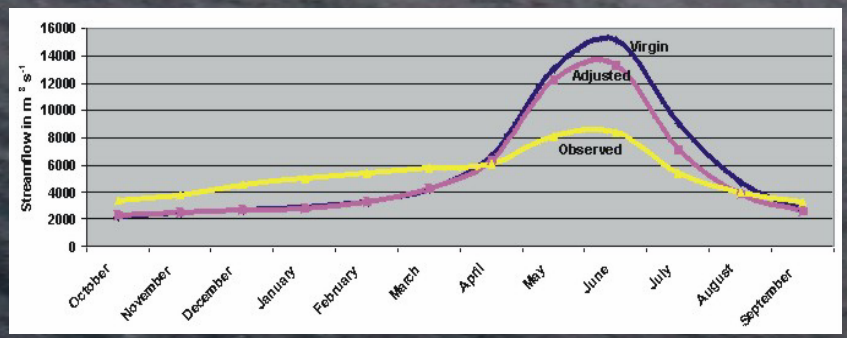
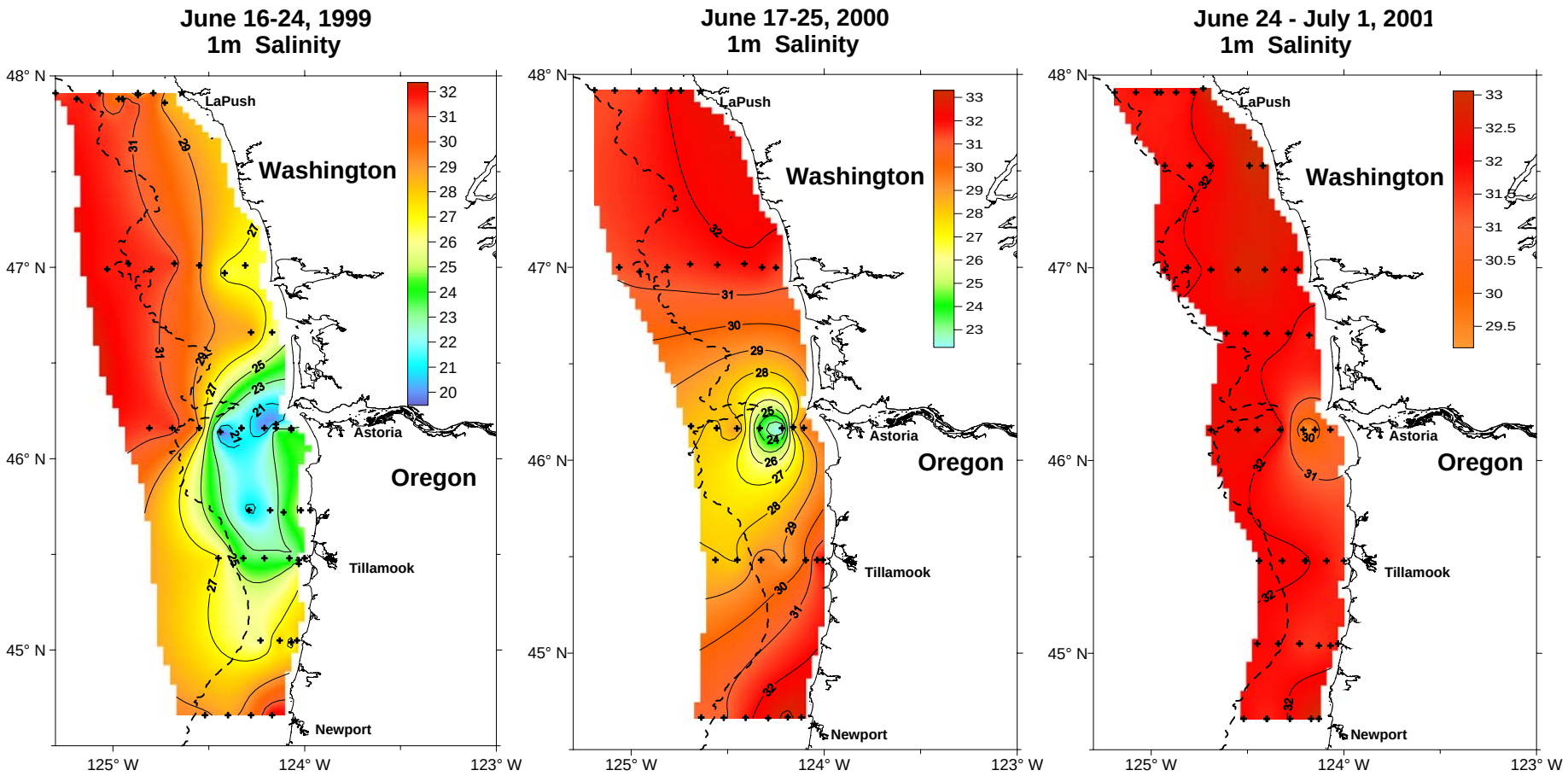
The CR Plume – where the river meets the ocean

Plume

Ocean

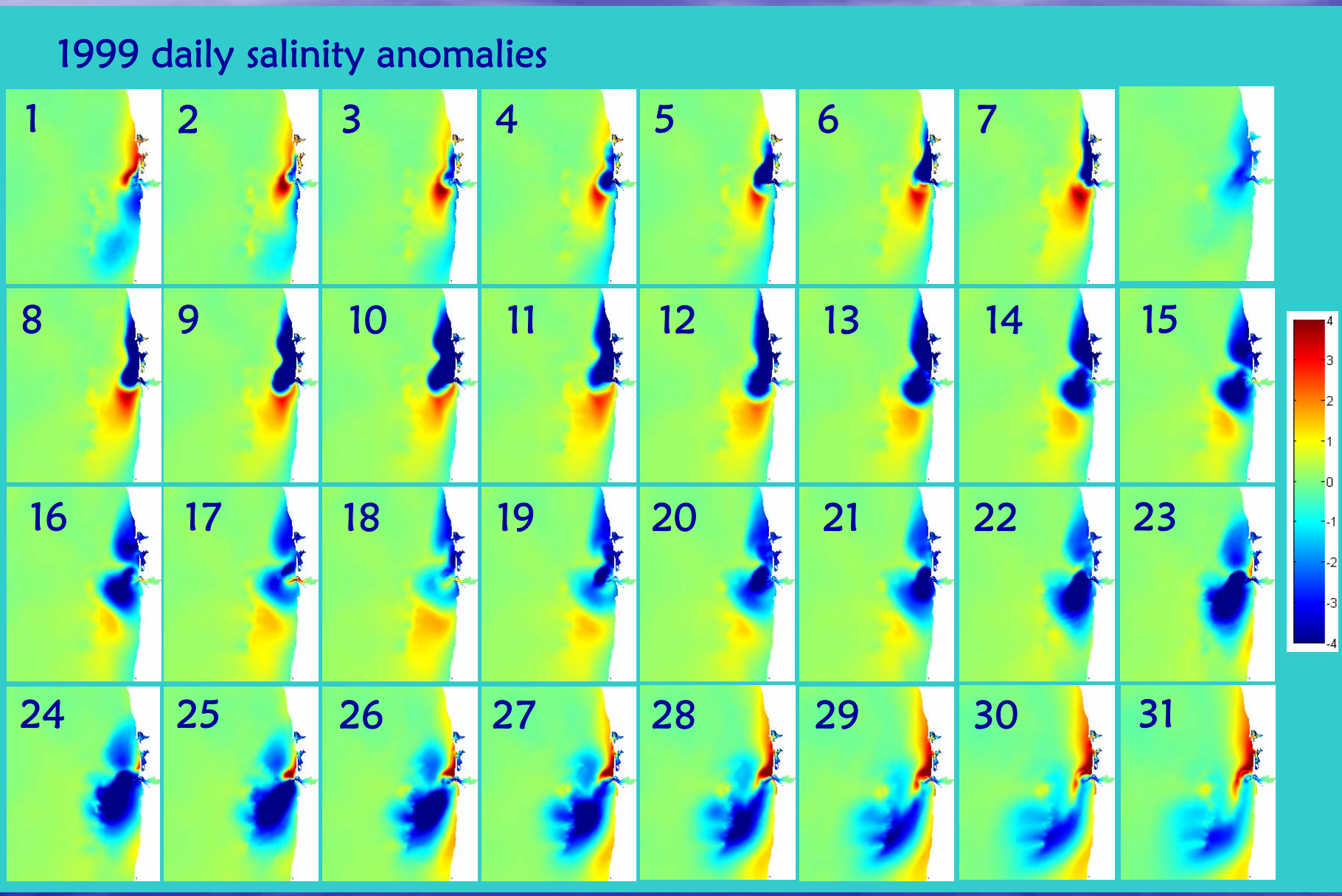


Plume: Variable and Dynamic

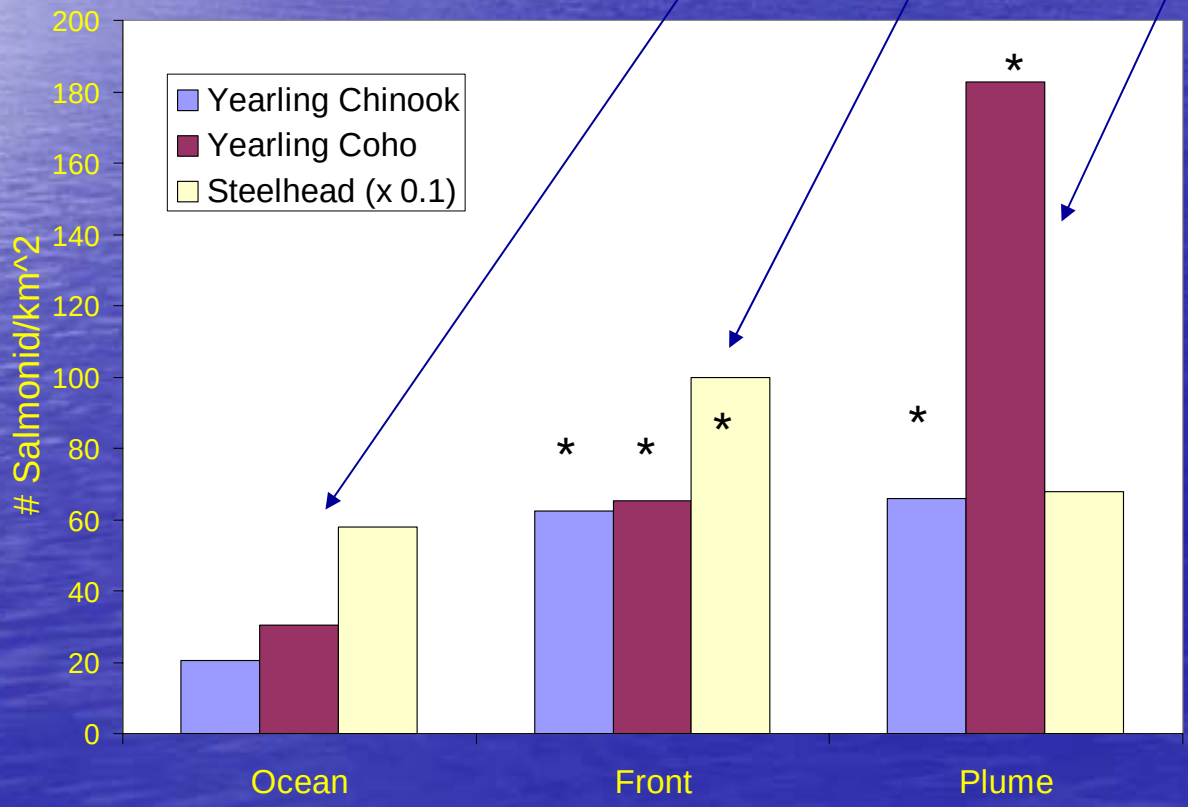


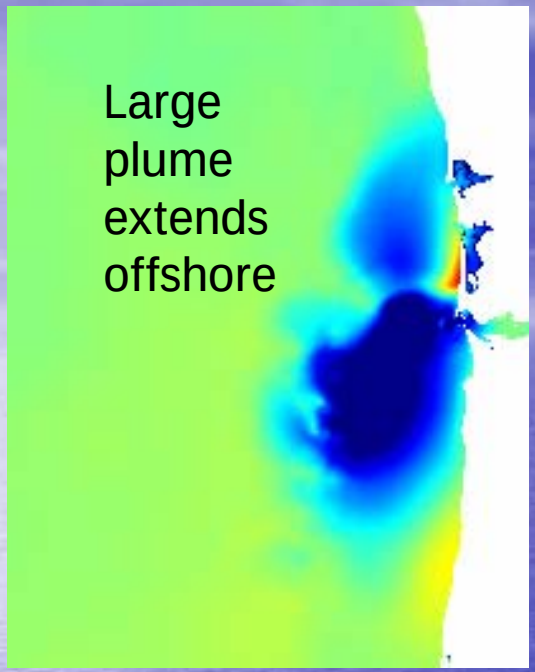
Plume Daily variability - May (peak of the salmon migration season)

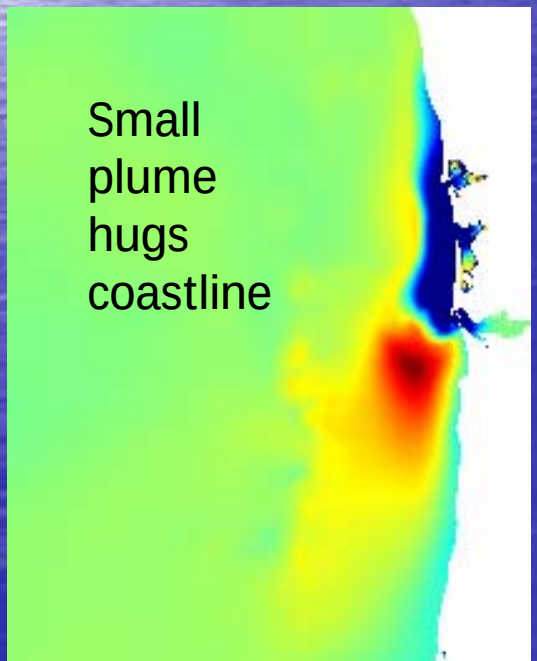
Plume Structure related to flow and atmospheric/oceanographic forces



Plume Fronts as Habitat- Juvenile Salmon & Steelhead







Plume Structure Affects SARs

The number of adult Steelhead returning to the Columbia River is related to plume structure

A larger plume that is further offshore 7 to 10 days after juvenile steelhead enter the ocean leads to higher numbers of returning adults (yearling Chinook salmon also benefit from a larger plume, but to a lesser degree)

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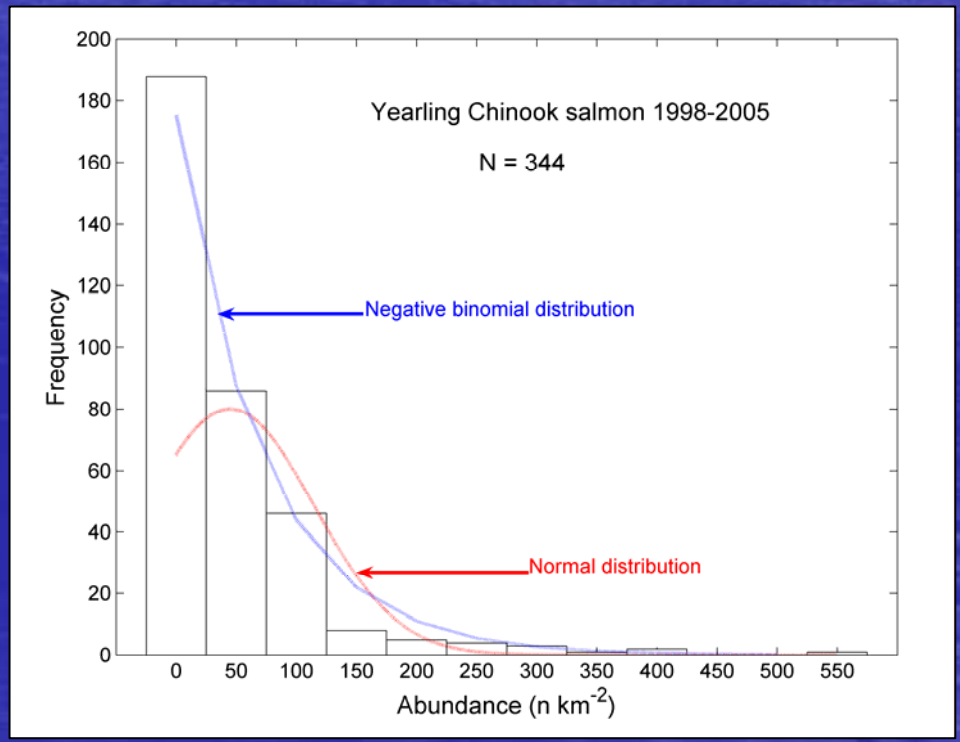
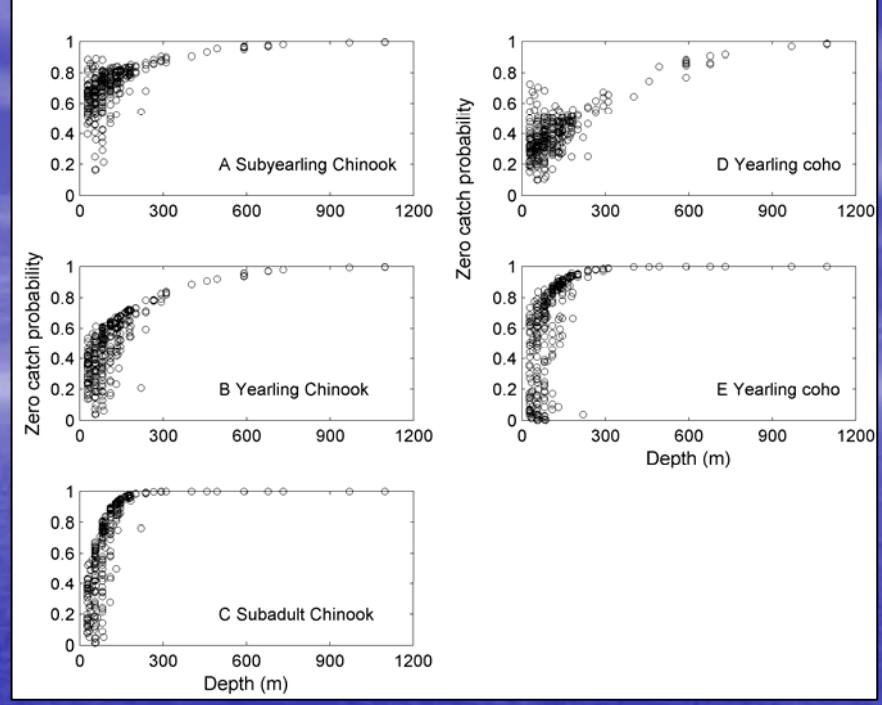
Habitat Characterization – Analysis Issues

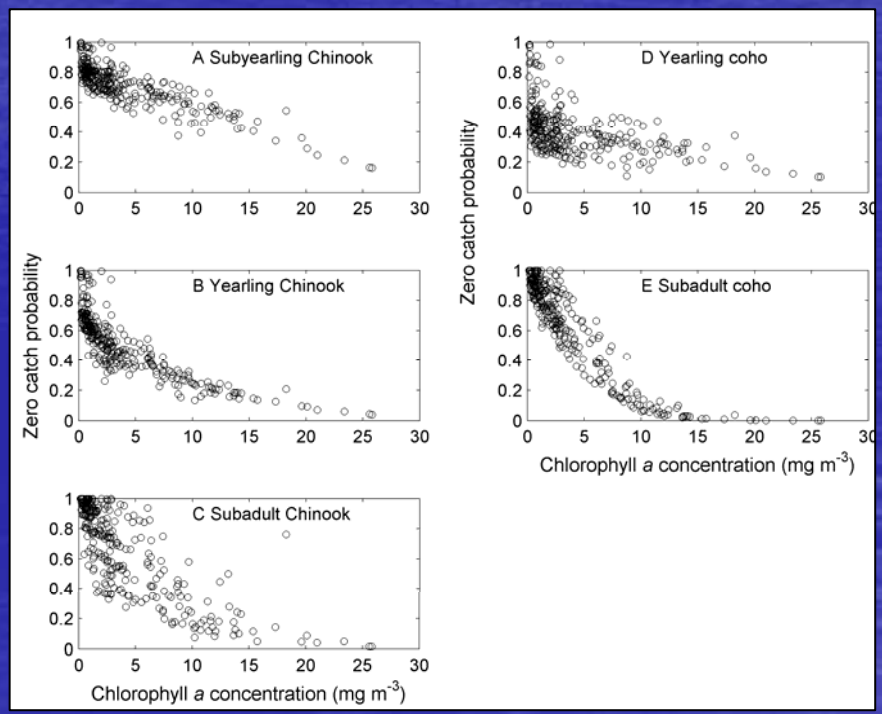
- Use presence/absence and abundance to define habitat
- Expanse of ocean habitat might relate to salmon marine survival
- Problems:
  - Excessive zeros
  - Non-homogeneous variance
  - Over-dispersed



Logistic regression

- Zero-catch probability = chlorophyll + depth + salinity + temperature
- Stepwise selection



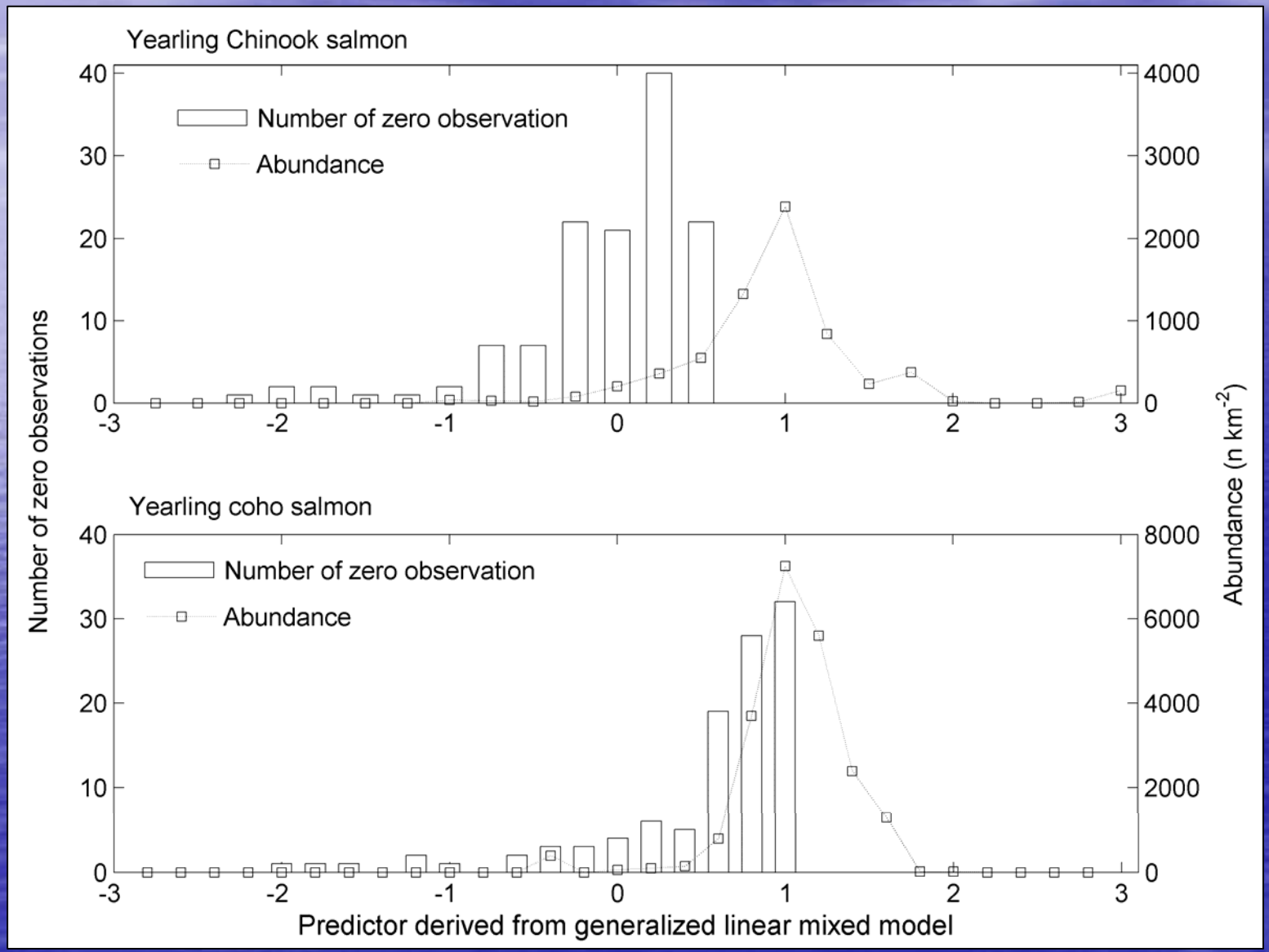


Model physical and biological attributes of the habitat to characterize variation in salmon abundance and distribution - Forecasting

- Generalized linear mixed model with a negative binomial distribution

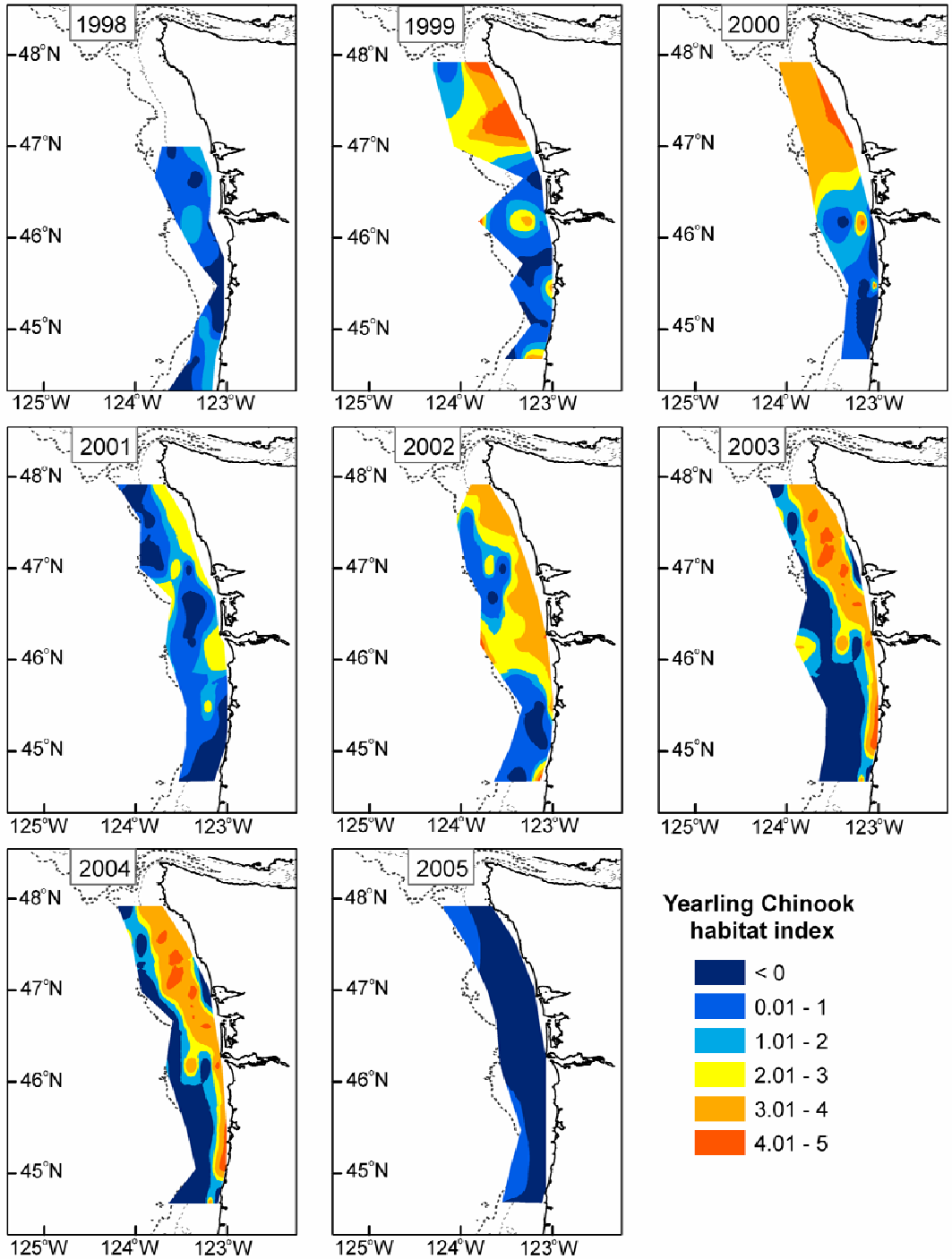
  $Y = a * X + b * Z + e$
- Response variable: Juvenile salmon abundance
- Predictor variables: copepod indices, chl, depth, temperature, salinity
- Copepod indices developed from principal factor analysis

Model Prediction vs Reality



Yearling Chinook spatial pattern

- > 3 indicate good habitat
- Inter-annual variation: 1998 – 2005
- Spatial variation



Conclusions

- Growth and survival related to ocean conditions
- Ecosystem productivity varies at interdecadal, interannual, seasonal, and daily rates
- Understanding the interactions of the processes leads to forecasting tools to gauge the contribution of ocean conditions to the number of returning salmon and to value fw actions