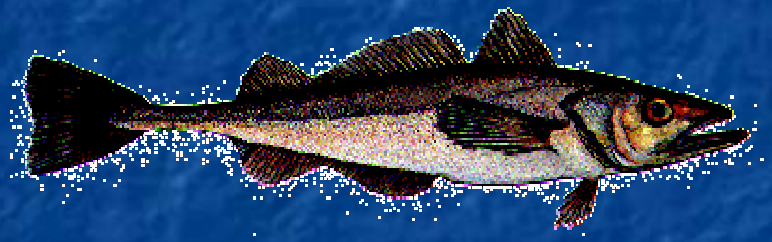
Interannual Changes in Pacific Hake (*Merluccius productus*) Growth in Relation to Oceanographic Conditions



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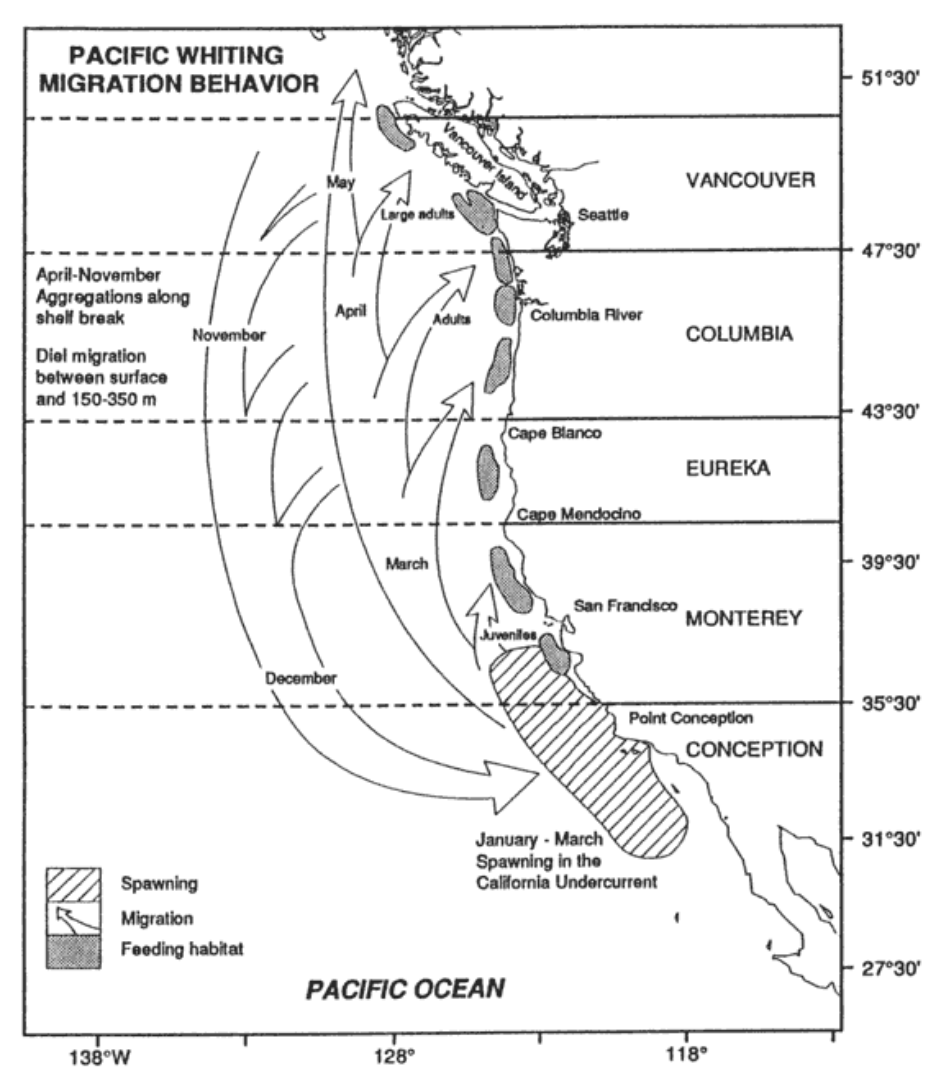
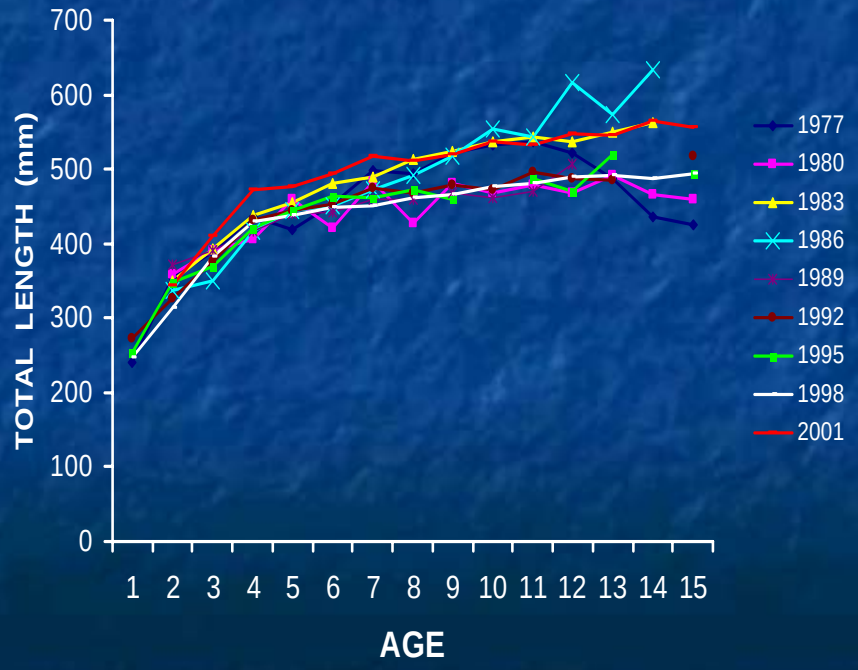
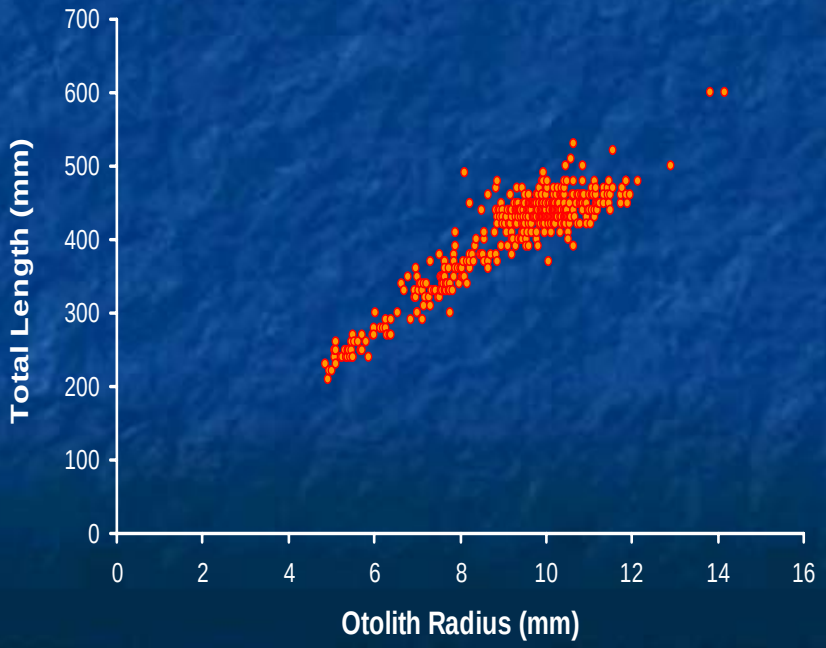
United States

Generally, Hake Migrate South in Winter to Spawn North in Summer to Feed…



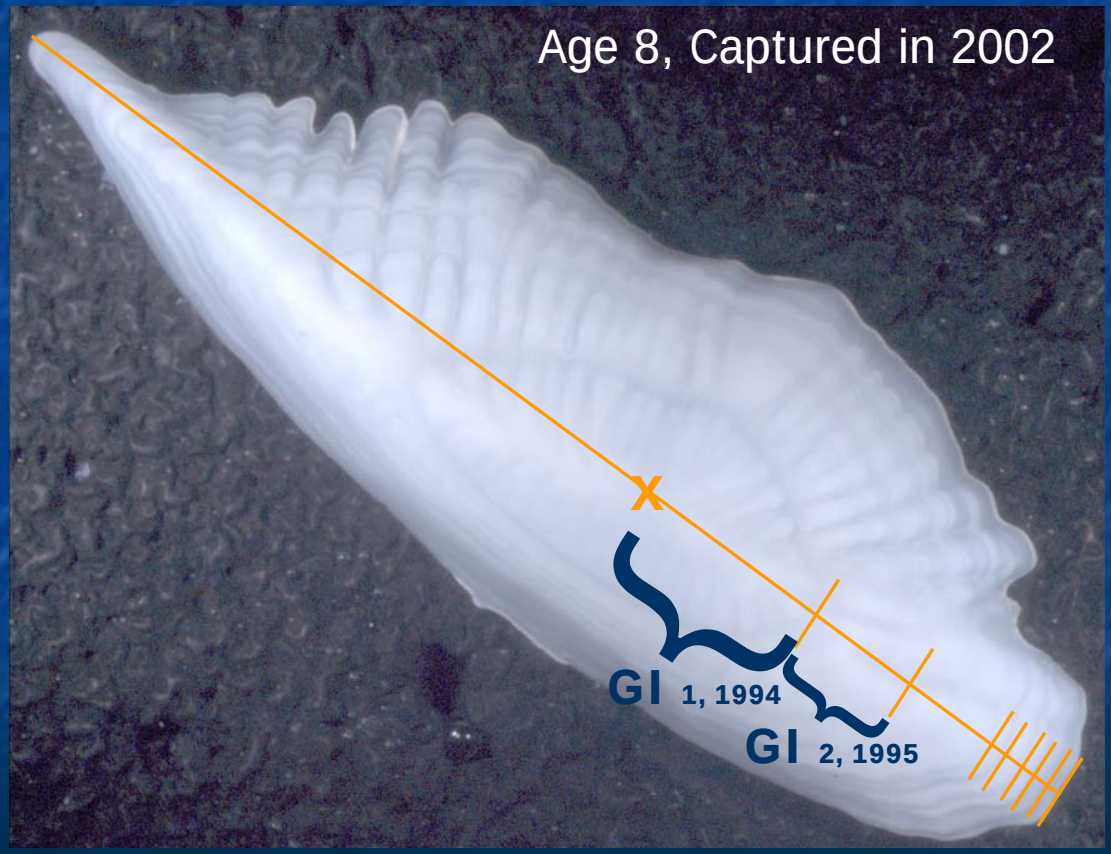
Length-at-Age has changed significantly over time, and since otolith radius is proportional to body length, otoliths can be used as chronometers of past growth





Individual Growth Increments were assigned an Age and Year: GI (age, year)

- By knowing the age of the fish and the year of capture we determined the year that the growth increment was formed
- In this manner growth increments can be used to build a growth (age, year) matrix



A GLM was used to further partition the differences in GI's into specific effects and interactions

GI = age + sex + area + year + error

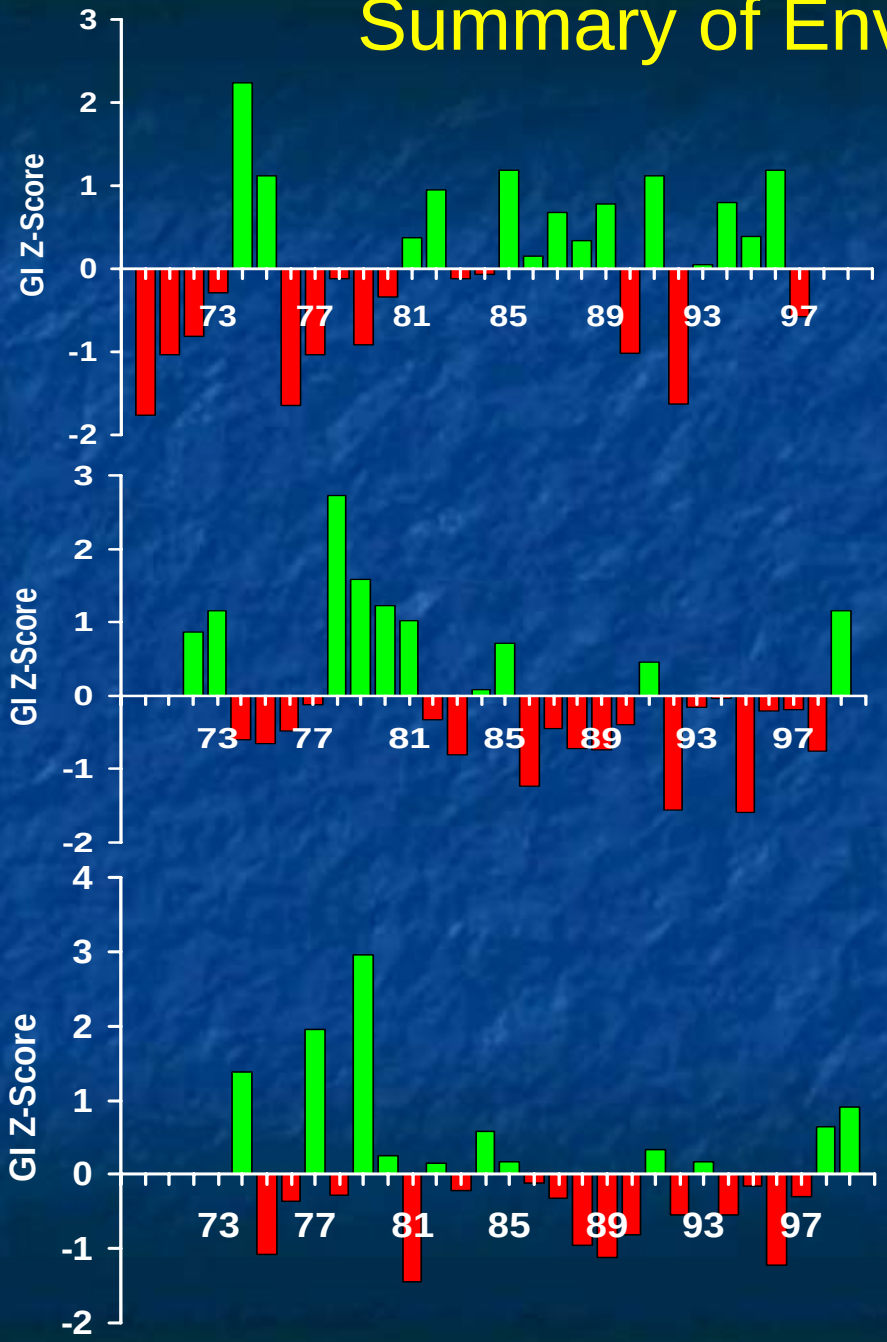
With difference due to *age*, *sex*, and *area* (and *interactions*) accounted for, *year* effects were used to represent effects due to environmental changes. No *age* effect was found for ages 7+ so these ages were combined

Ages were Partitioned into Three Age Groups Based on Biological Life Stages

- Juveniles – Ages 1 and 2
- Transitional – Ages 3 and 4
- Adults – Ages 5, 6, 7+

Source	DF	F Value	Pr > F
Group	2	1034.2	<0.0001
Sex	2	1.25	0.2879
Year	30	5.11	<0.0001
Group x Year	49	11.69	<0.0001

Summary of Environmental Effects



AGE 1 & 2 (Juveniles)

Sexually immature, non-migratory,
eat mostly zooplankton and euphausiids

AGE 3 & 4 (Transitional)

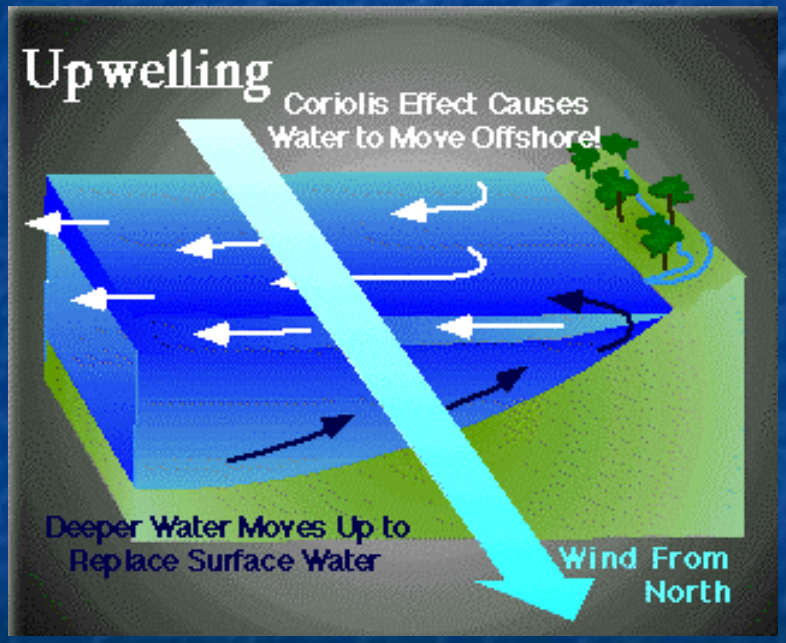
Sexual maturity, begin to migrate,
Eat mostly euphausiids

AGE 5-7+ (Adults)

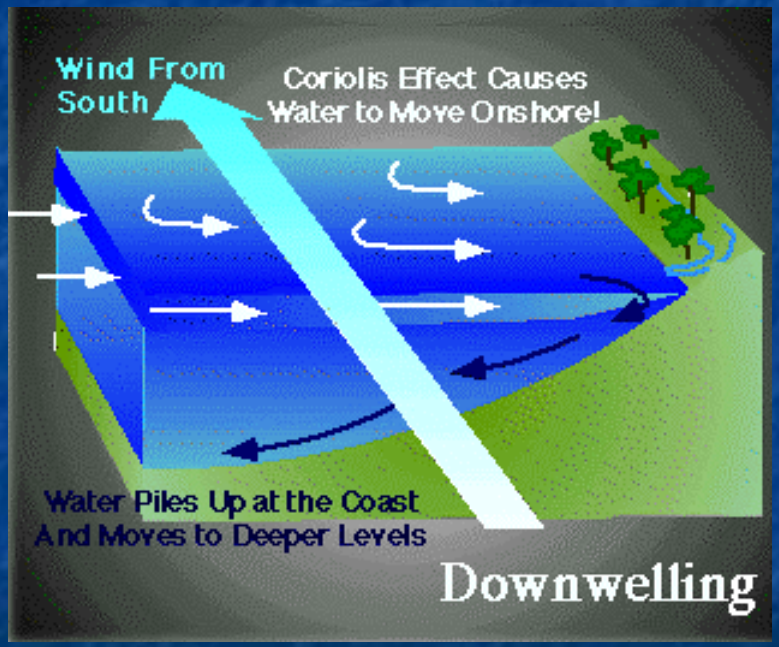
Sexually mature, fully migratory with
Largest individuals found furthest north,
diet of euphausiids and herring

US West Coast is a Wind Driven System

Summer



Winter



http://www.naylamp.dhn.mil.pe/english/enlaces/afloramiento_costero.htm

Wind Stress Curl

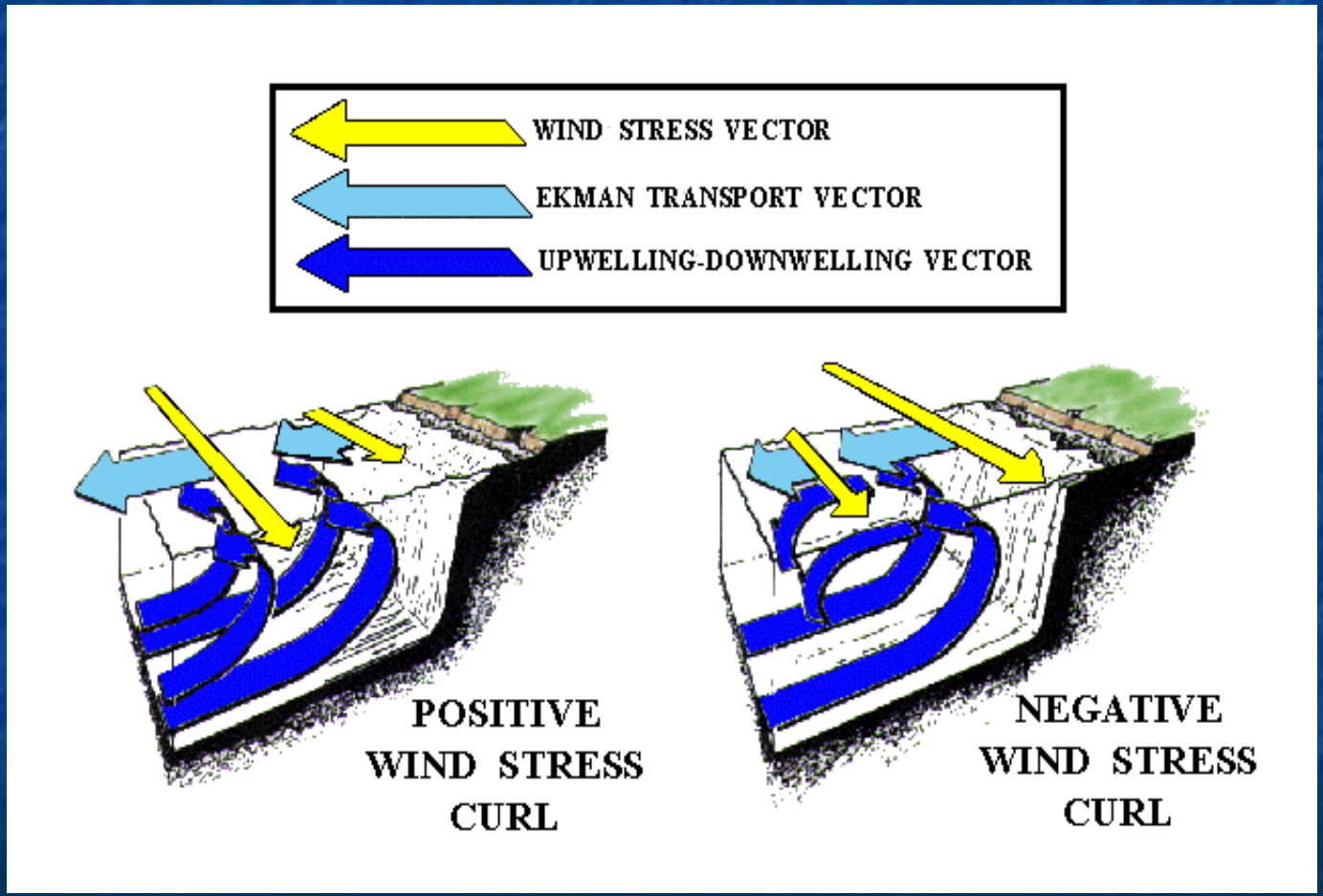
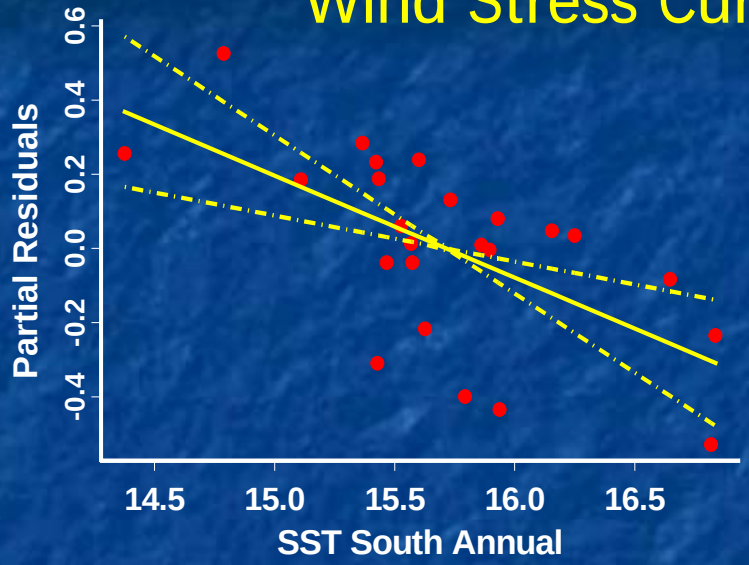


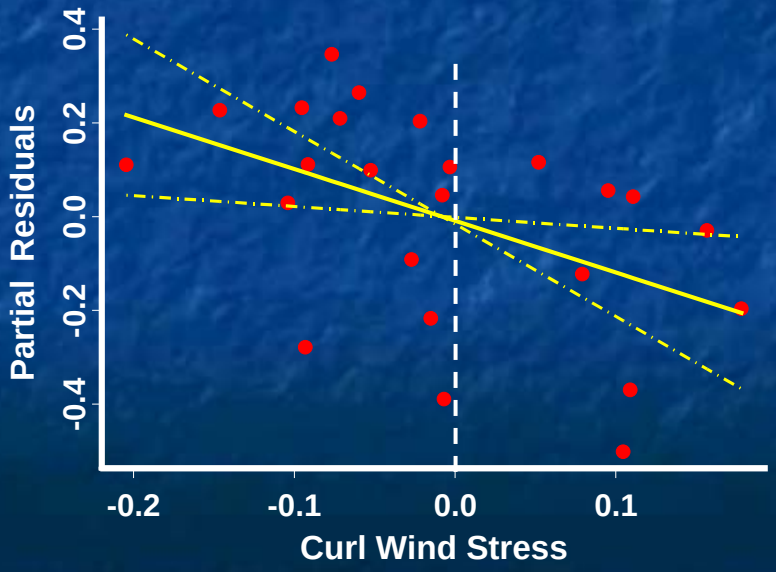
Figure courtesy of NOAA Fisheries – Pacific Fisheries Environmental Laboratory

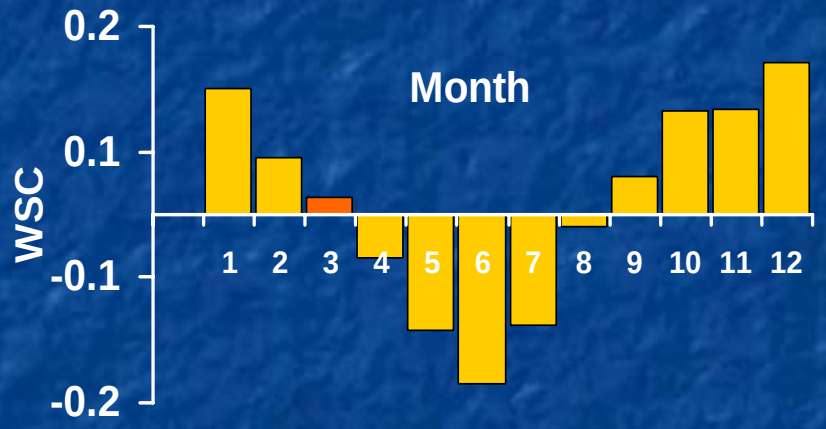
AGE 1 & 2 (Juveniles)

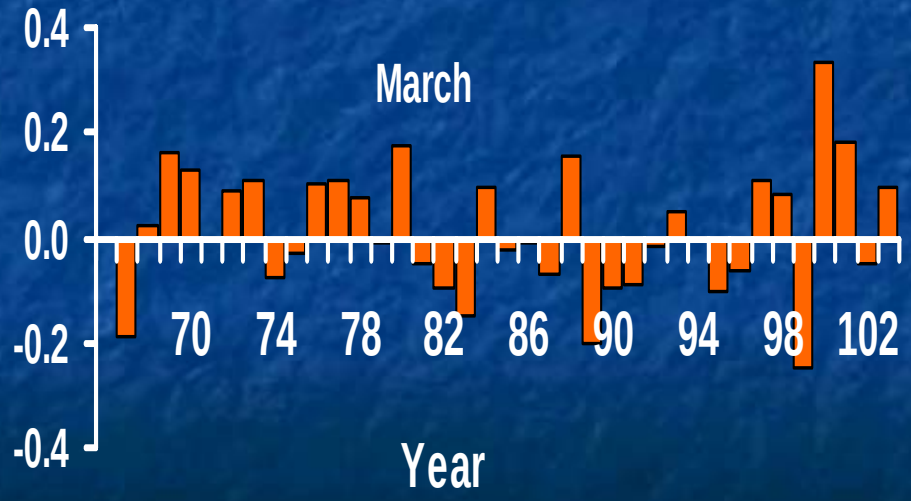
Annual SST / Southern Coast (30°-38° LAT)

Wind Stress Curl / Southern Coast in March



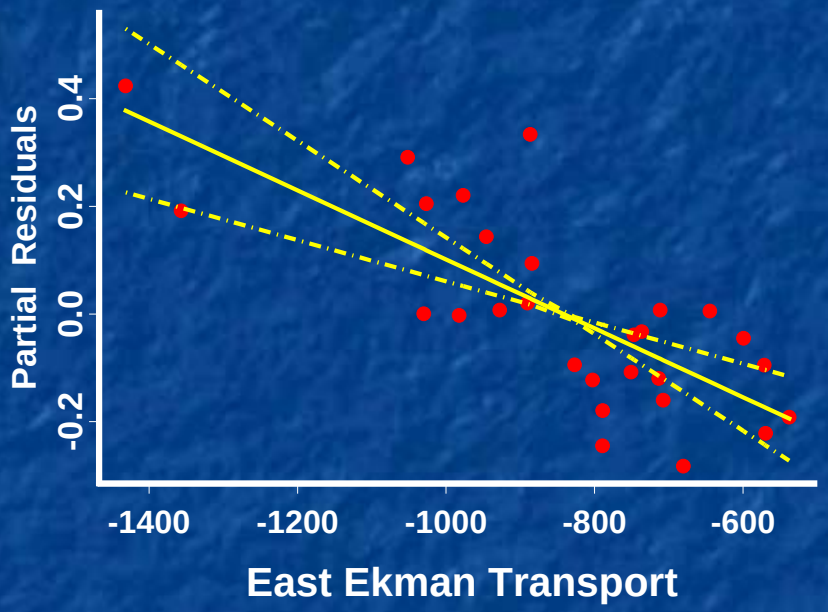


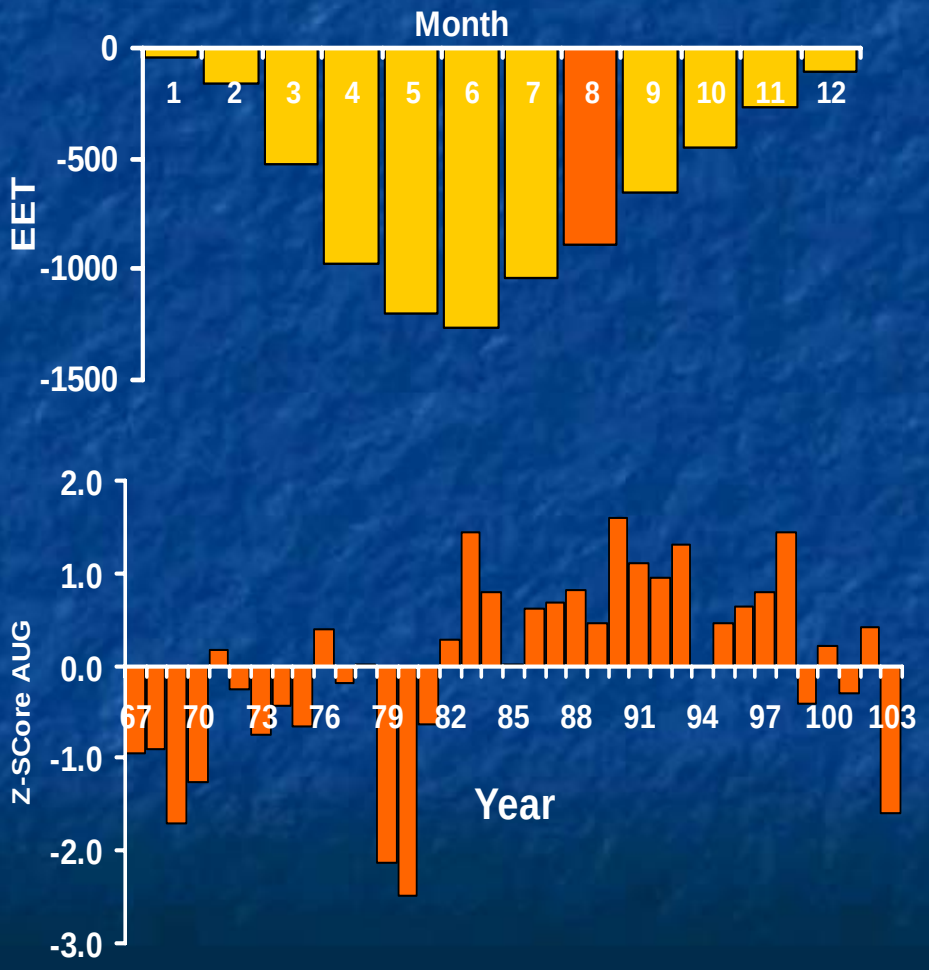




AGE 3 & 4 (Transitional)

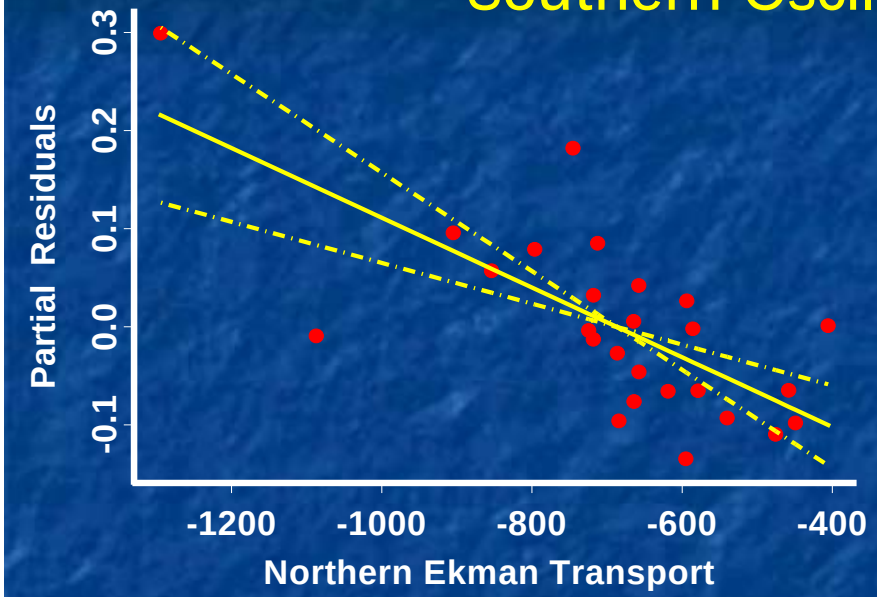
East Ekman Transport / Southern Coast in August

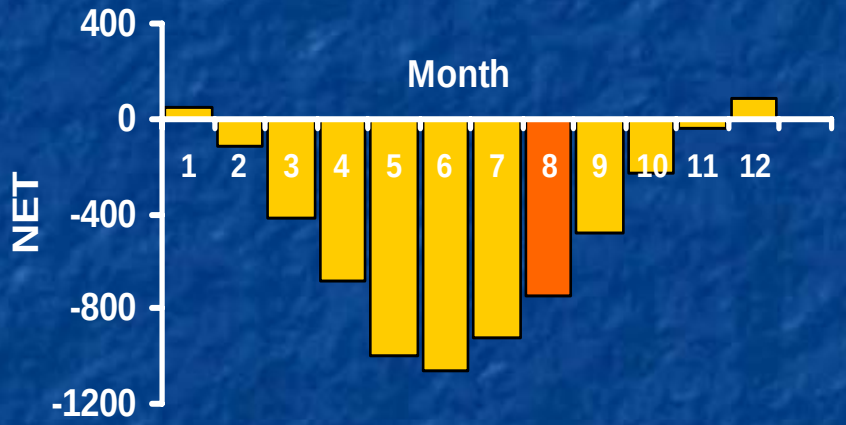


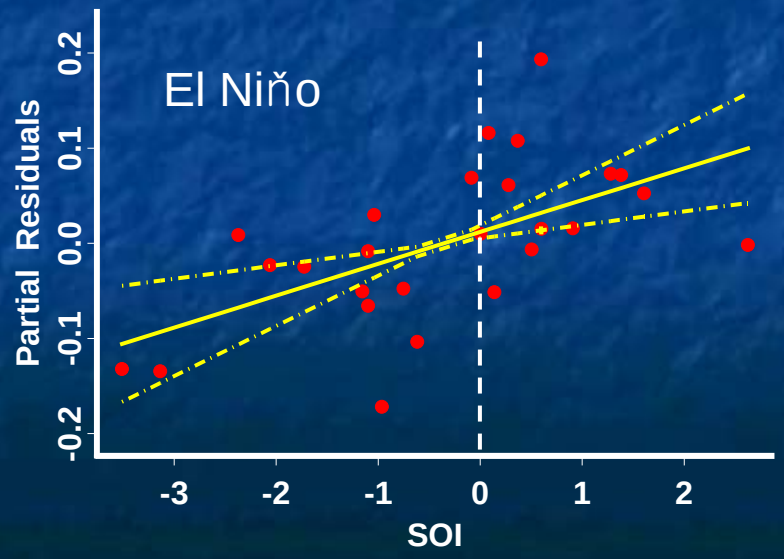


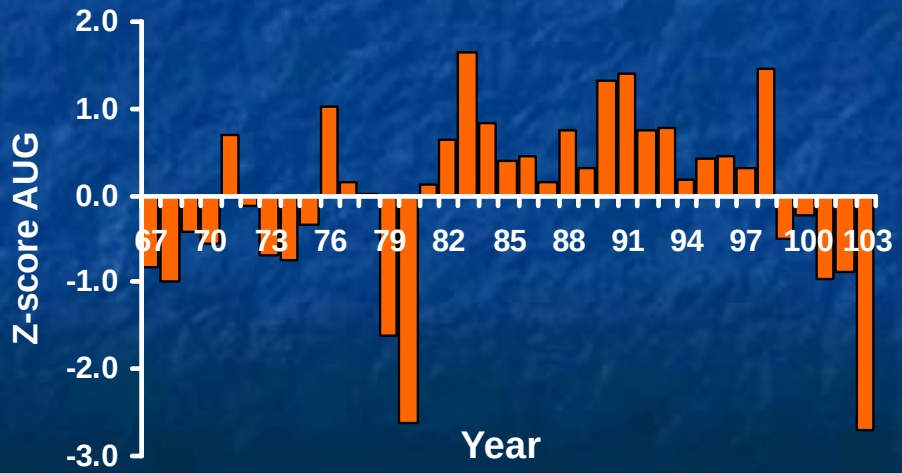
AGE 5-7+ (Adults)

Northern Ekman Transport / Southern Coastal in August
Southern Oscillation Index in August









Summary - Age Group Annual Mean Growth Increment

Ages 1 & 2

- Average Annual SST, Southern Coast (-)
- Wind Stress Curl, Southern Coast in March (-)

Ages 3 & 4

- East Ekman Transport, Southern Coast in August (-)

Ages 5, 6, & 7+

- North Ekman Transport, Southern Coast (-)
- Southern Oscillation Index in August (+)

What are the Mechanisms?

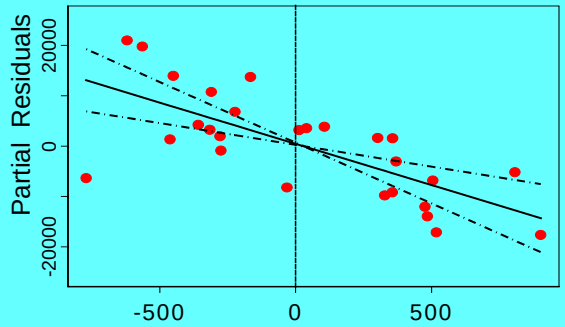
1. Sea Surface Temperature is an indicator of season circulation patterns; cold anomalies are associated with increased equatorward flow of high-nutrient water out of the north
2. Wind Stress Curl, when negative, may help to maintain nutrients and primary productivity on the shelf where it can be more fully utilized by fish; earlier start of the transition of the seasonal cycle seems to be beneficial

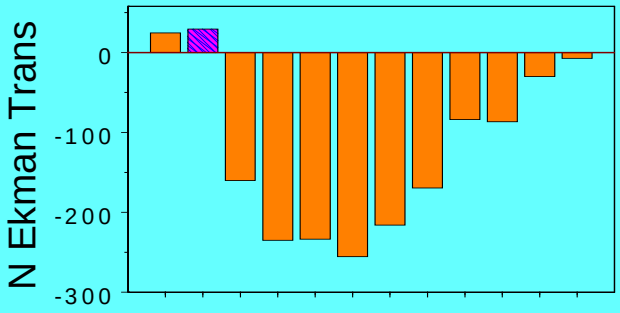
What are the Mechanisms?

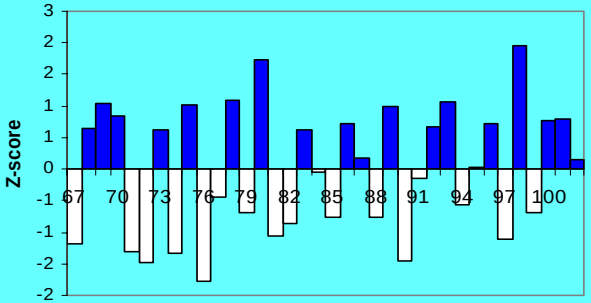
3. Increased Negative East Ekman Transport (off-shore flow of water) is indicative of increased upwelling which leads to overall higher productivity on the shelf
4. Negative Northern Ekman Transport (increased equatorward flow) and positive SOI indicates non-El Nino to La Nina conditions, which are also indicative of increased upwelling.

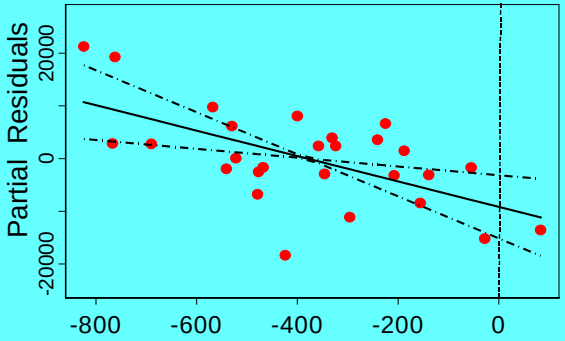
Sablefish Recruitment in California Current

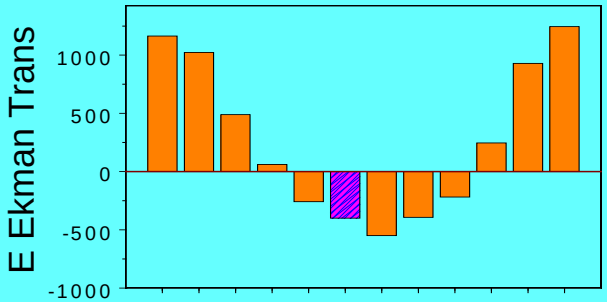
Schirripa and Colbert, Fisheries Oceanography (in press)

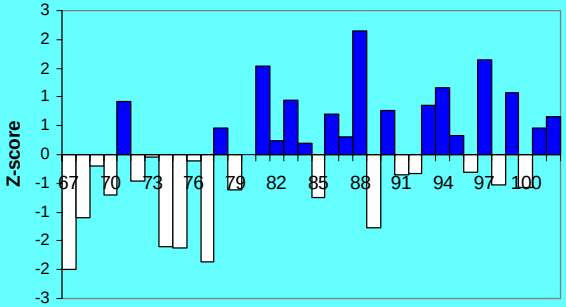


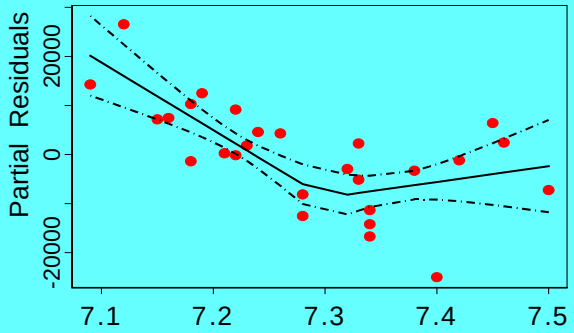


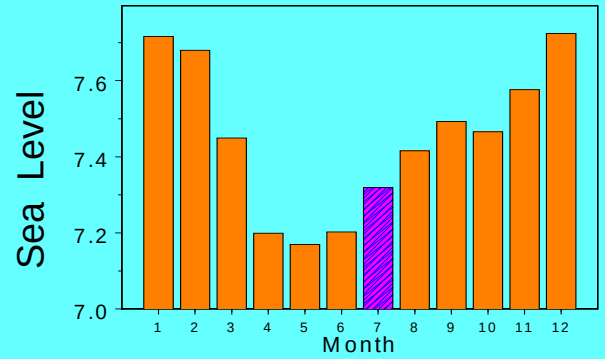


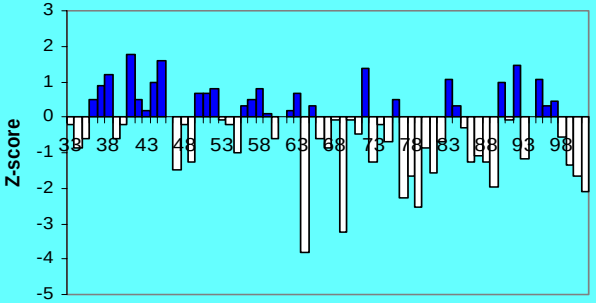












Conclusions

- Hake growth may be modulated by several different oceanographic conditions at several different life stages
- Increased equatorward and offshore flows of water from the North seems to produce a more productive California Current
- While the magnitude of the equatorward/offshore flow is seemingly important, the timing of the start of seasonal cycles may be just as critical to growth and recruitment

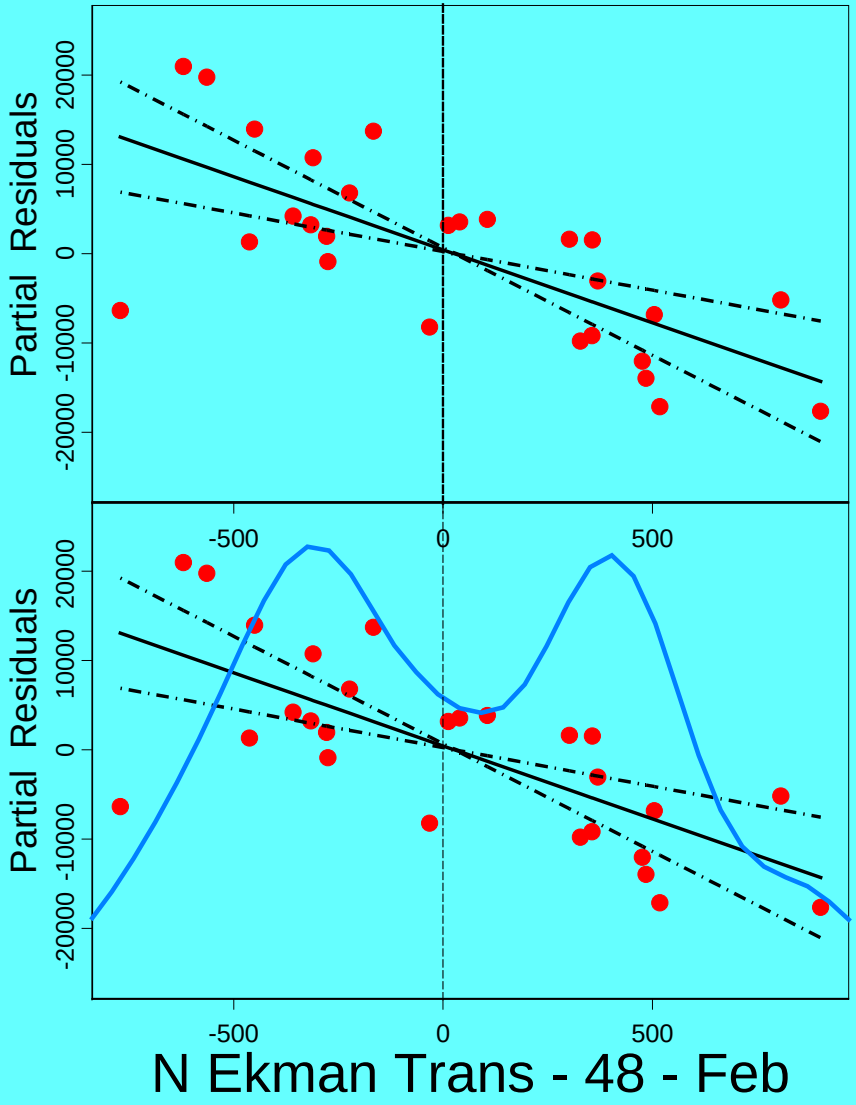
Acknowledgements

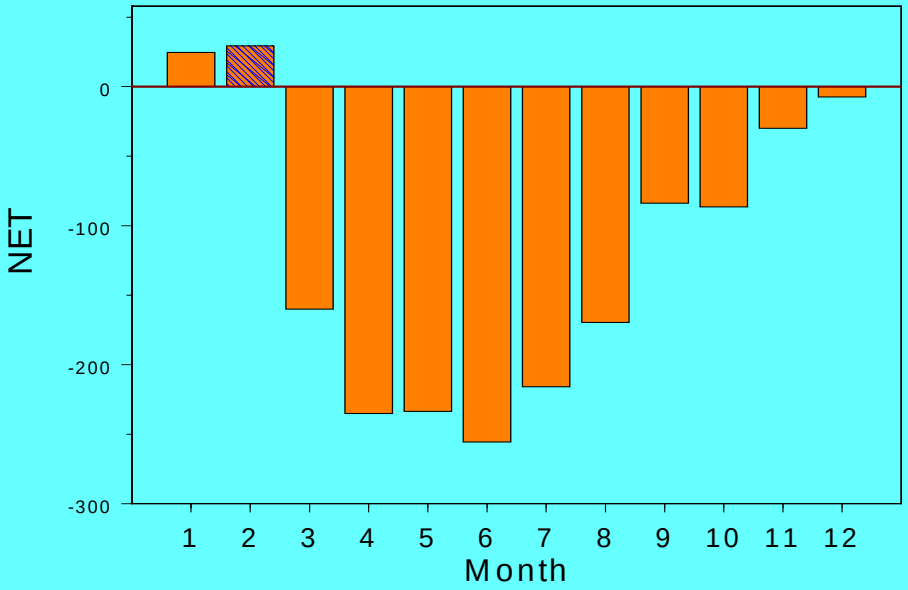
- This work is funded in part by FATE (Fisheries And The Environment), NOAA Fisheries
- Pacific Fisheries Environmental Laboratory (NOAA Fisheries) in Pacific Grove California for assistance with oceanographic data

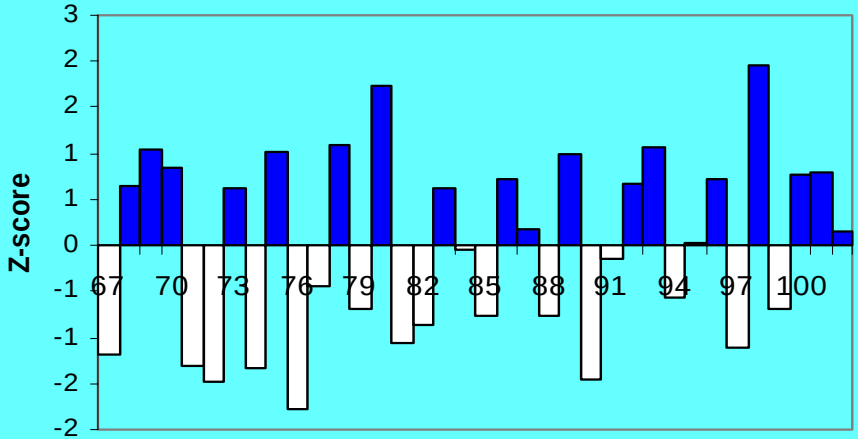
Extra Slides
&
Top Secret Data

Sablefish Recruitment

Northward Ekman Transport (NET) at 48 °Lat in February alternates between north(+) and south(-)

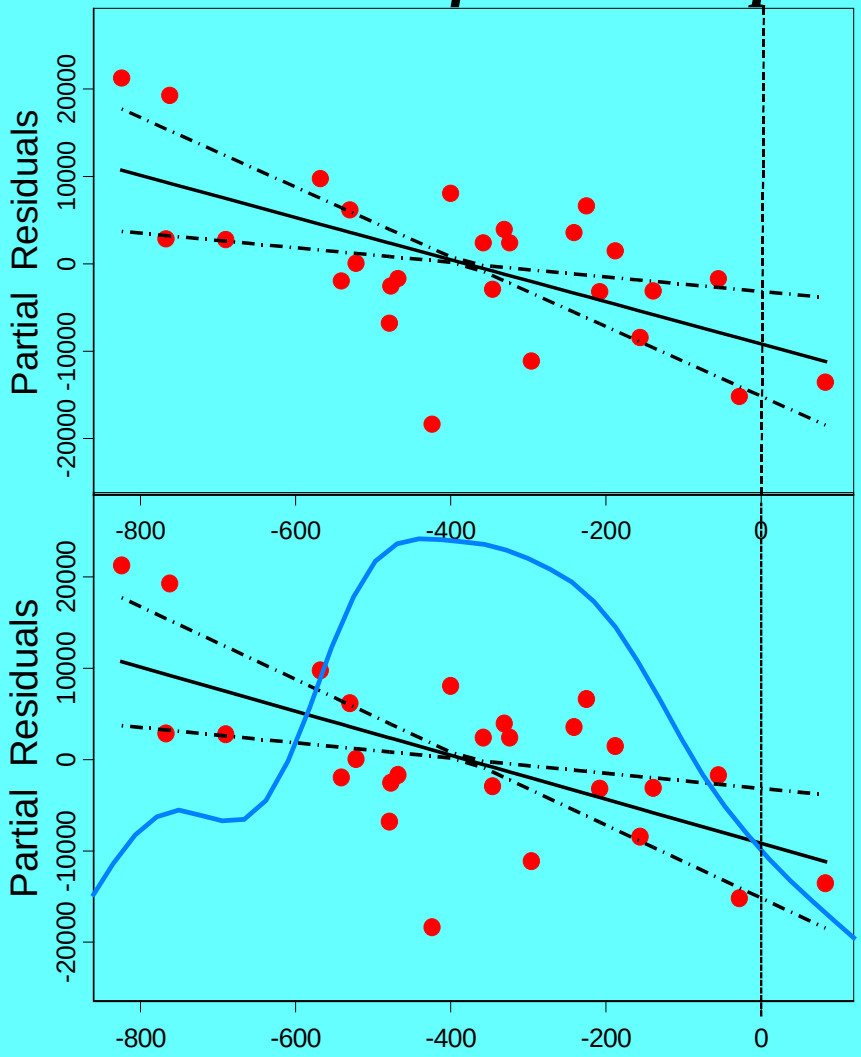


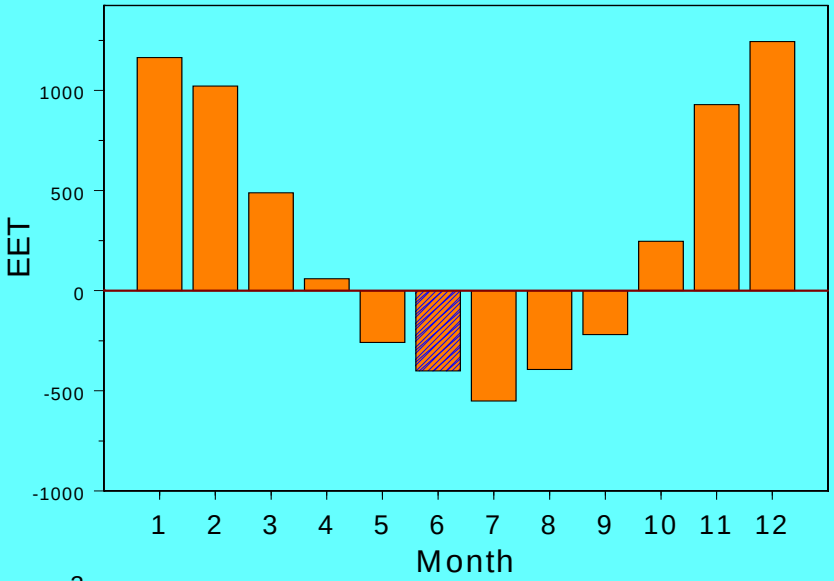


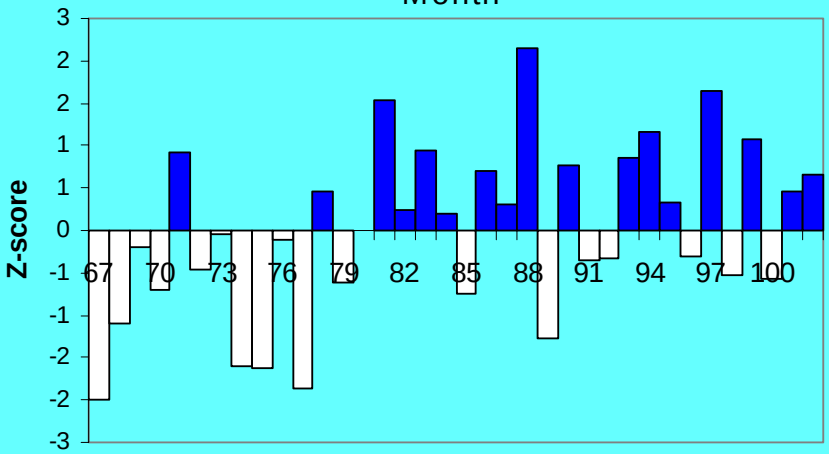


Sablefish Recruitment

Eastward Ekman Transport (EET) at 45º in June is an index of summer upwelling and is generally west(-)

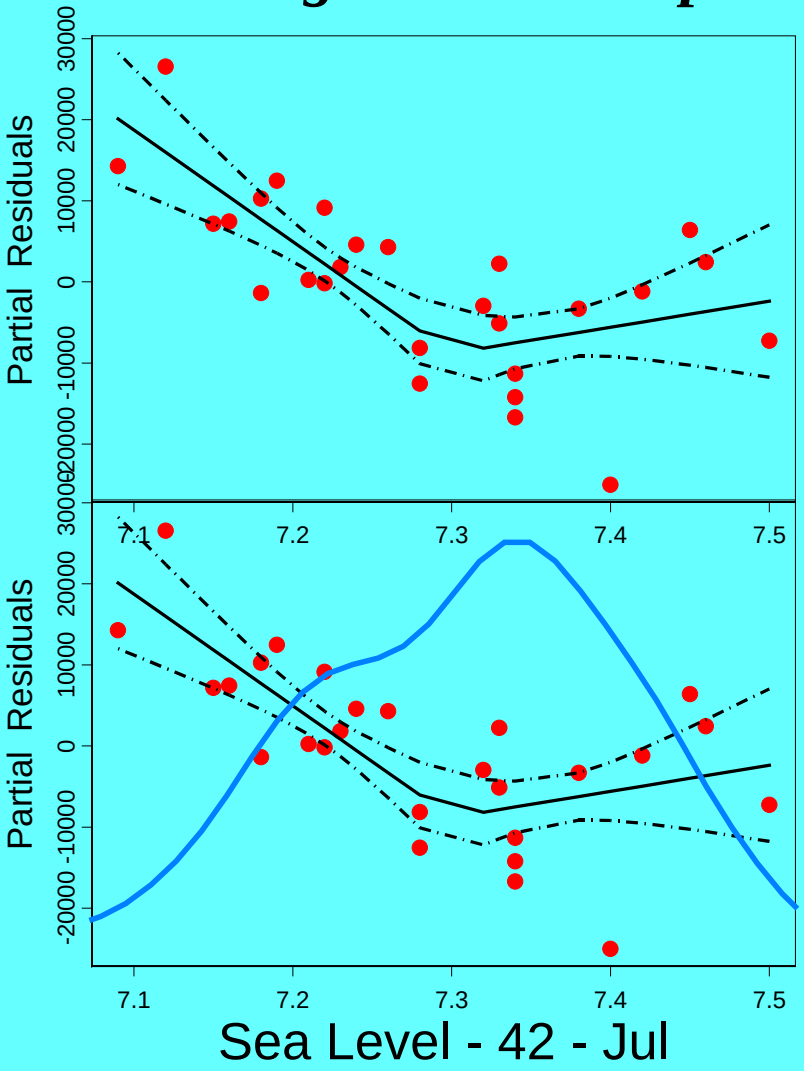


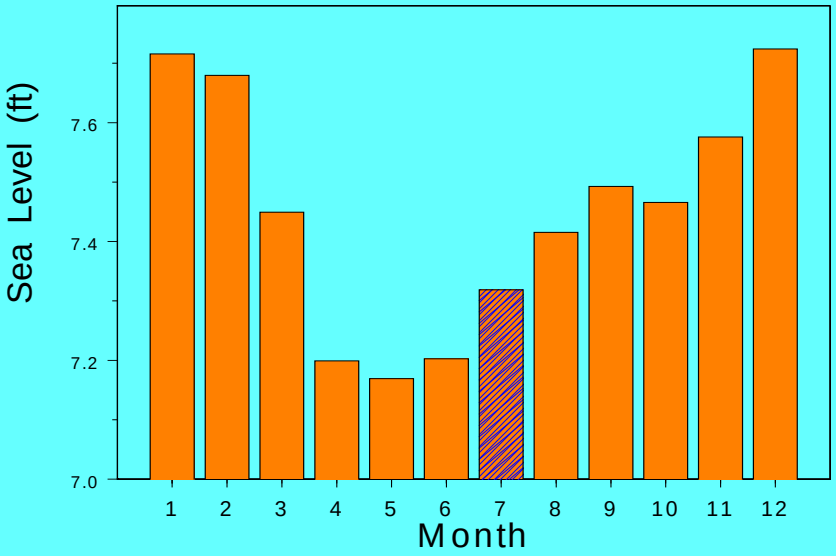


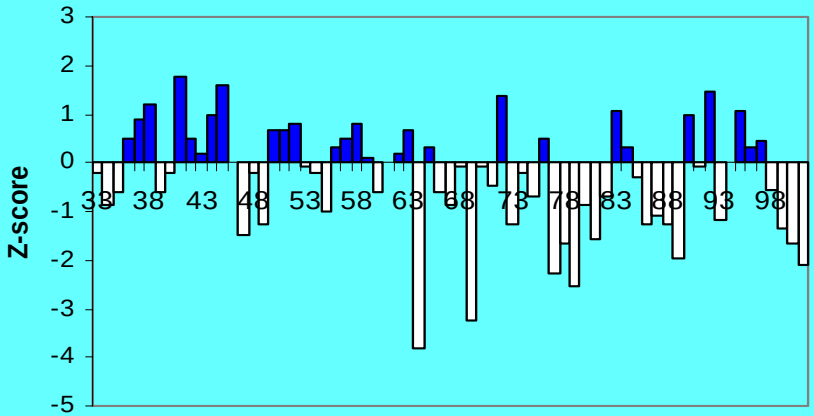


Sablefish Recruitment

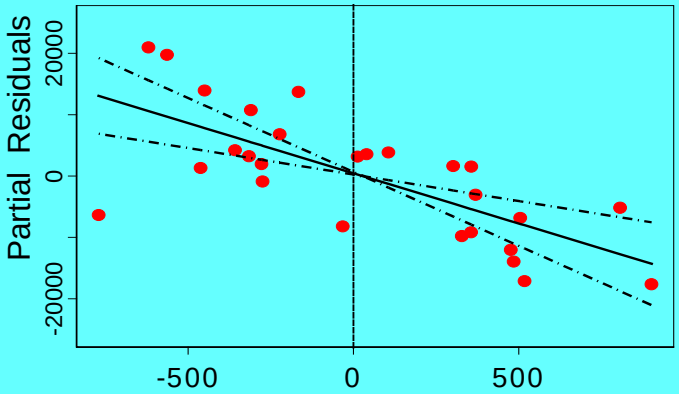
Sea Level (SL) at 42º in July is an indicator of Along Shore Transport (< sea level = > transport)

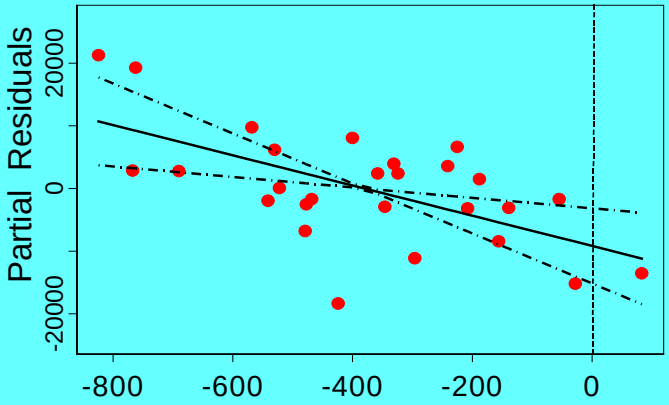


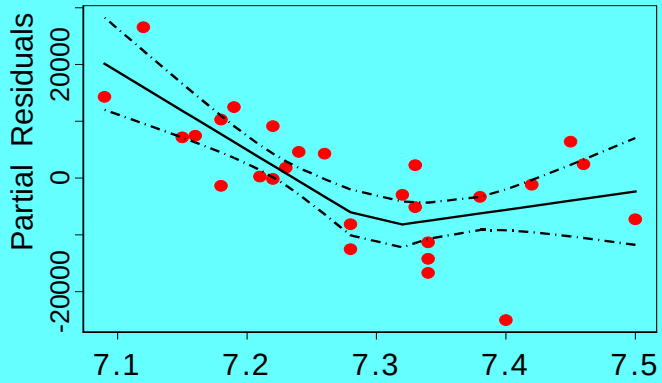


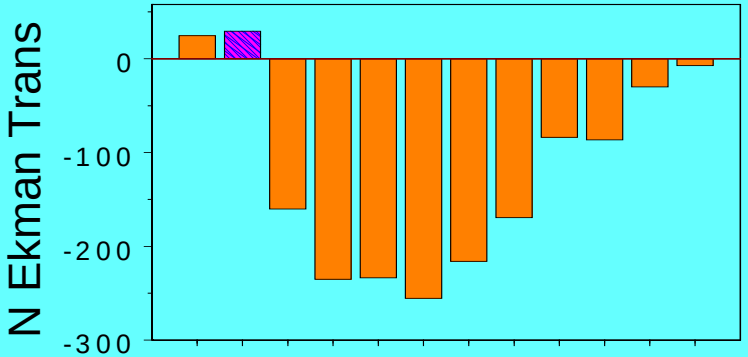


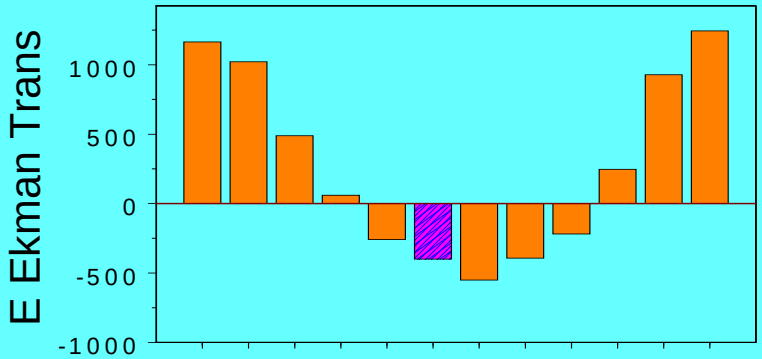
Sablefish Recruitment in California Current

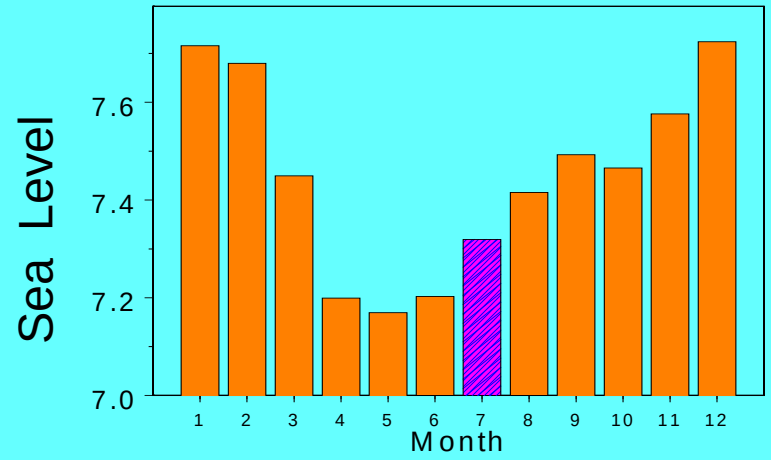




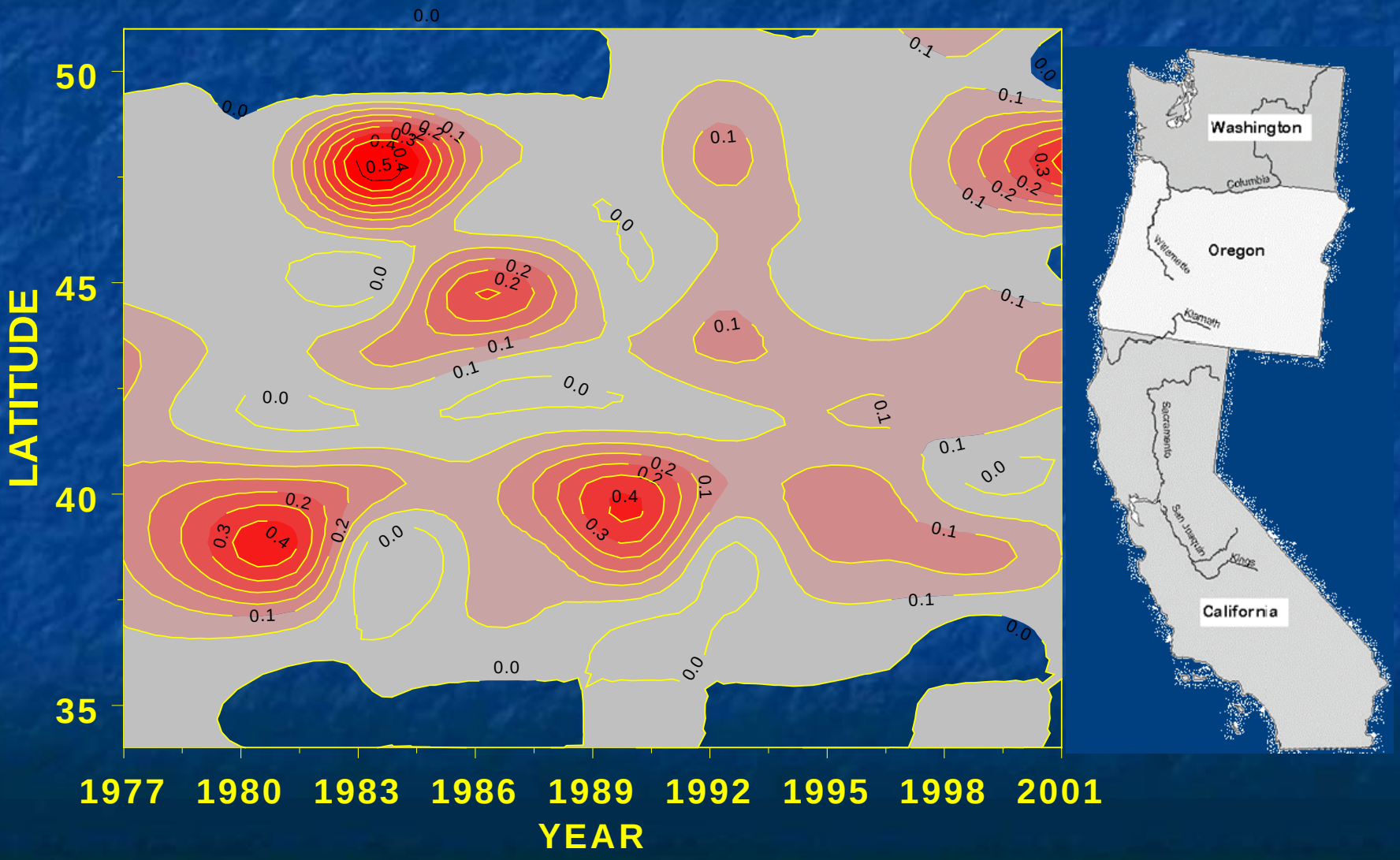






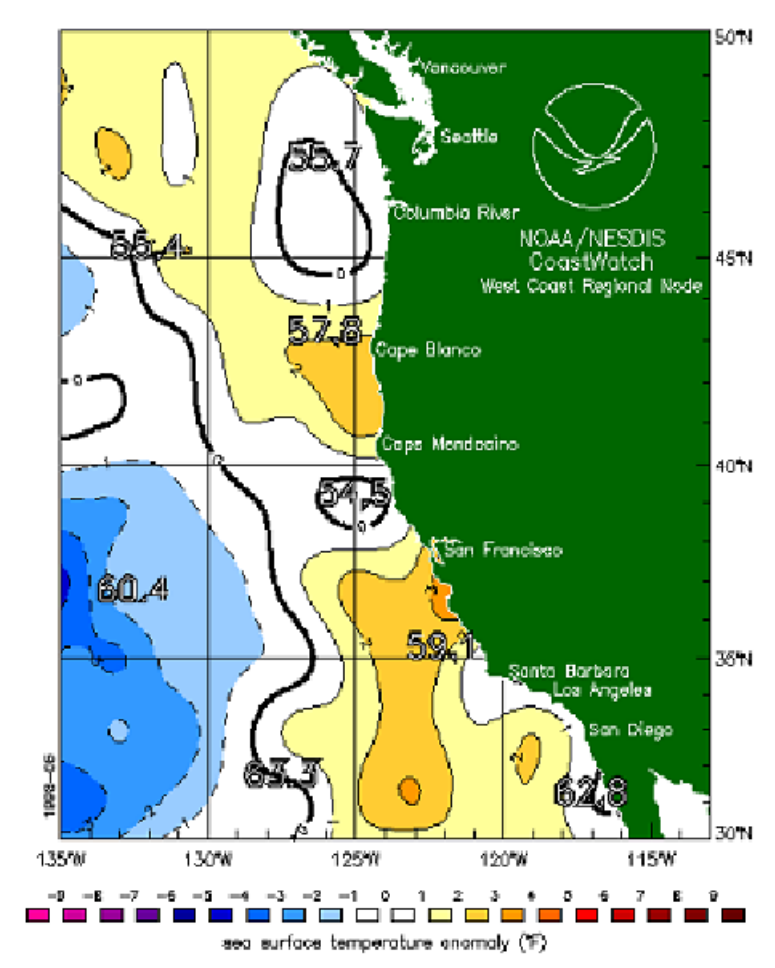


…However, Migration Varies with Ocean Conditions



Hake Migration May Be in Response to SST

1998 – Found South



2001 – Found North

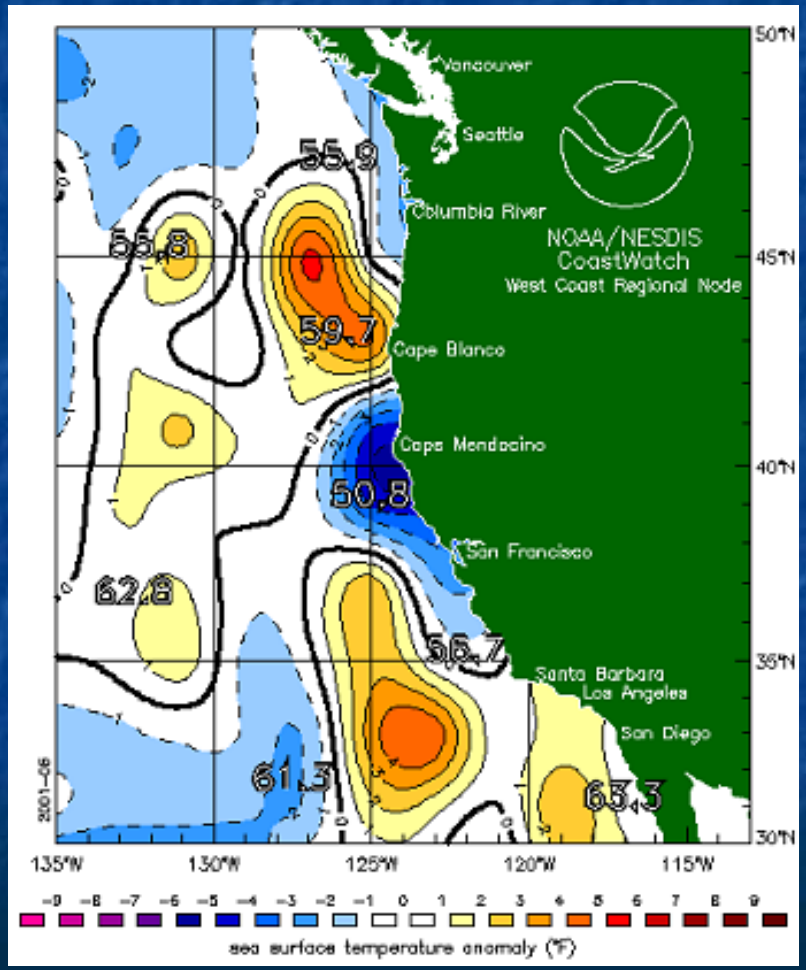
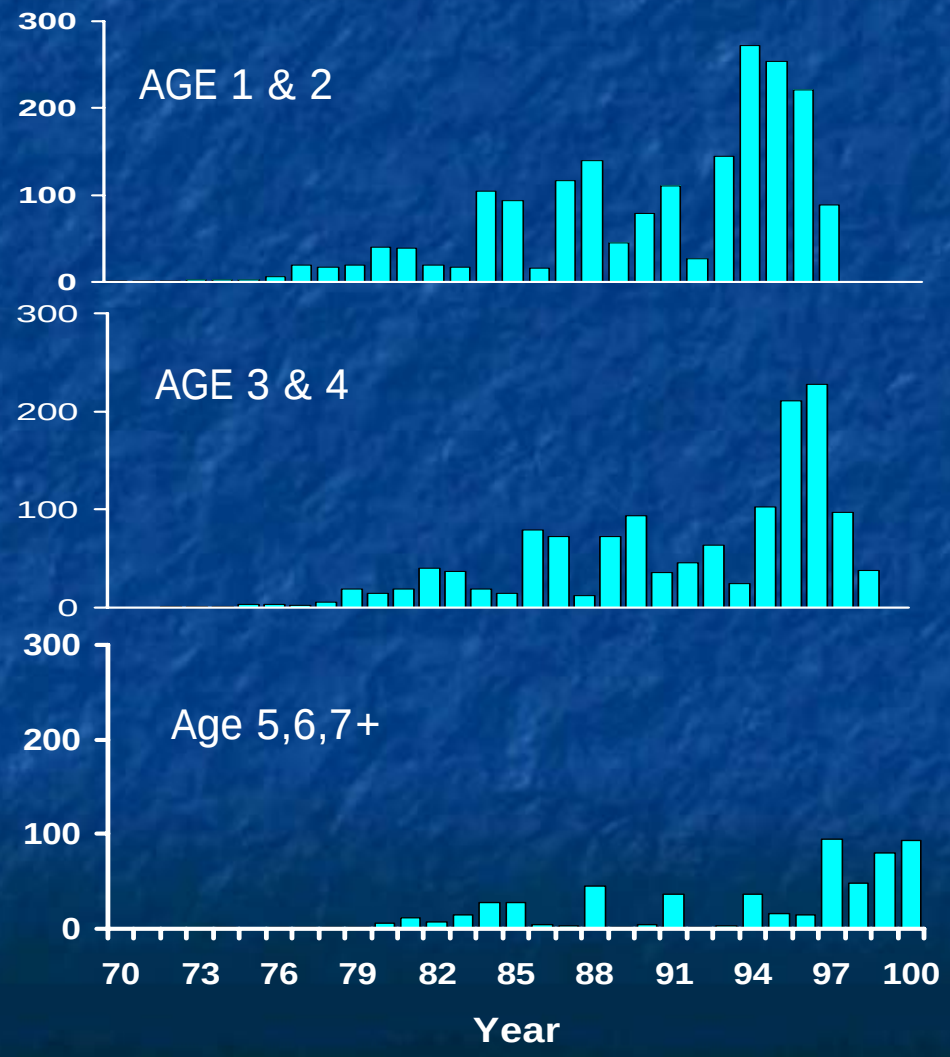


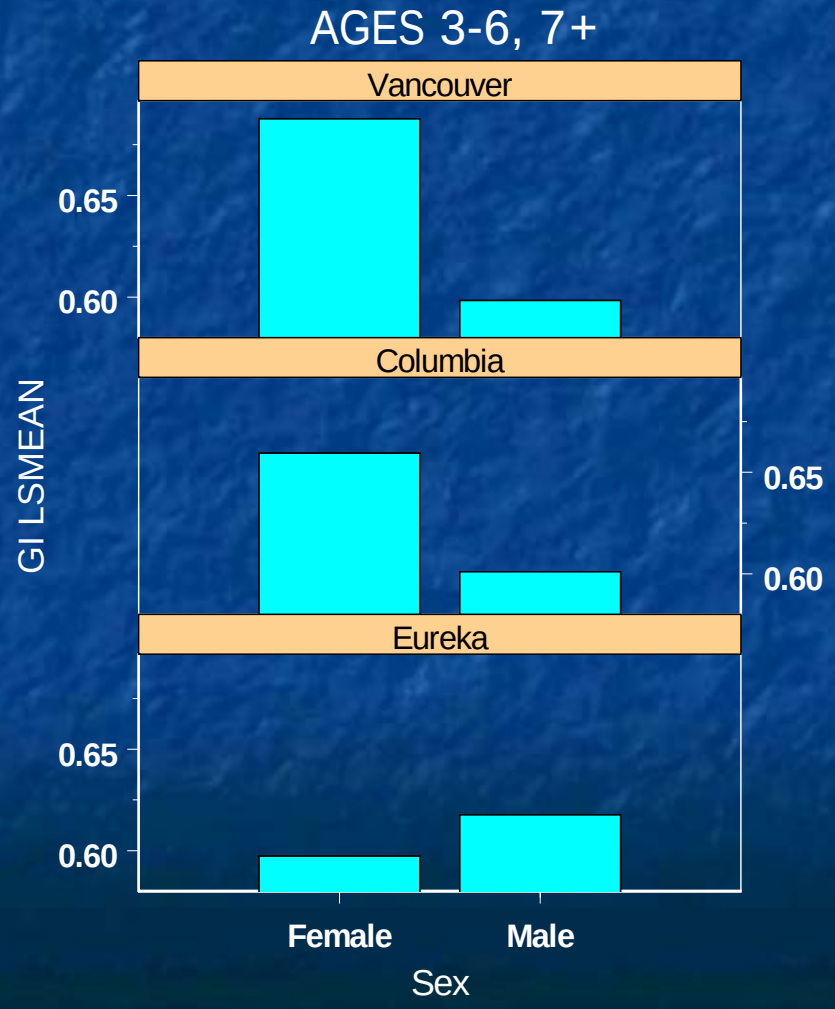
Figure courtesy of NOAA Fisheries – Pacific Fisheries Environmental Laboratory

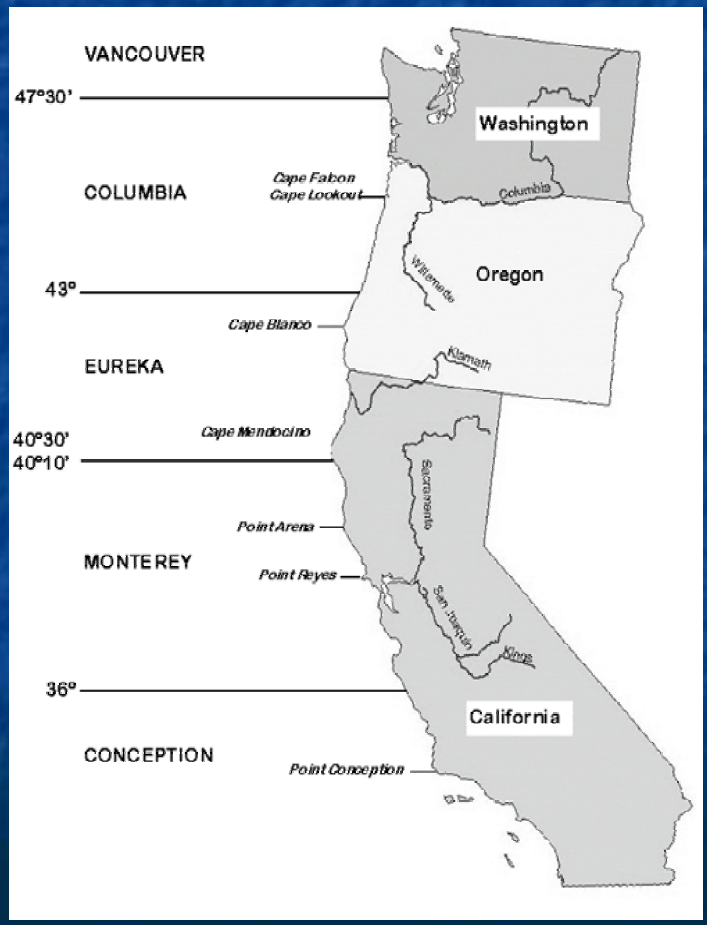
Sample Size Matrix is yet unbalanced so Least Square Means ($GI_{age, year}$) were used



Known Results Were Repeatable

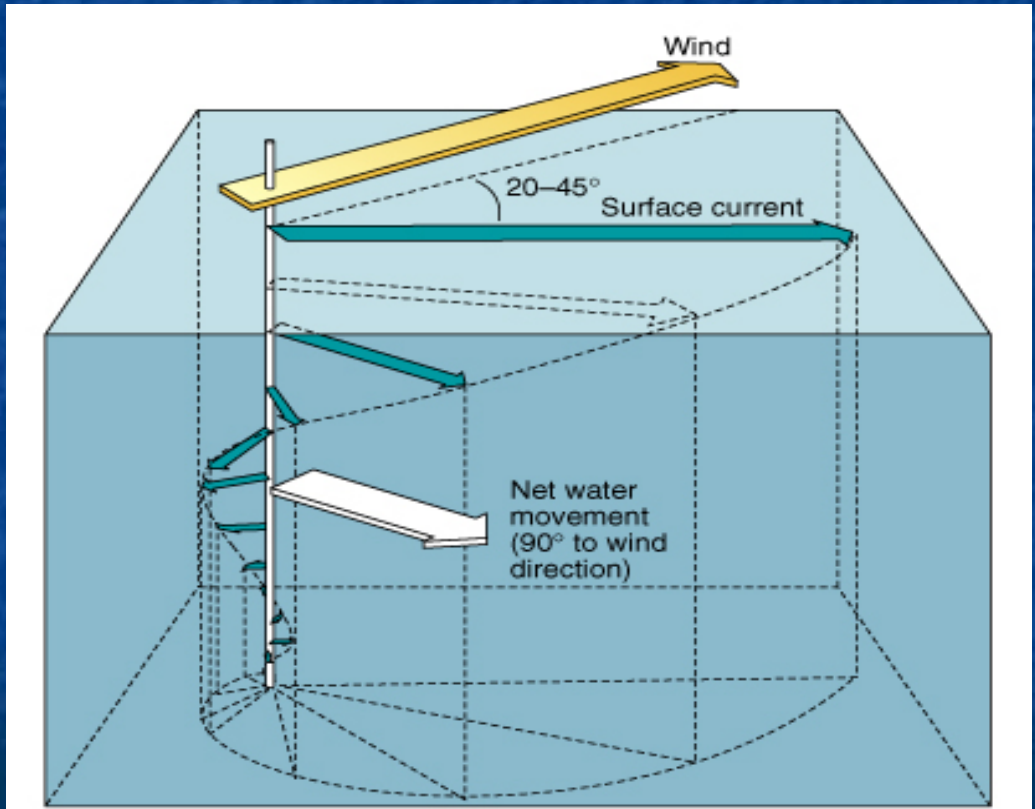
Adult Female Hake are Larger than Males, and those in the North tend to be Larger than those in the South





Ekman transport creates a net movement of water 90 degrees to wind direction

Direction = $4.3W/\sin(Lat)^{1/2}$



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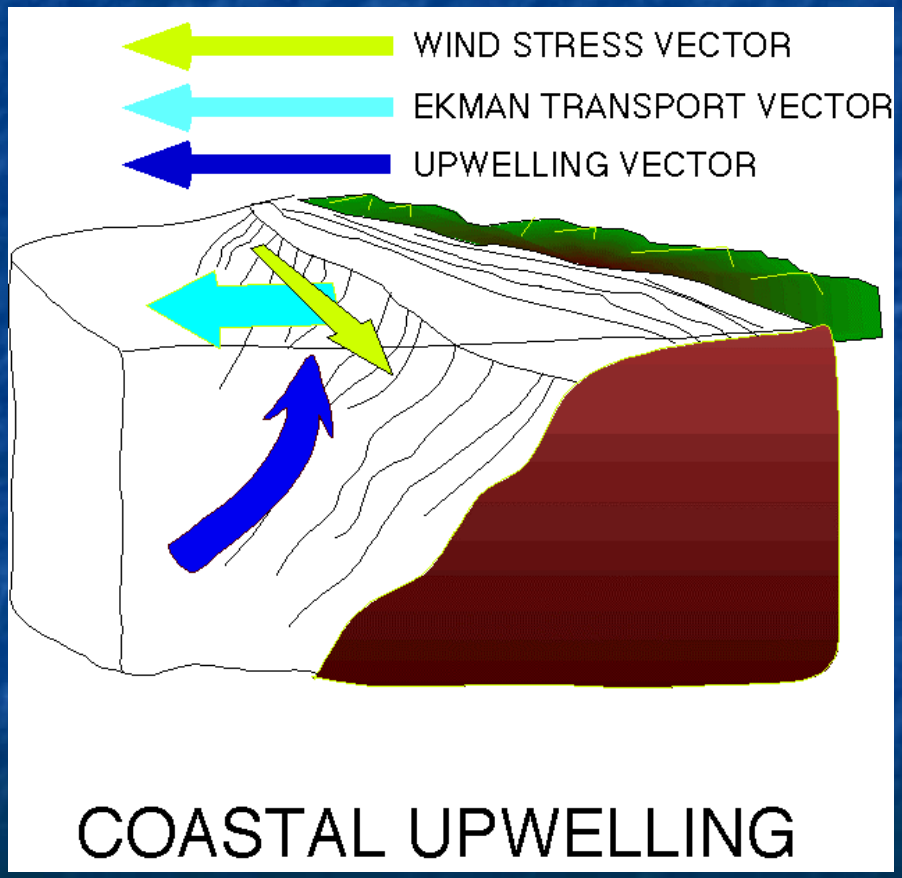
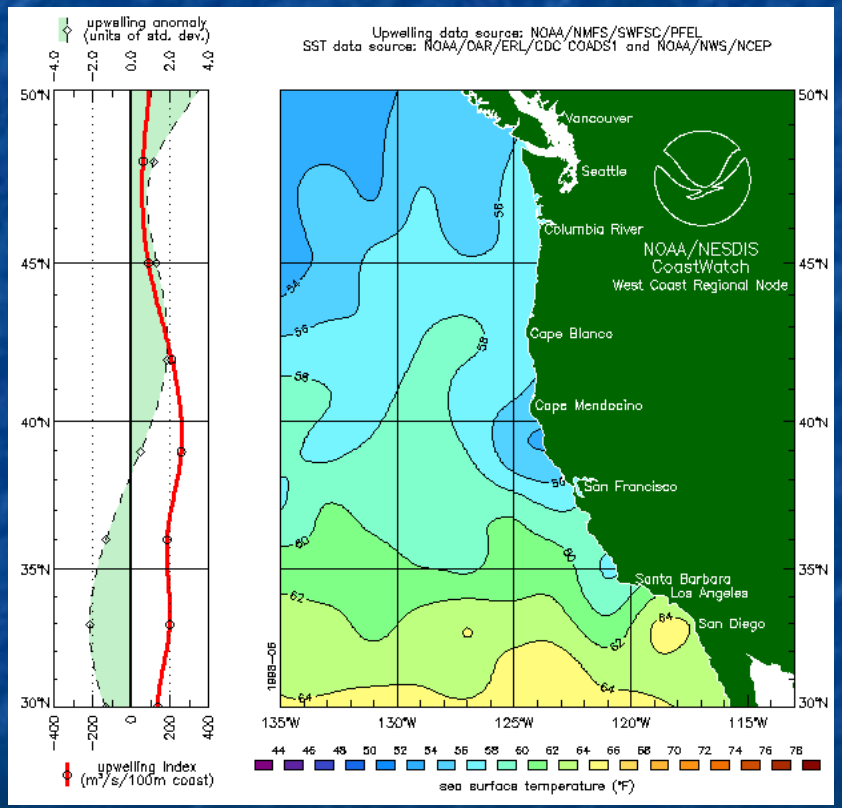
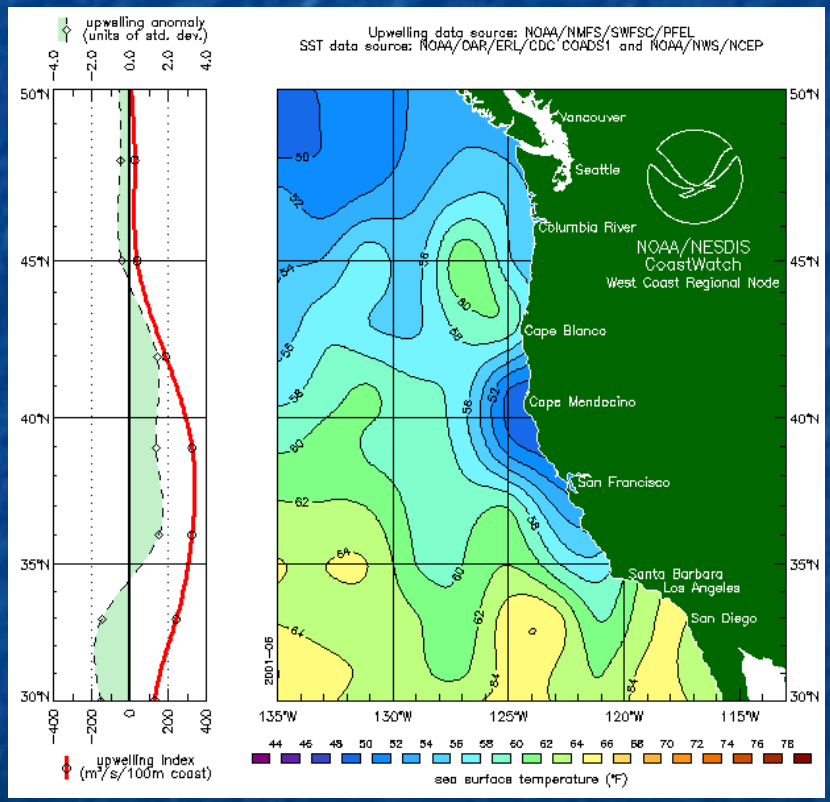
Upwelling


WIND STRESS VECTOR
EKMAN TRANSPORT VECTOR
UPWELLING VECTOR
COASTAL UPWELLING

1998


upwelling anomaly
(units of std. dev.)
-4.0 -2.0 0.0 2.0 4.0
Upwelling data source: NOAA/NMFS/SWFSC/PFEL
SST data source: NOAA/DAR/ERL/CDC COADS1 and NOAA/NWS/NCEP
50°N
45°N
40°N
35°N
30°N
Vancouver
Seattle
Columbia River
NOAA/NESDIS
CoastWatch
West Coast Regional Node
Cape Blanco
Cape Mendocino
San Francisco
Santa Barbara
Los Angeles
San Diego
1989-06
135°W 130°W 125°W 120°W 115°W
-400 -200 0 200 400
upwelling index
(m³/s/100m coast)
44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78
sea surface temperature (°F)

2001


upwelling anomaly
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