Climate Change and the NCSS (NOAA Fisheries Climate Science Strategy)

Examples from Changing Ocean Conditions and Its Impacts on the U.S. West Coast and Pacific Regions

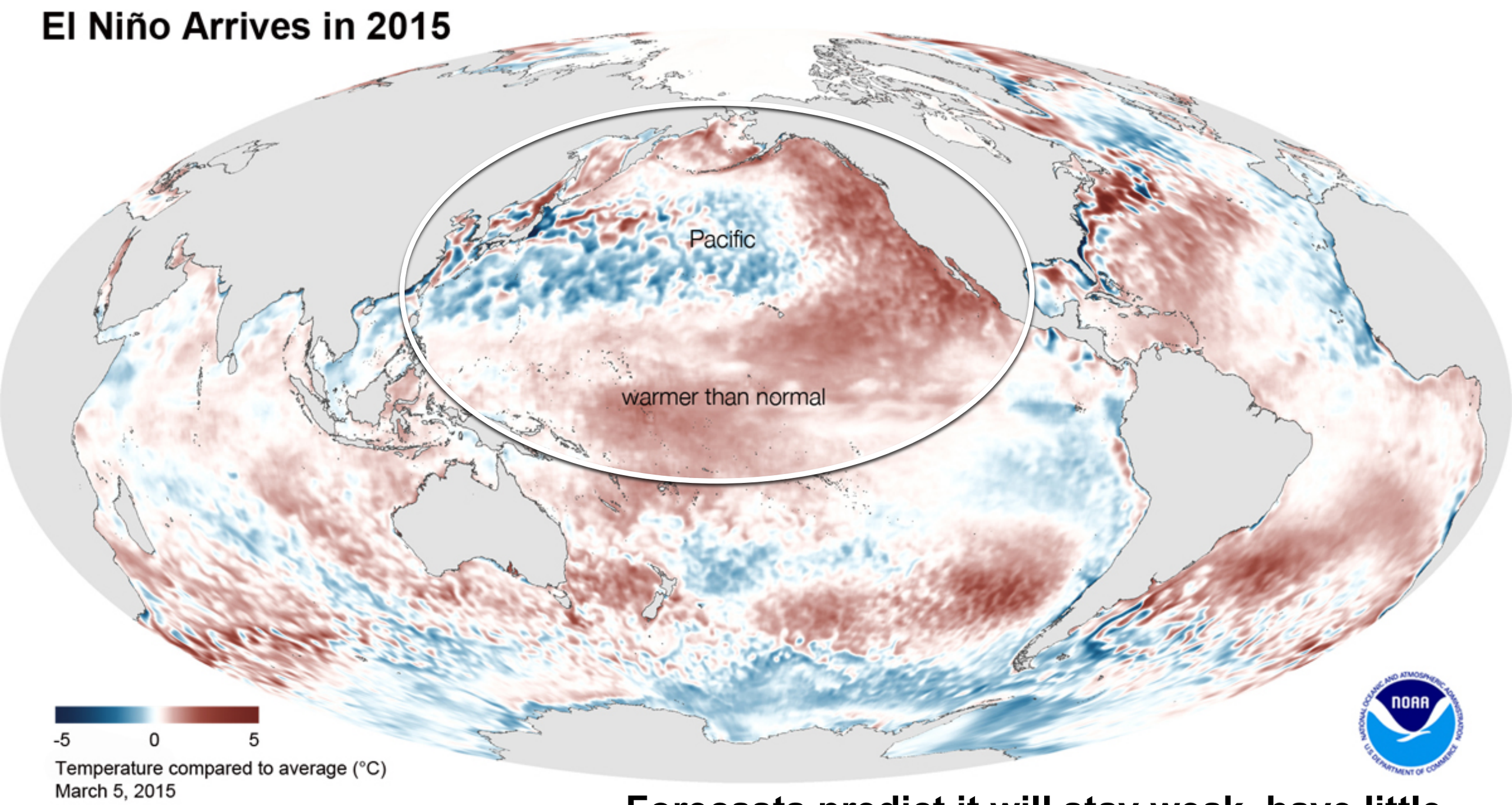
Cisco Werner

Southwest Fisheries Science Center

Outline

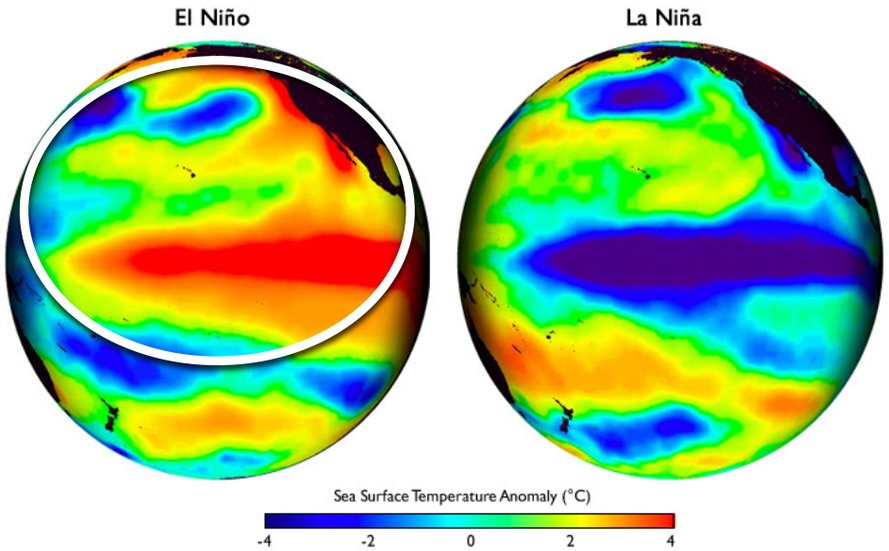
- Present conditions in the Pacific (focusing on the U.S. West Coast)
- The NCSS – draft Climate Science Strategy
- Pacific (U.S. West Coast) examples of the NCSS in the
- Concluding remarks

El Niño and a positive phase of the PDO (Pacific Decadal Oscillation)

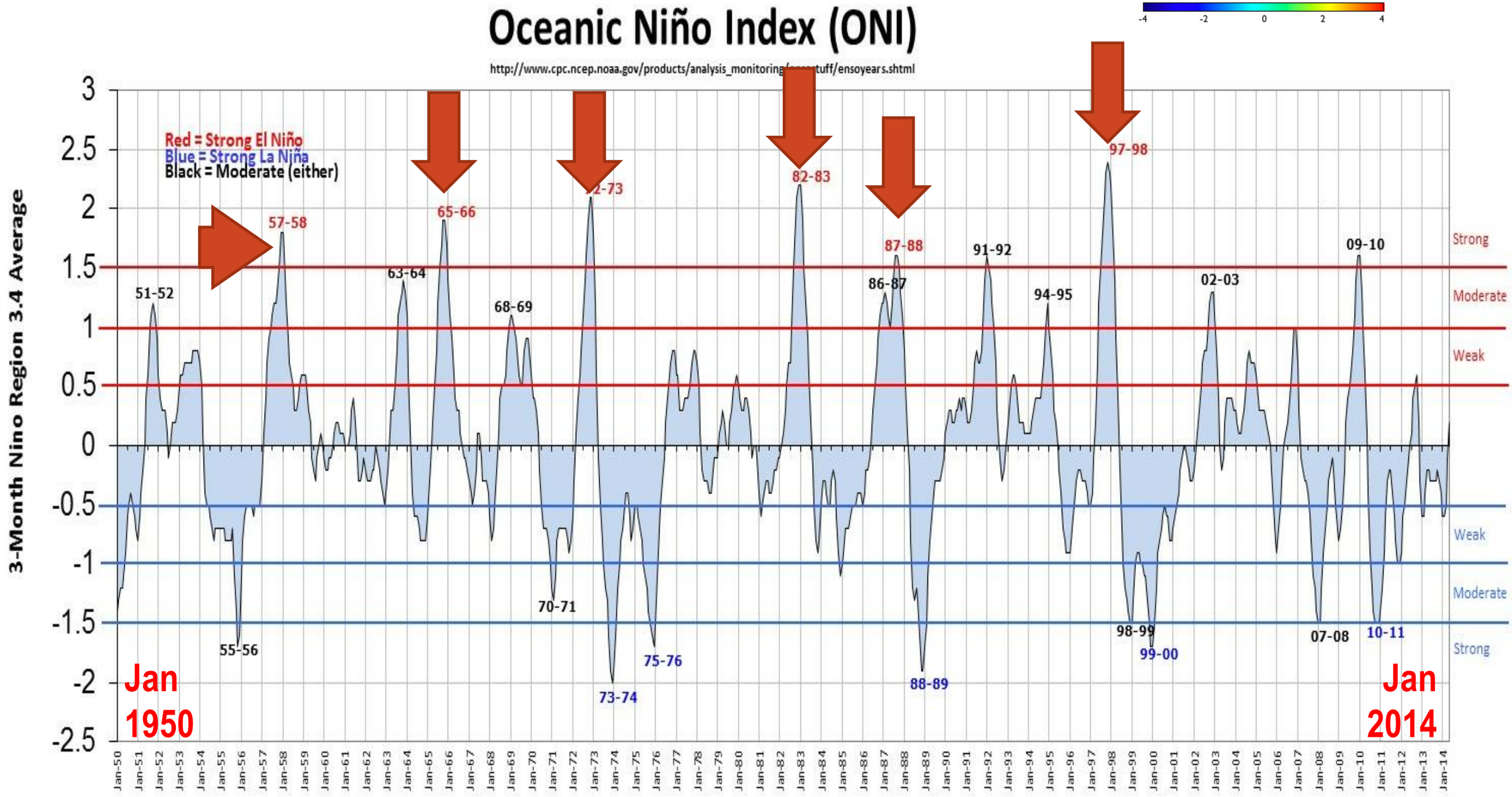


Forecasts predict it will stay weak, have little influence on weather and climate - but …

El Niño/La Niña occurrences since 1950

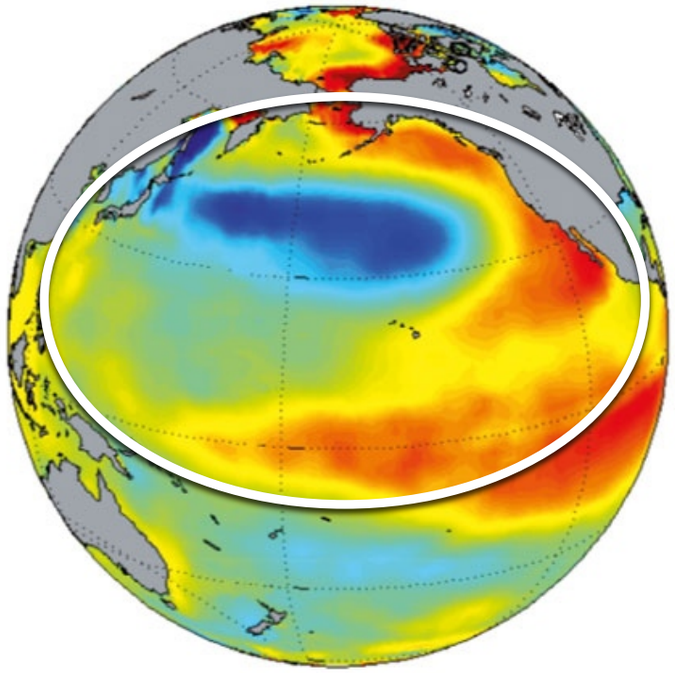


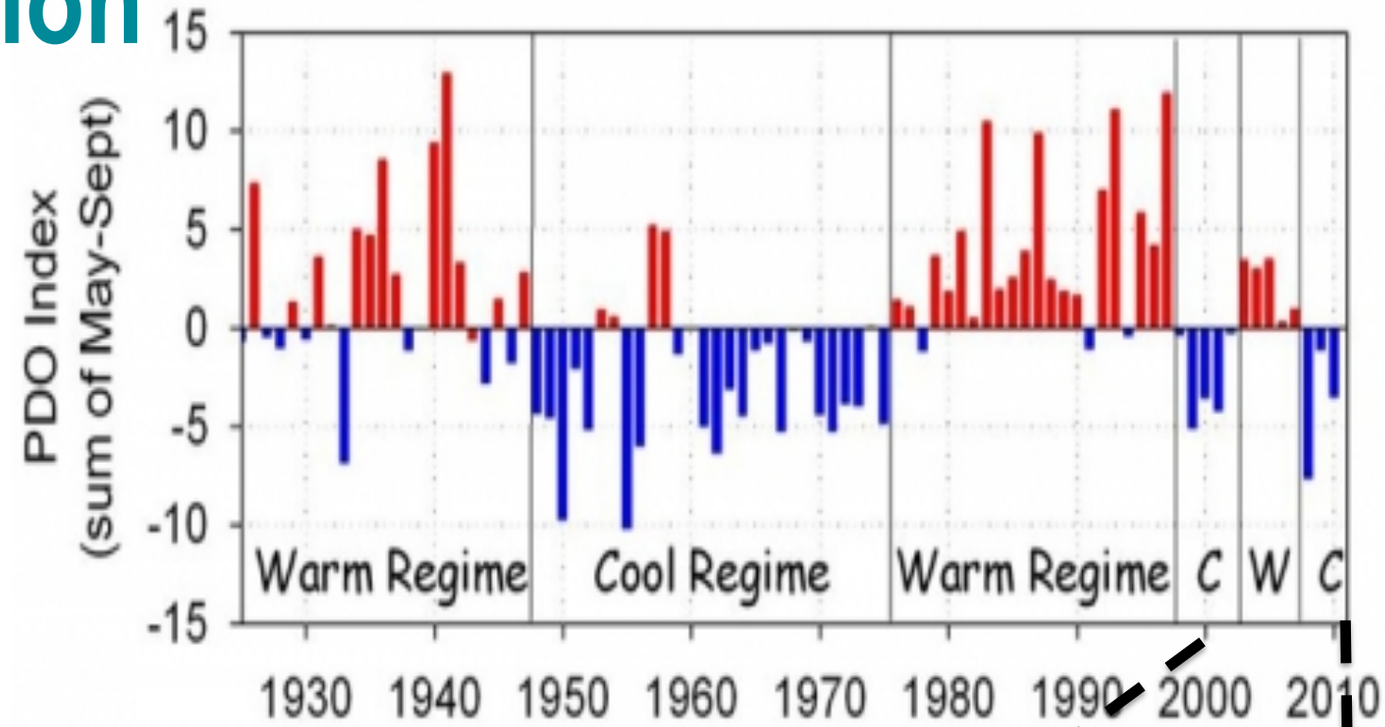
Six "strong" and eight "moderate" *El Niños*
And five "strong" and four "moderate" *La Niñas*



Pacific Decadal Oscillation (PDO)

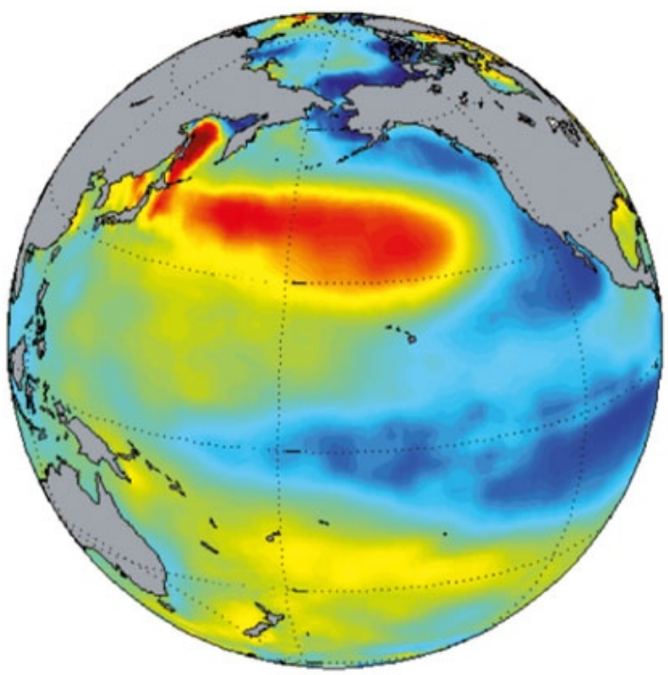
Warm (Positive) Phase

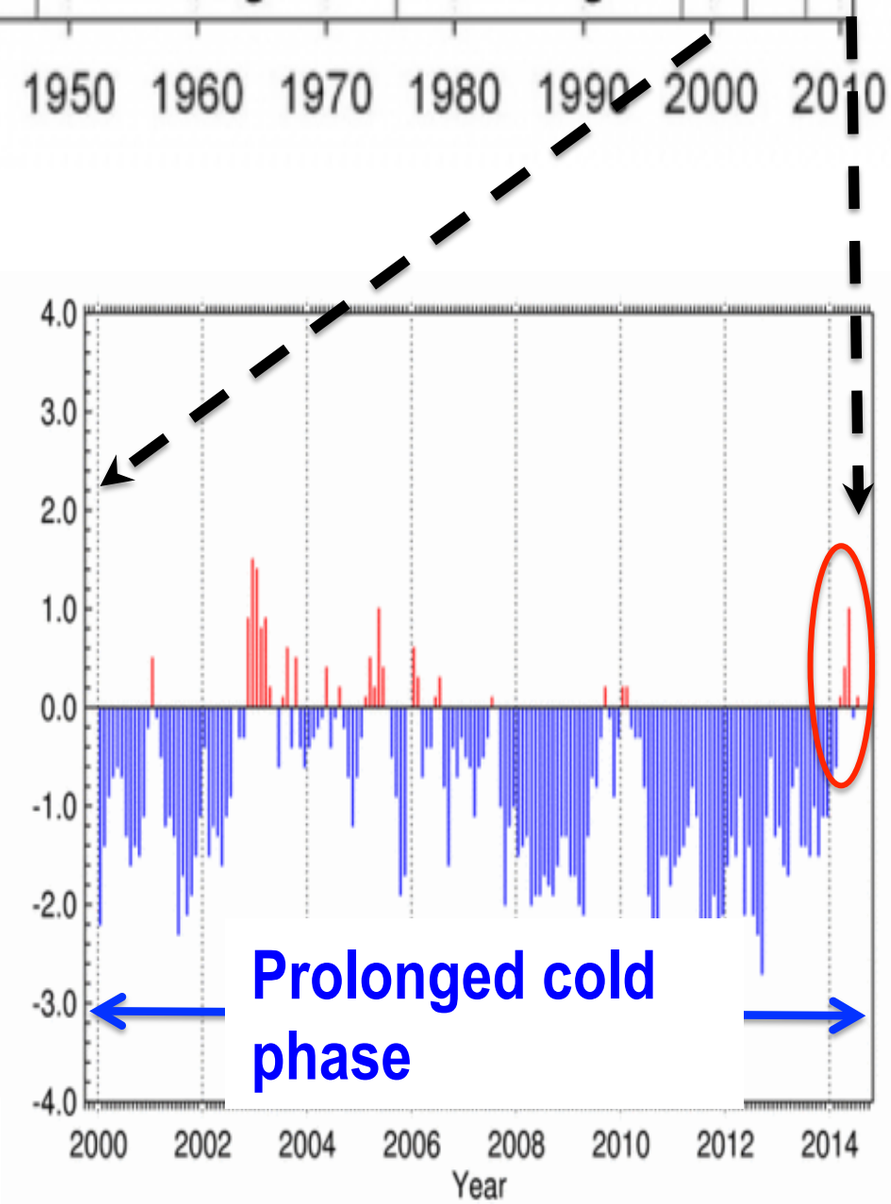




Departures from average ocean temperatures (°C) associated with the warm and cool phases of the PDO

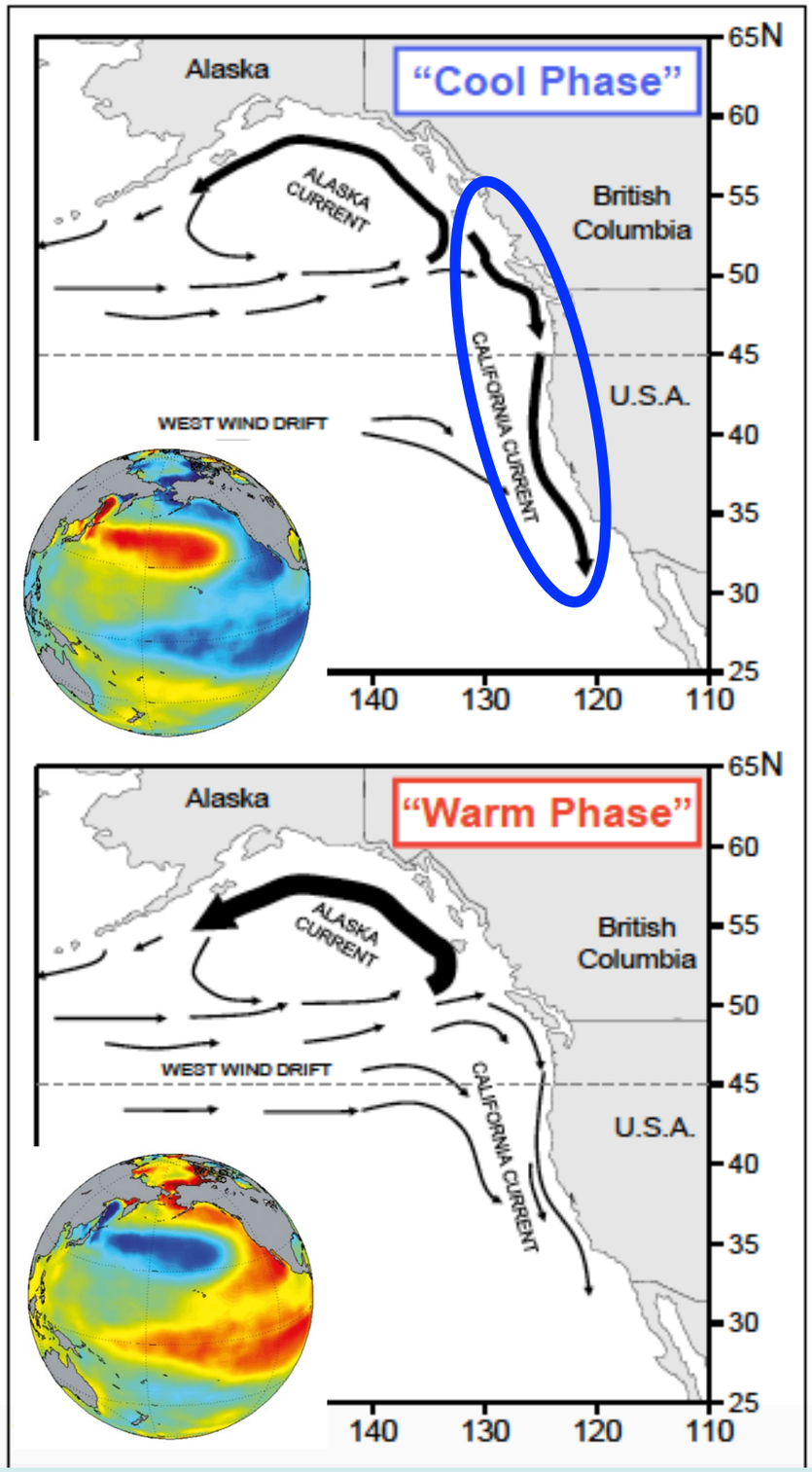
Cold (Negative) Phase





NOAA FISHERIES

Juvenile salmon … biological and physical processes



(K. Fresh)

Cool Phase of PDO=High Survival

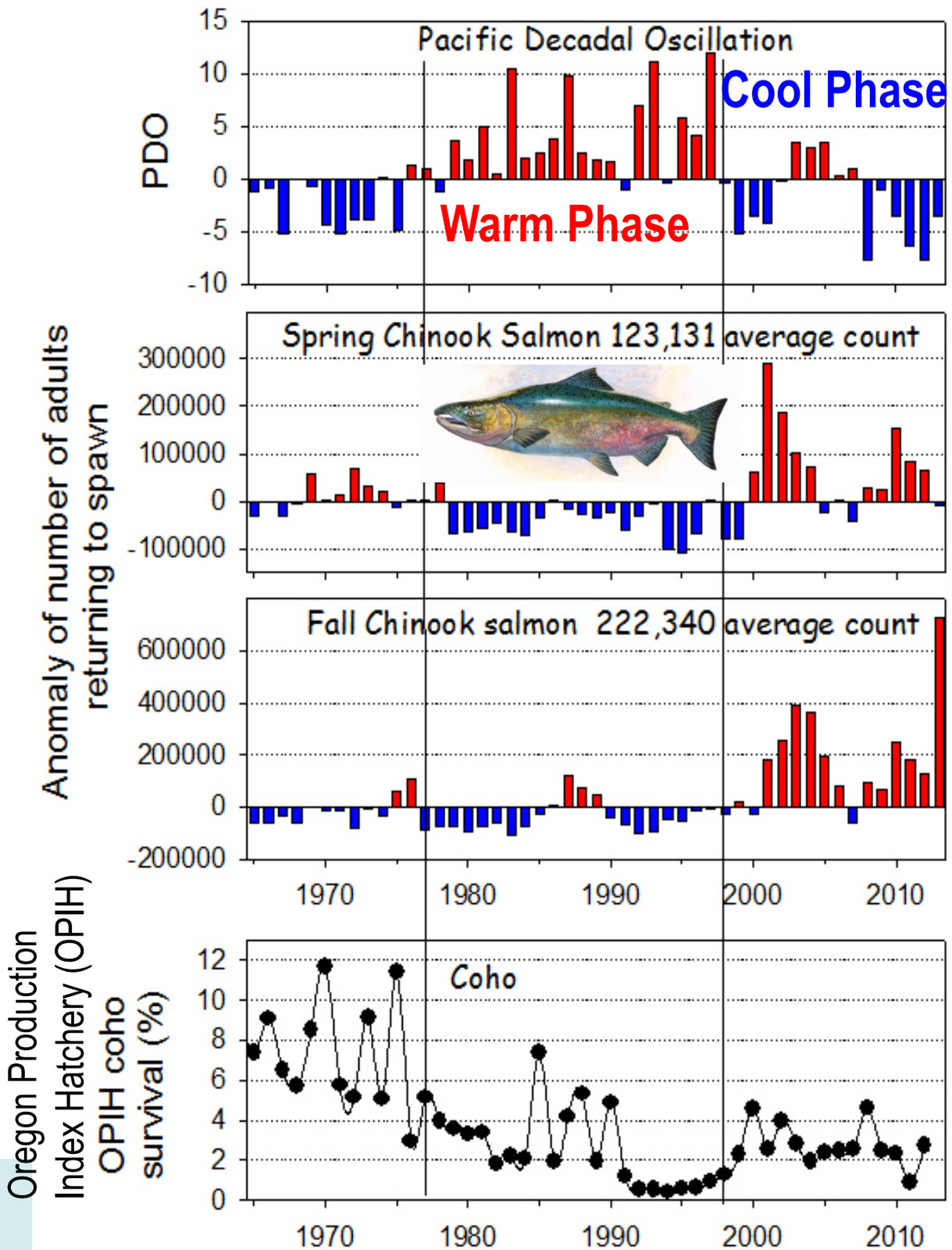
- Flow from the North
- Cold water – Lipid-rich copepods
- Low number of large predators

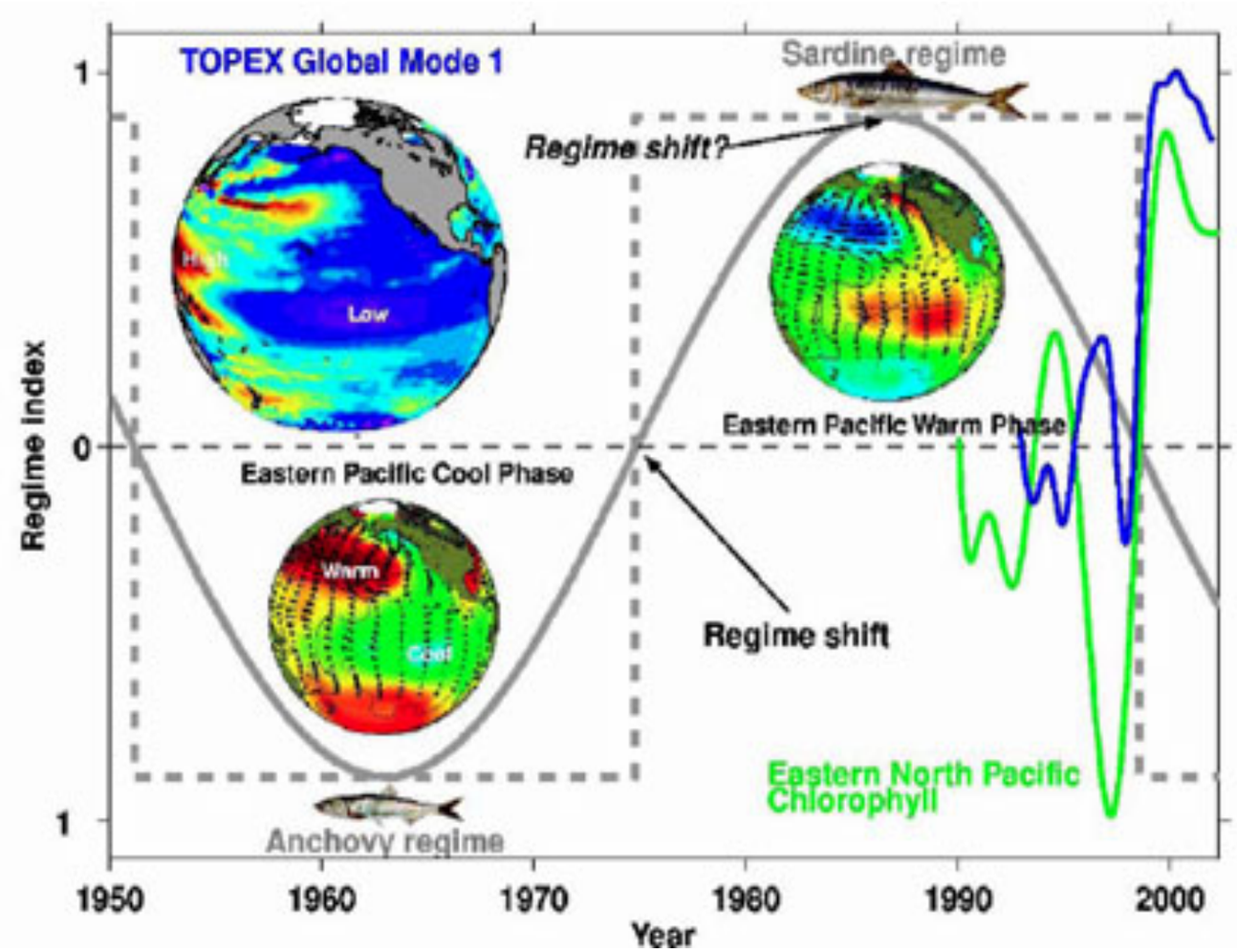
Warm Phase of PDO=Low Survival

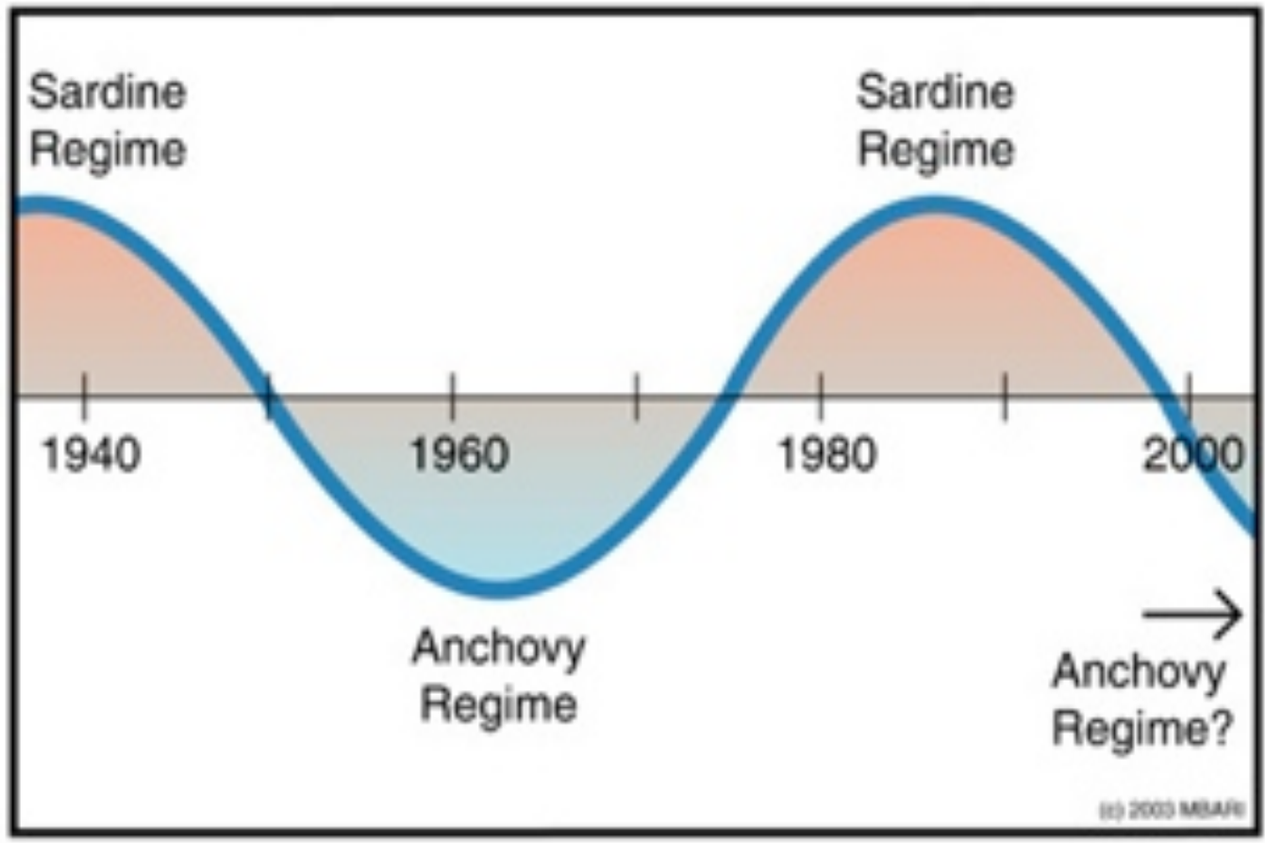
- Flow from offshore & South
- Warm water – Low lipid copepods
- High number of large predators

PDO=Pacific Decadal Oscillation

PDO and fisheries





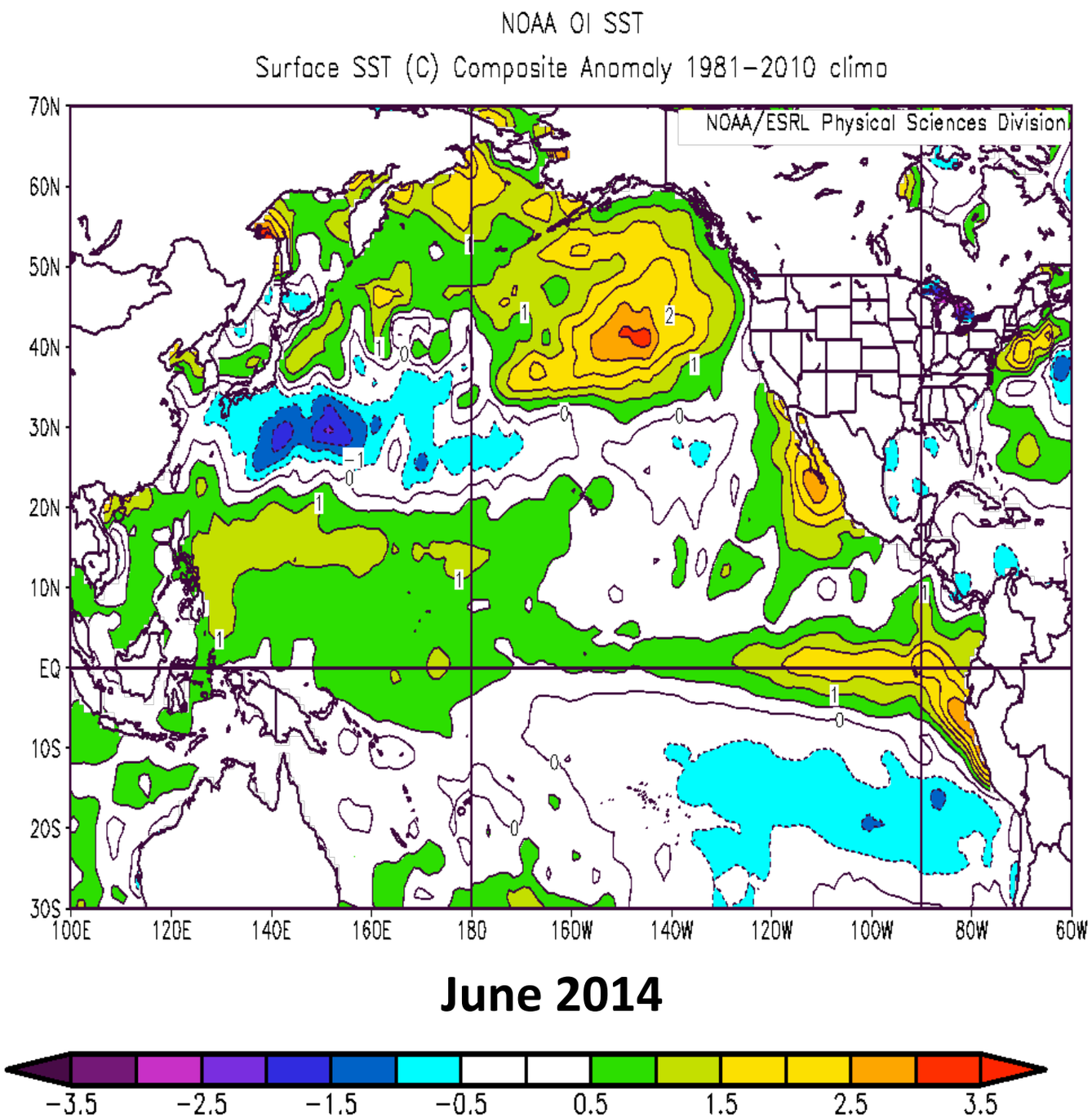


Unusual conditions

- Northeast Pacific warmed *before* the Eastern Tropical Pacific
- Gulf of Alaska has been extremely warm for the **past year and a half** (weak winter conditions)
- Baja and So. California near-shore have been warm **since June 2014** (local winds – not remotely-forced ENSO)

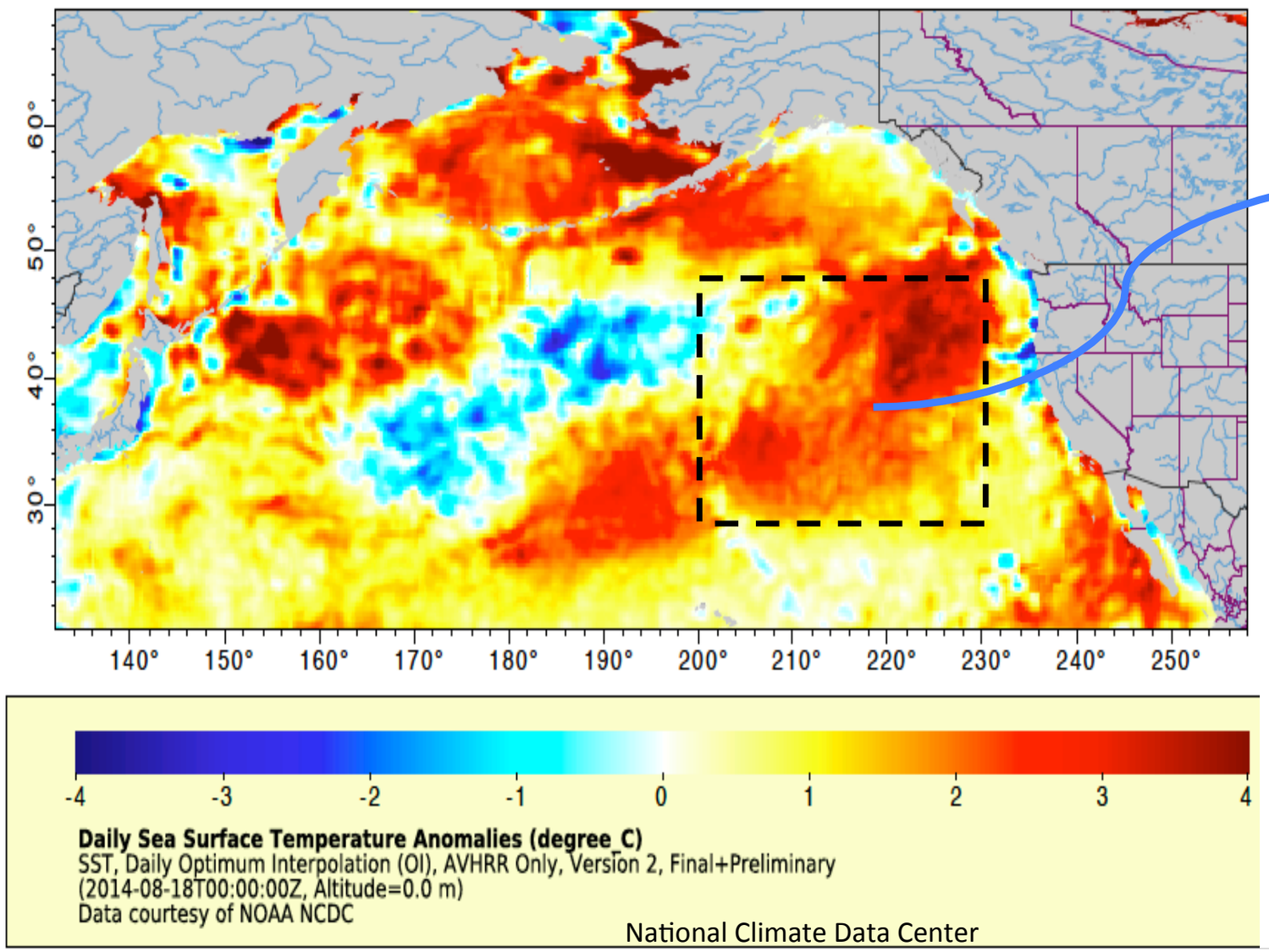
False Killer Whales, 24 Feb 2015; Photo: M. Robbins

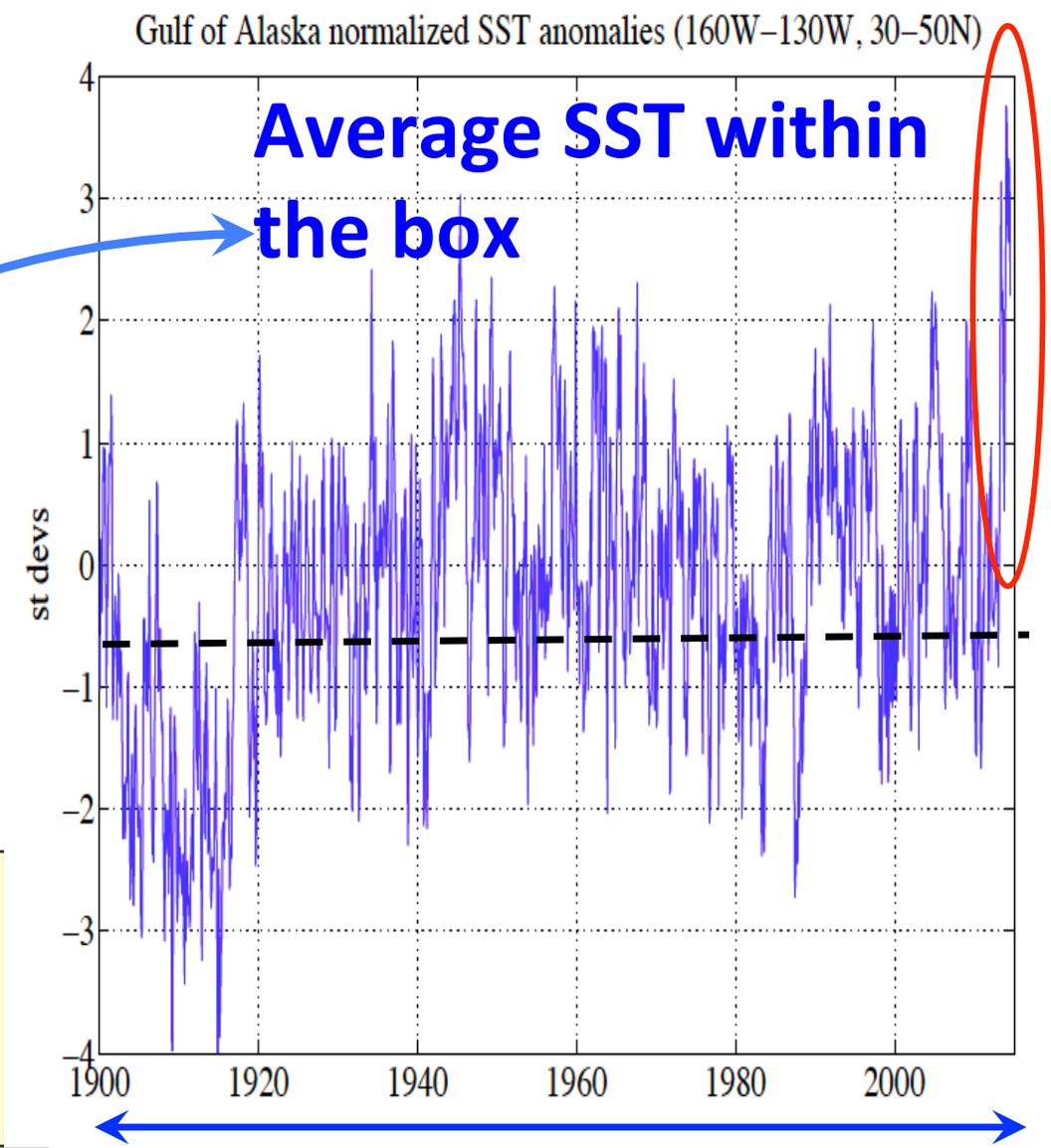
Sea Surface Temperature Anomaly (relative to 1981-2010)



June 2014

The 100+ year time series of Sea Surface Temperature in the eastern Pacific shows this is the warmest



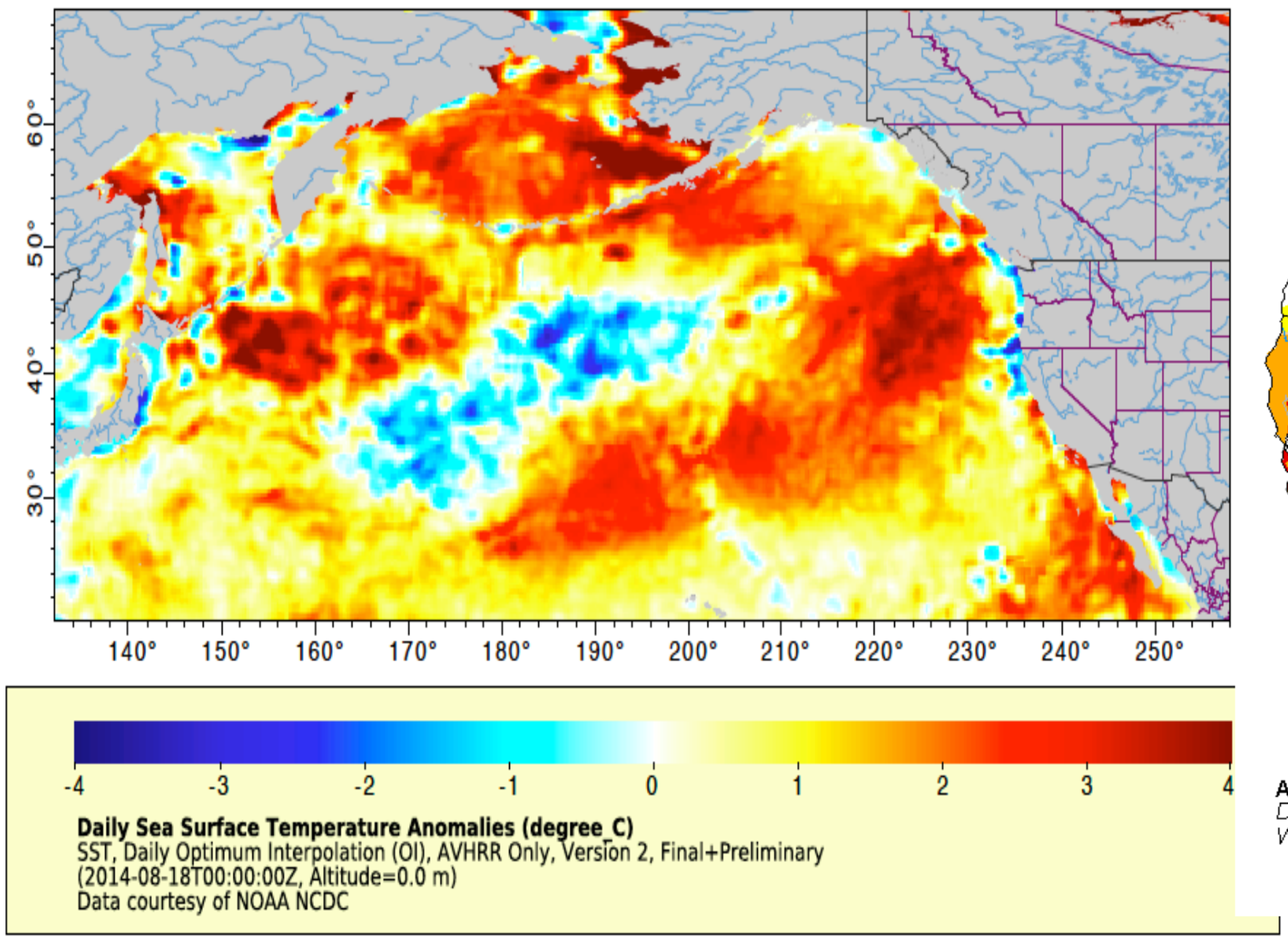


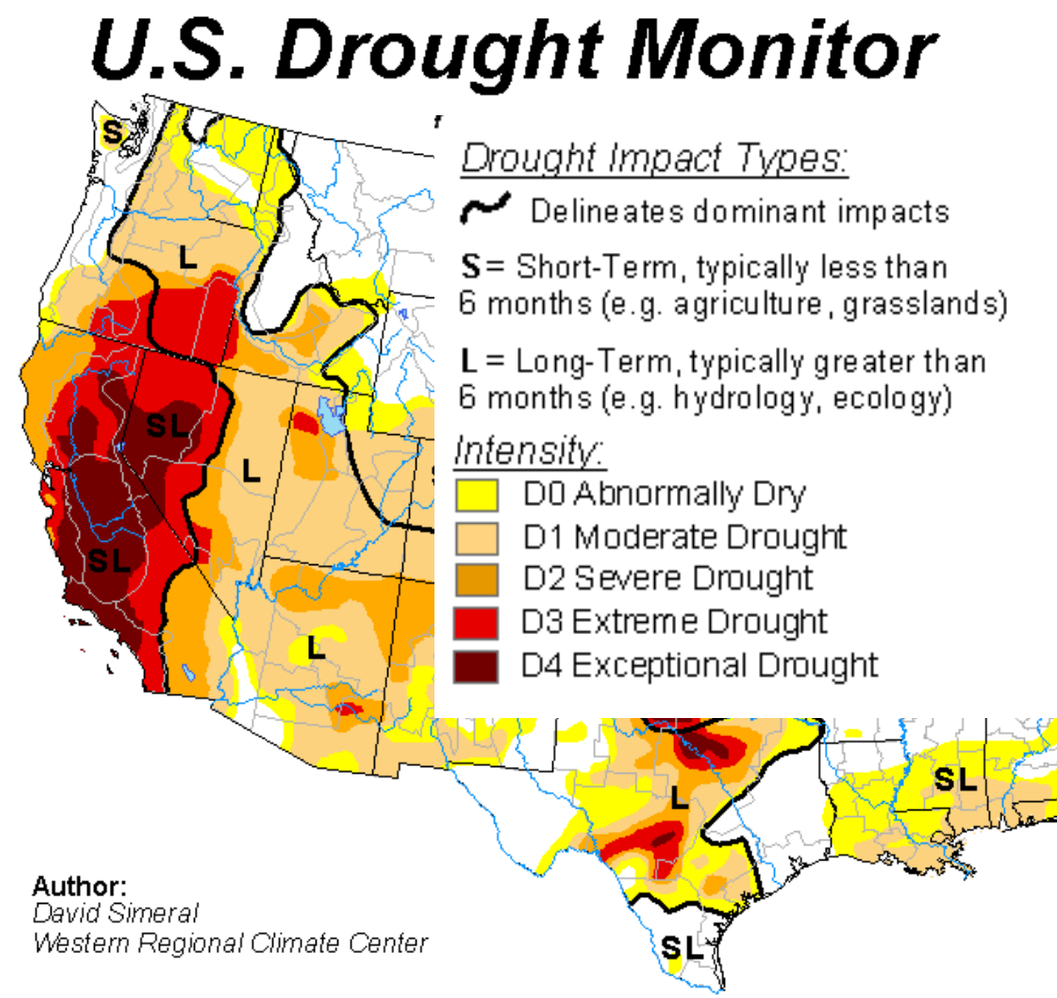
Daily SST anomaly (18 Aug 2014) relative to the 30-year (1982-2010) climatology

114 Years

Ocean and land conditions are *significant*

"There's something happening here, what it is ain't exactly clear…" (Buffalo Springfield)





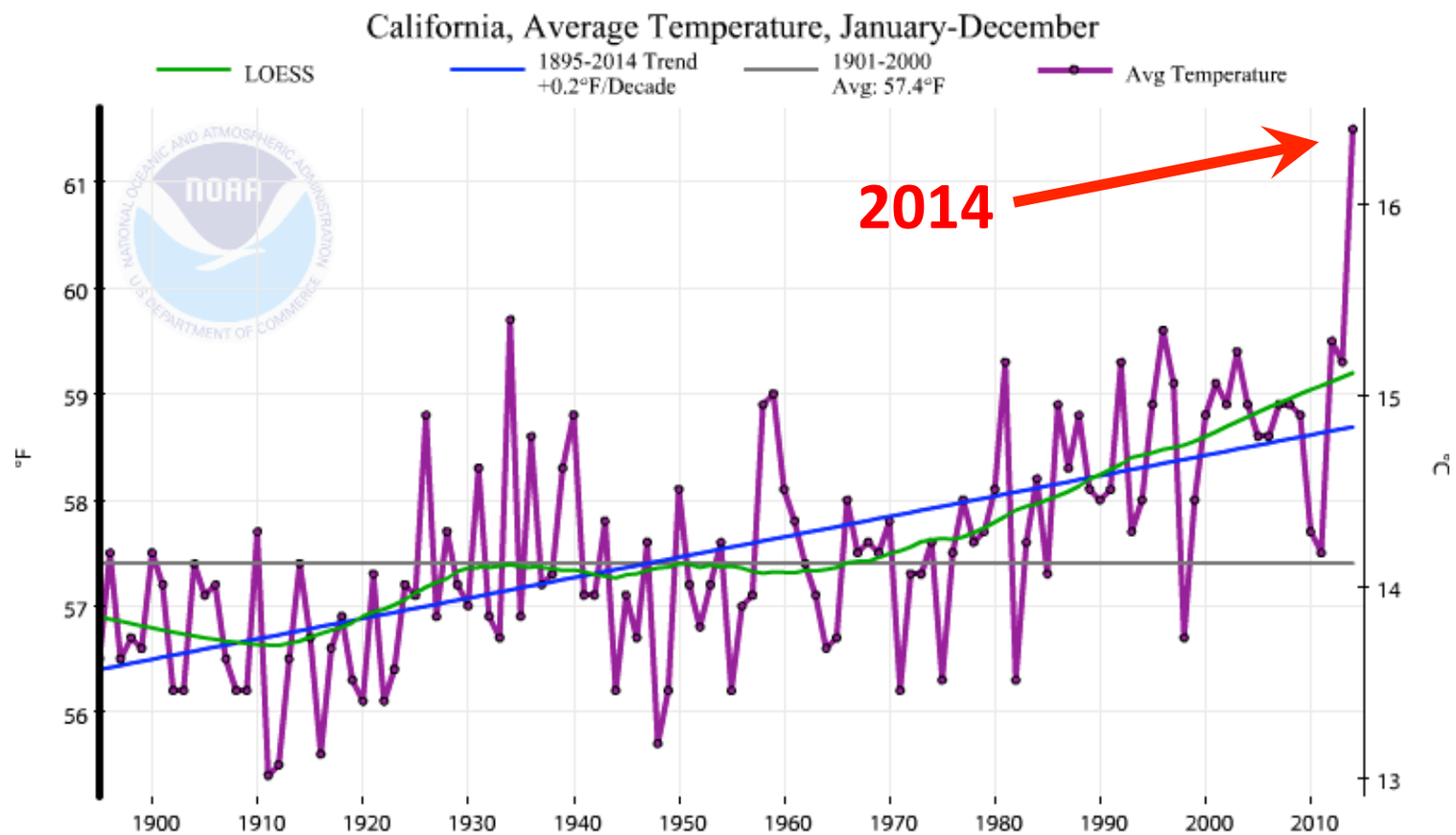
Daily SST anomaly (18 Aug 2014) relative to the 30-year (1982-2010) climatology

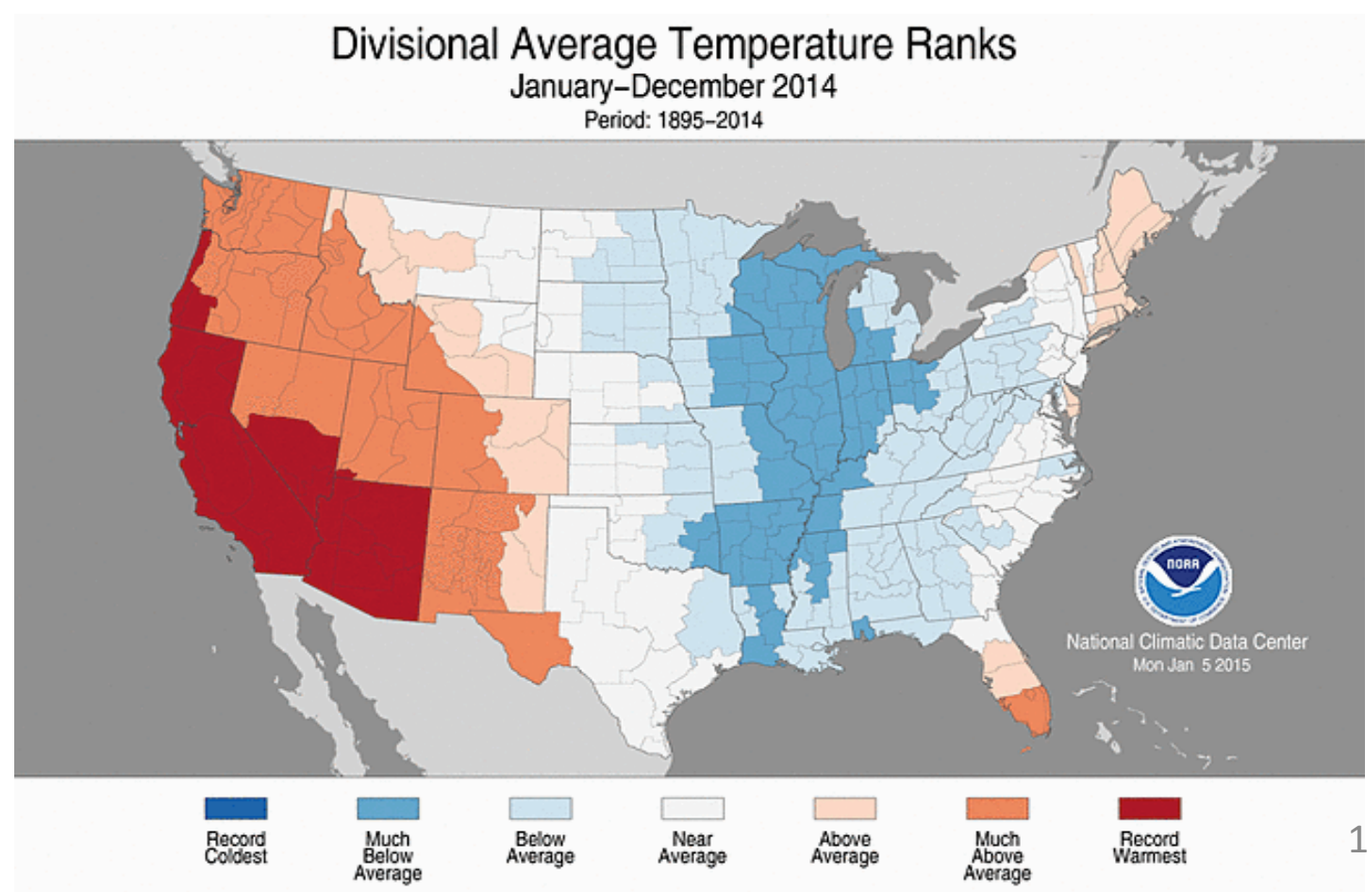
It wasn't just the ocean that was warm.

In California, 2014 weather was not only dry, but it was also extraordinarily hot

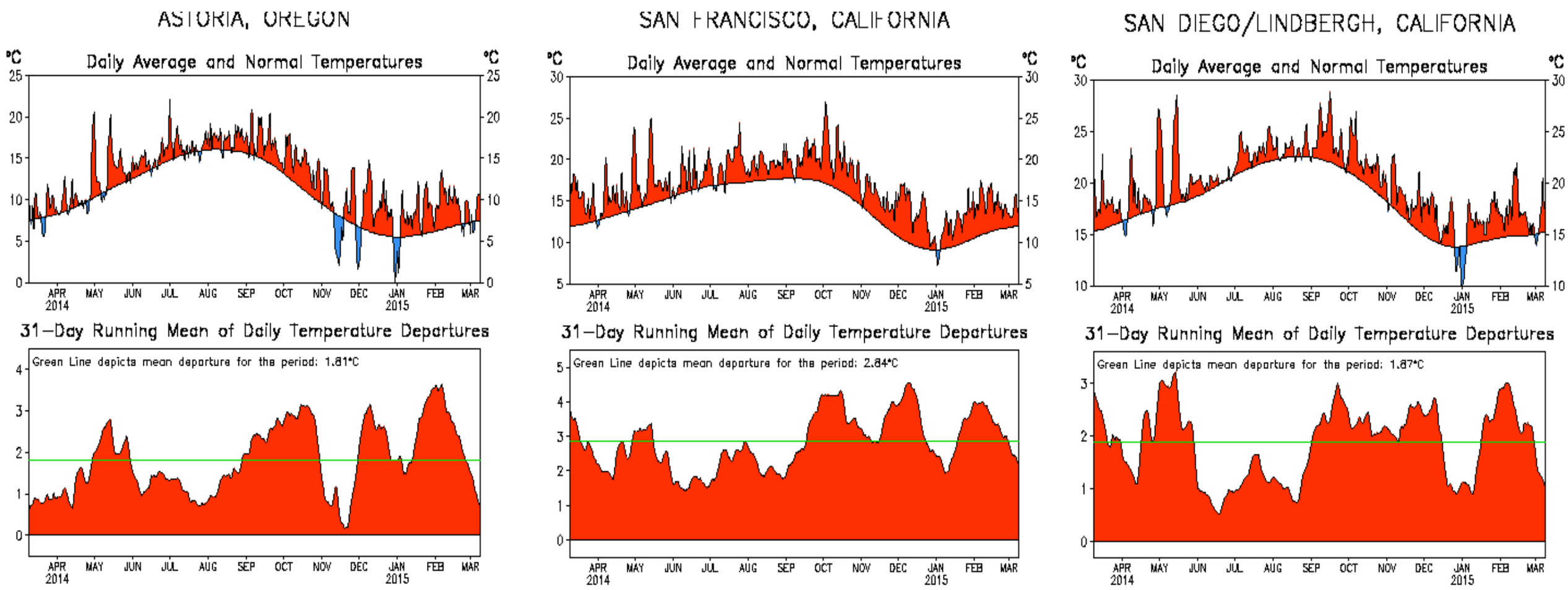
- Surface air temperature record was almost off the charts, ~ 1 °C warmer than the previous record

- Extraordinary warmth was confined to the southwest, centered in California



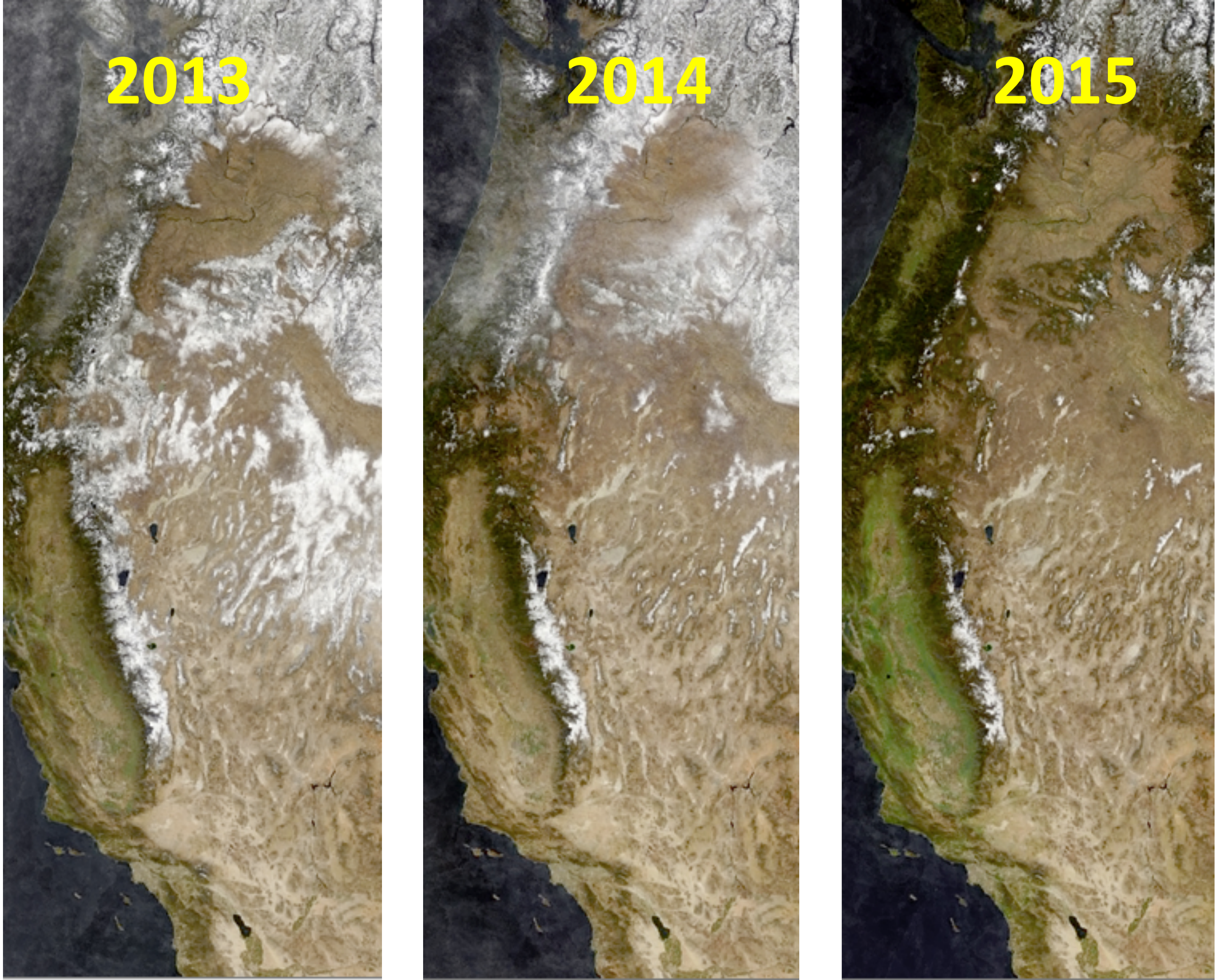


Almost every day in the last year was warmer than average at most West Coast locations

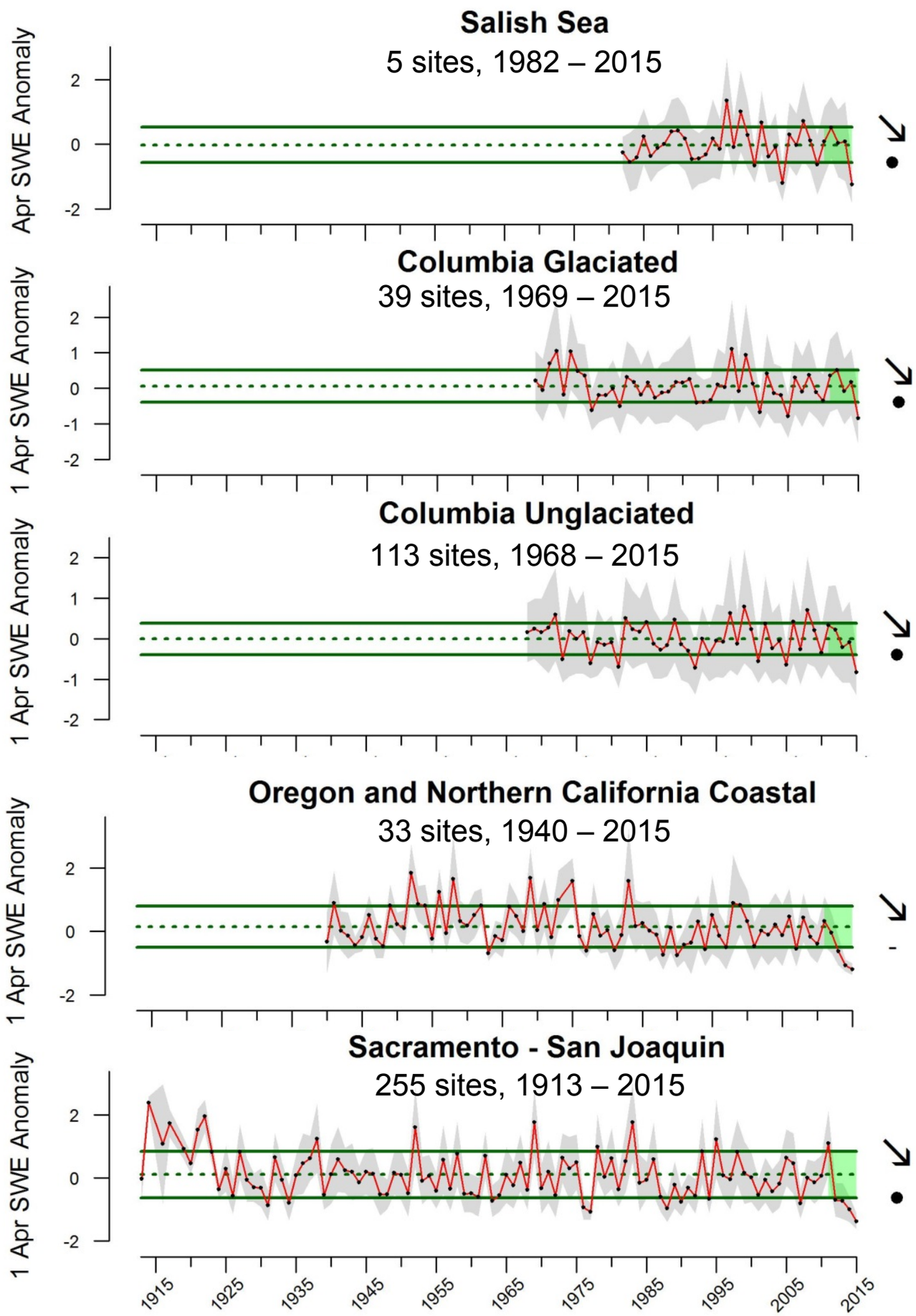


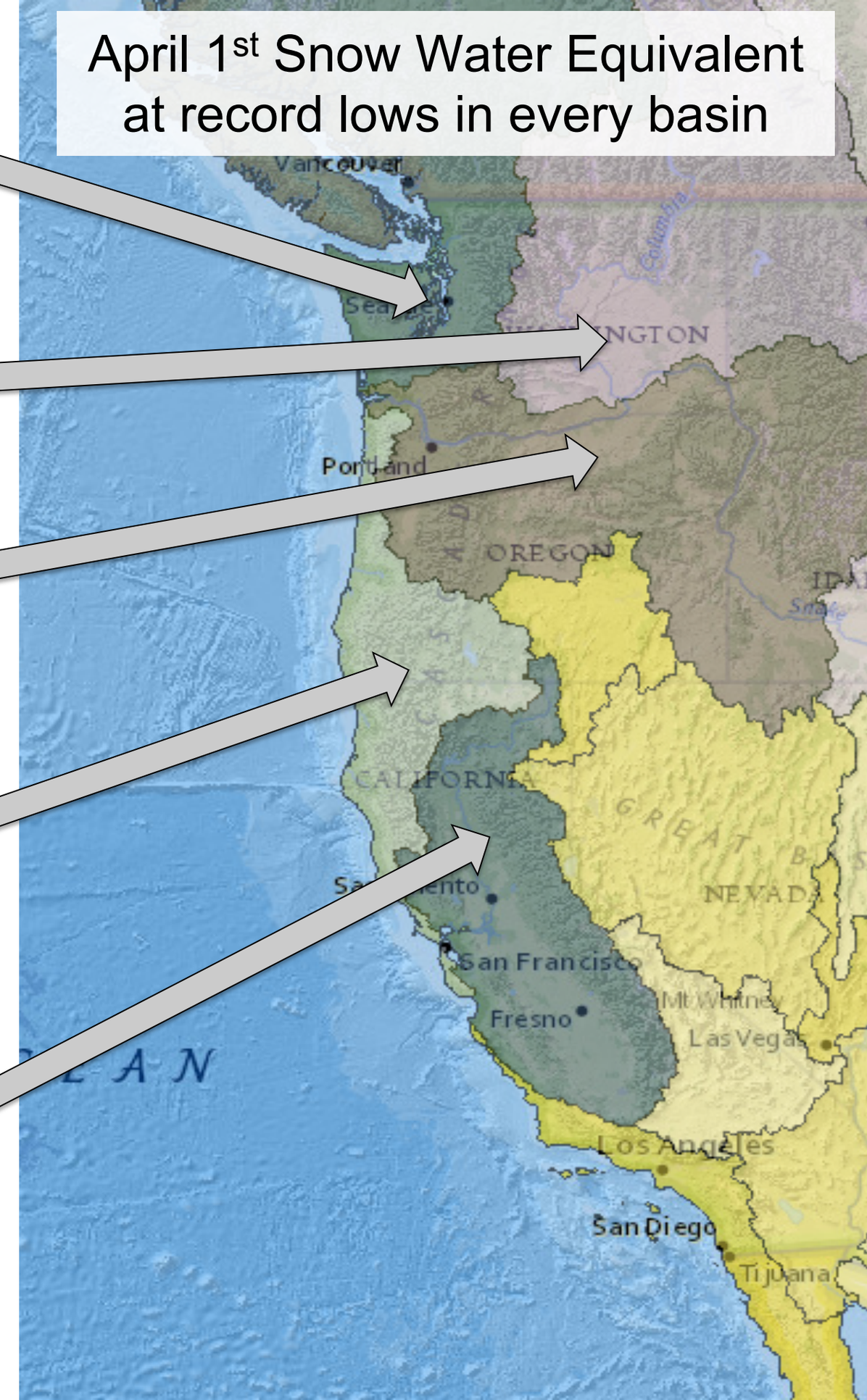
http://www.cpc.ncep.noaa.gov/products/global_monitoring/temperature/global_temp_accum.shtml

http://www.nytimes.com/interactive/2015/03/05/us/one-giant-picture-of-all-the-snow-across-the-us.html?smid=tw-share&_r=0



April 1st Snow Water Equivalent at record lows in every basin





NOAA FISHERIES

DRAFT

CLIMATE SCIENCE STRATEGY

NATIONAL MARINE FISHERIES SERVICE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

Draft for Public Review

January 2015

WHY	Growing demands and requirements for climate-related information.
GOAL	Increase the production, delivery, and use of climate-related information to support agency and stakeholder decisions.

Objectives of the NCSS

Management

1. Identify appropriate, **climate-informed reference points** for managing LMRs. *(Sardine CalCOFI temperatures)*
2. Identify **robust strategies** for managing LMRs under changing climate conditions. *(Albacore MSE – work with ISC and PICES)*
3. Design **adaptive decision** processes that can incorporate and respond to changing climate conditions. *(Closing of swordfish fishing area to minimize interaction with loggerhead turtles)*

Science

4. Identify **future states** of marine, coastal, and freshwater ecosystems, LMRs, and LMR-dependent human communities in a changing climate. *(Earth System Models)*
5. Identify the **mechanisms** of climate effects on ecosystems, LMRs, and LMR dependent human communities. *(Coupled IBM/ESMs)*
6. Track **trends** in ecosystems, LMRs, and LMR-dependent human communities and provide early warning of change. *(CCIEA)*
7. Build and maintain the **science infrastructure** needed to fulfill NOAA Fisheries mandates under changing climate conditions. *(R2O)*

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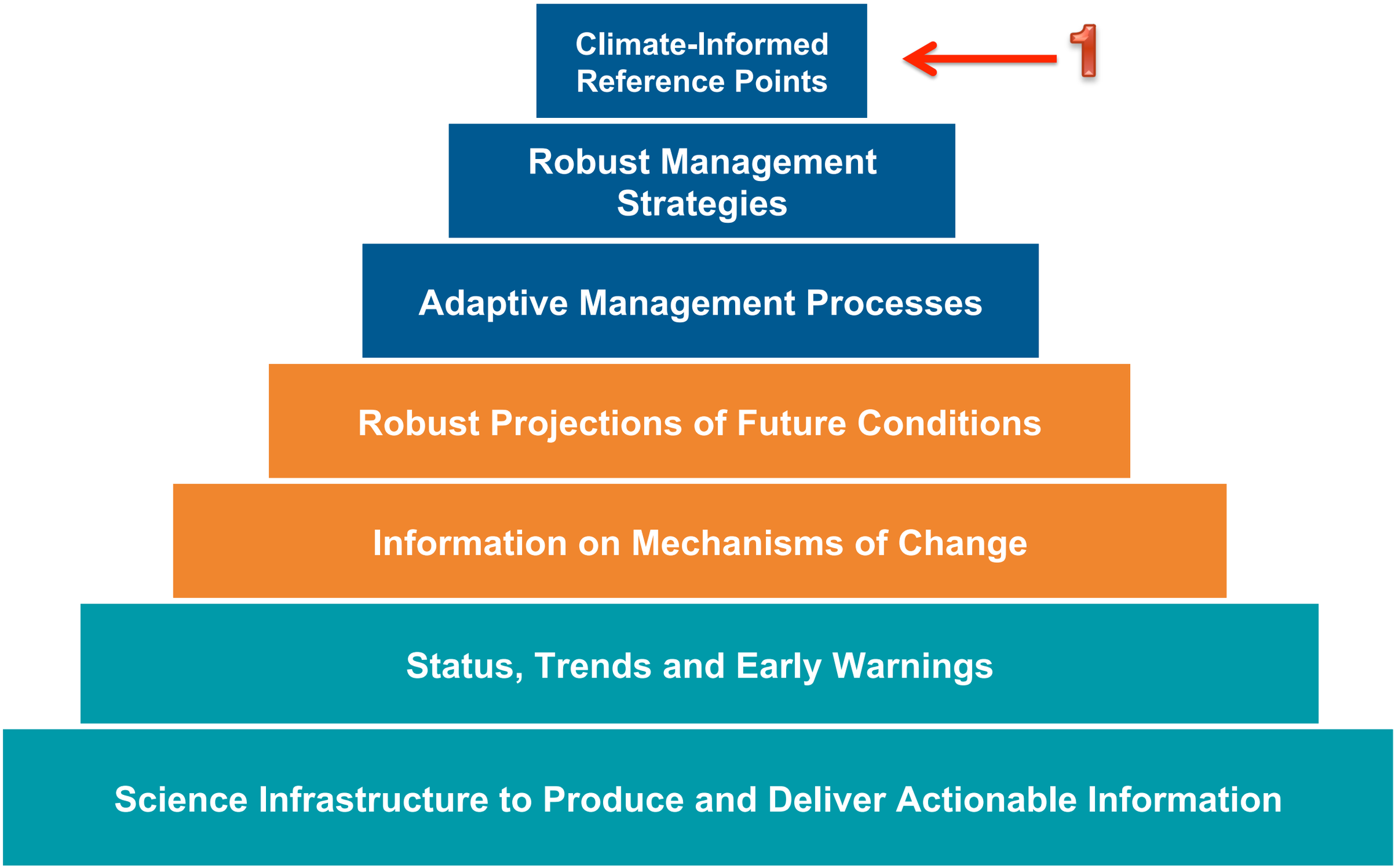
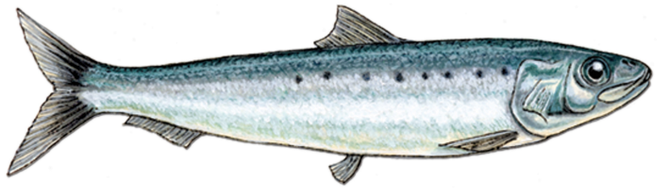
Draft Climate Science Objectives



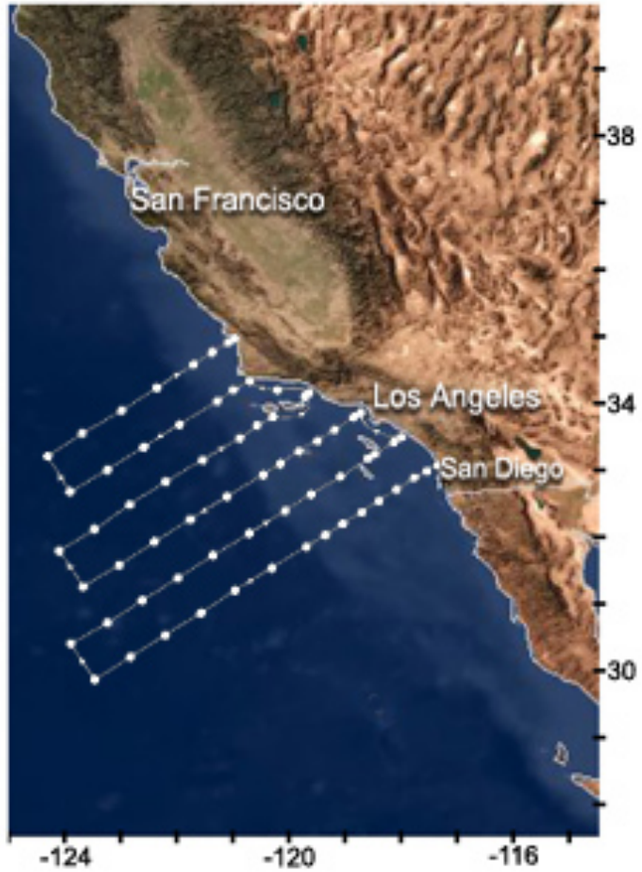
Objective 1. Identify appropriate, **climate-informed reference points** for managing LMRs.

Pacific Sardine Harvest Fraction

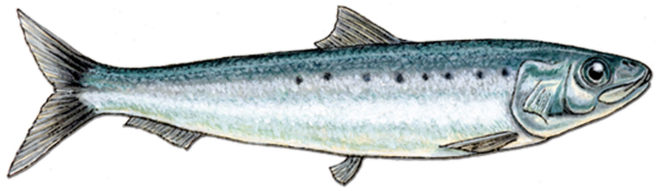


- The PFMC now uses the California Cooperative Oceanic Fisheries Investigations (CalCOFI) temperature index as well as a revised F_{MSY} relationship, for use in the Harvest Control Rule.

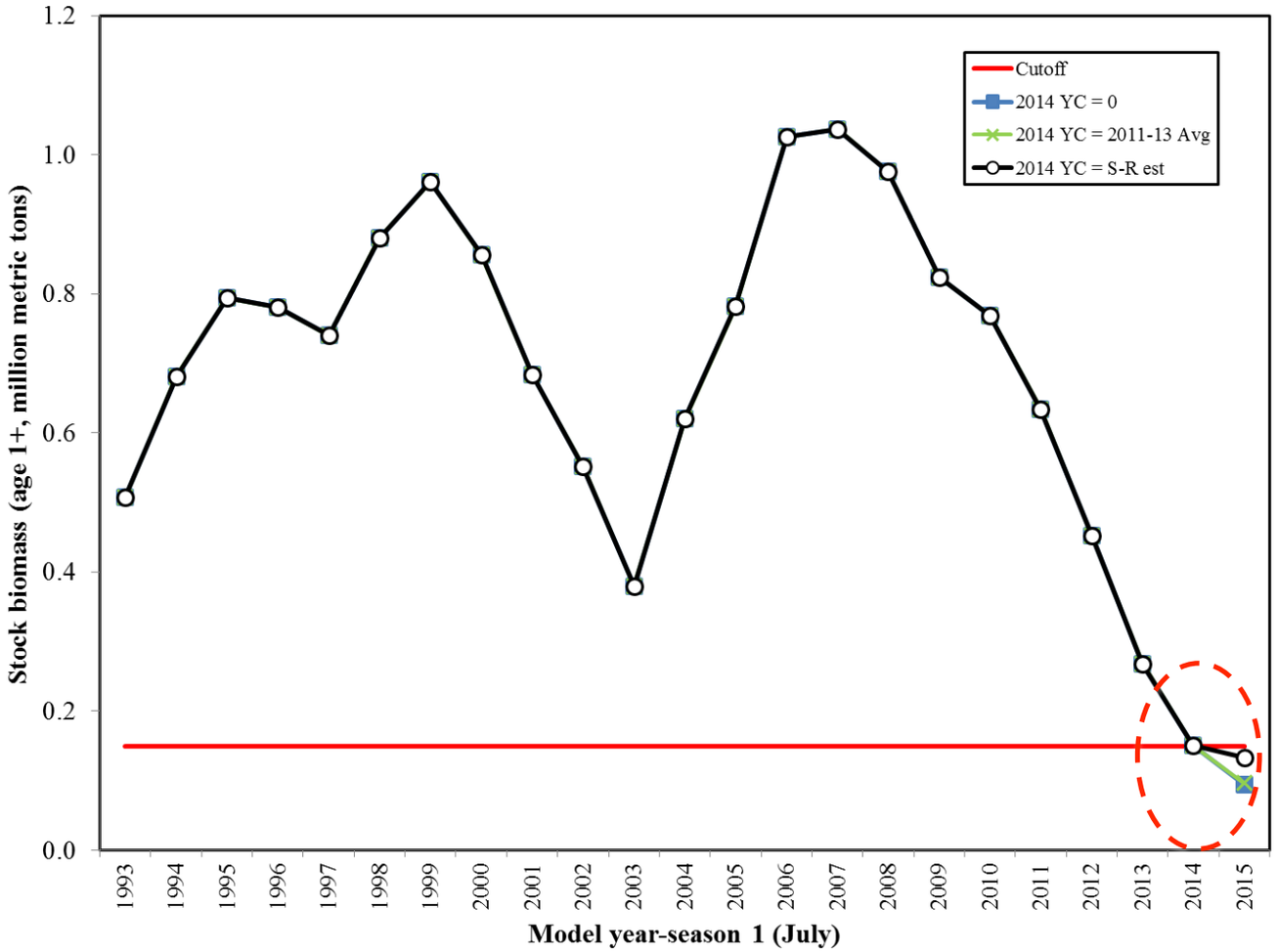
- The new temperature index and temperature-productivity relationship were used for establishing the OFL starting with the April 2014 meeting, when the Council established harvest specifications and management measures for the fishing year beginning July 1, 2014.

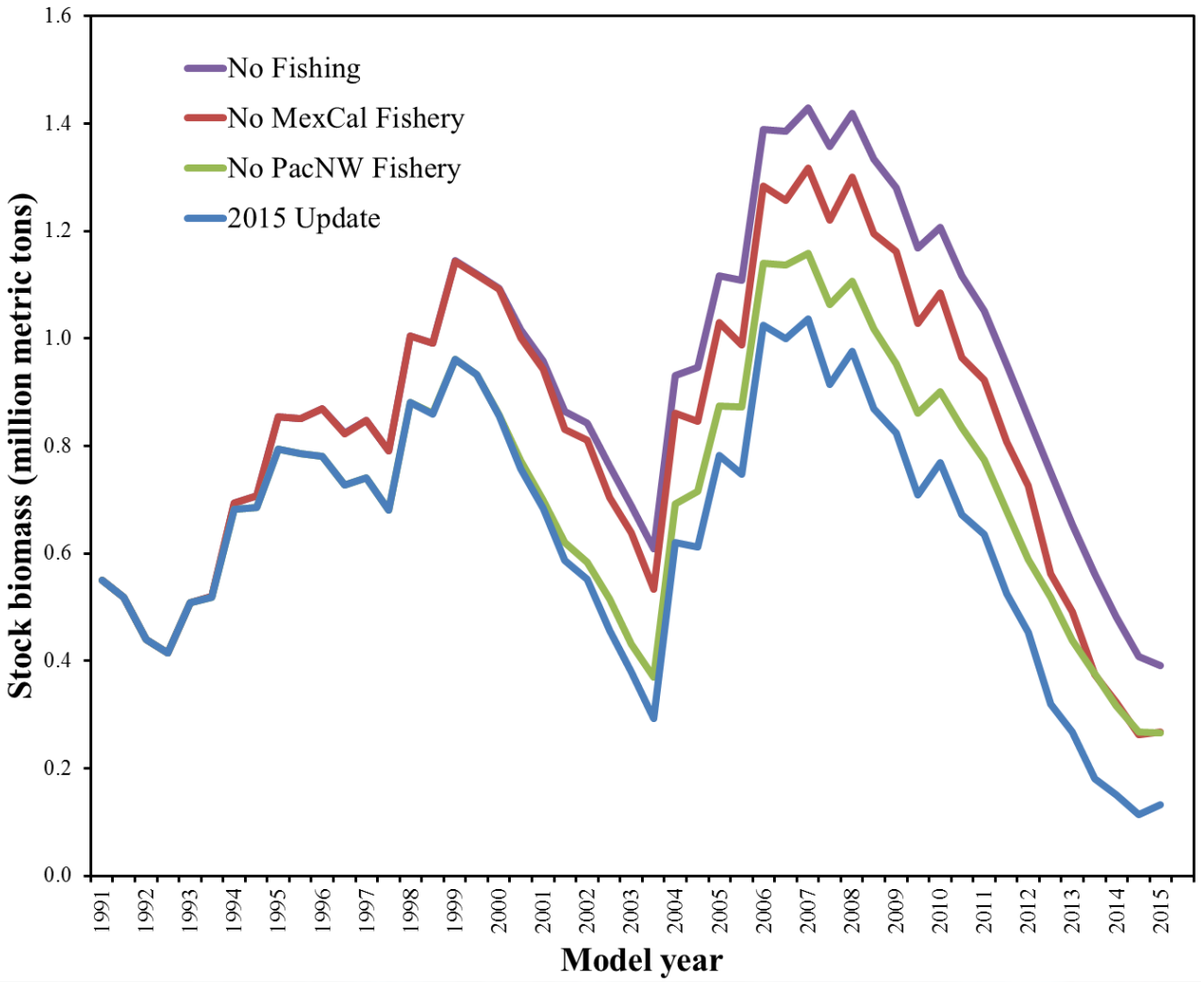


Estimated Sardine Stock Biomass Series For Three 2014 YC Scenarios



Fishery Impacts





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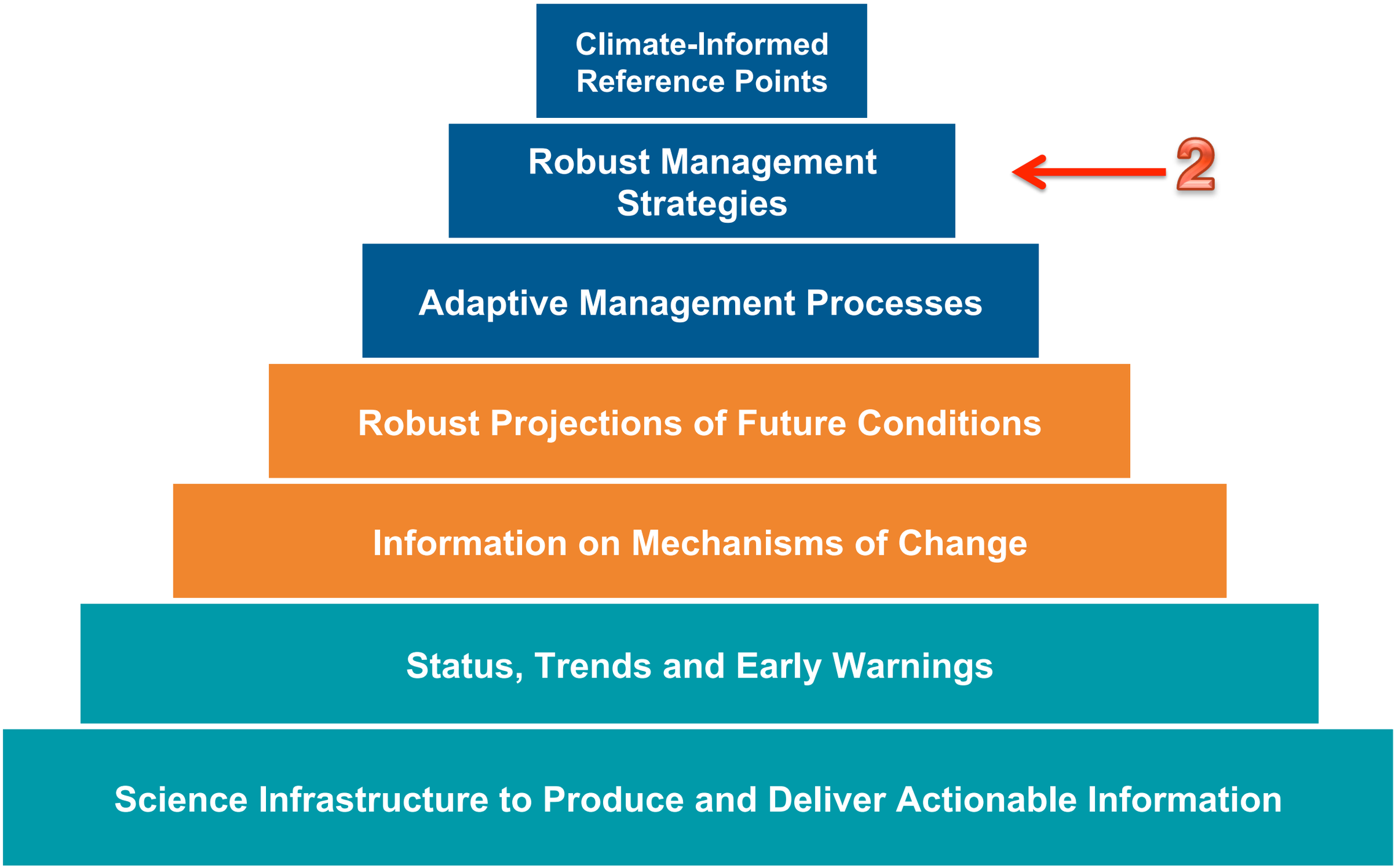
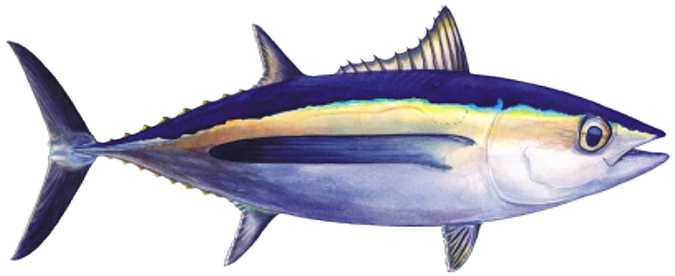


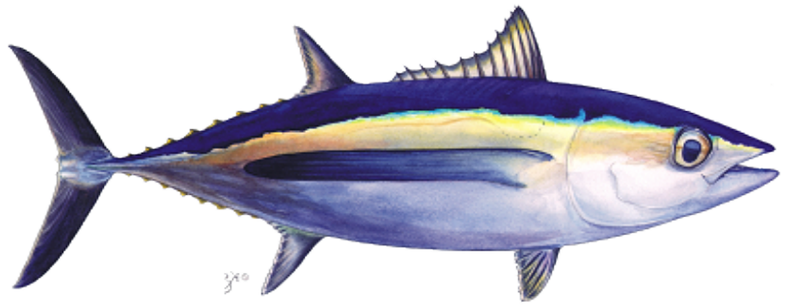
Objective 2. Identify **robust strategies** for managing LMRs under changing climate conditions.

Pacific Albacore

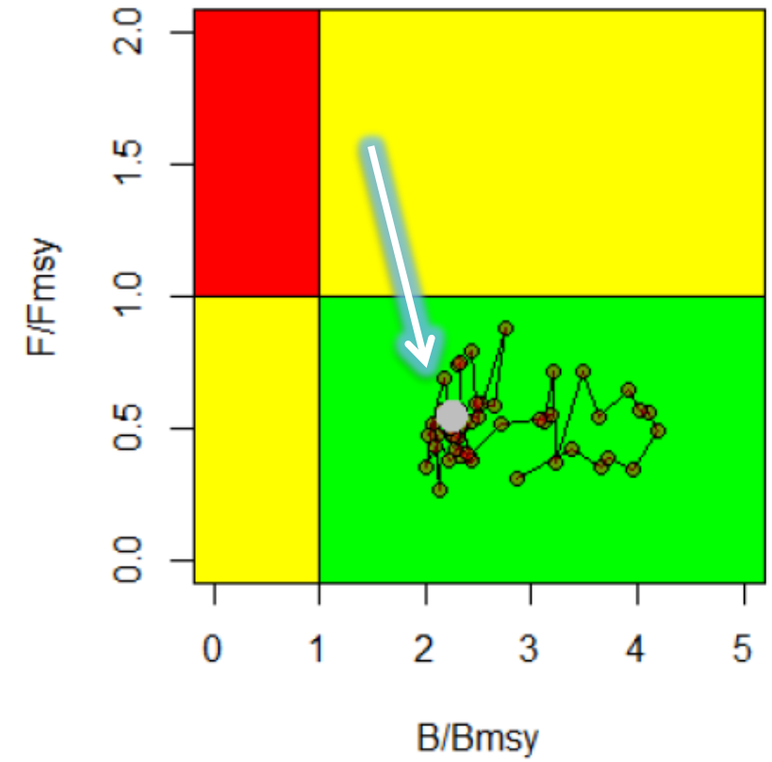


Management Strategy Evaluations

- **MSE**: using simulations to compare the relative effectiveness of different management strategies (that explicitly take spatial structure into account)
- Albacore will be the first species with ISC/PICES/SWFSC scientists taking the lead

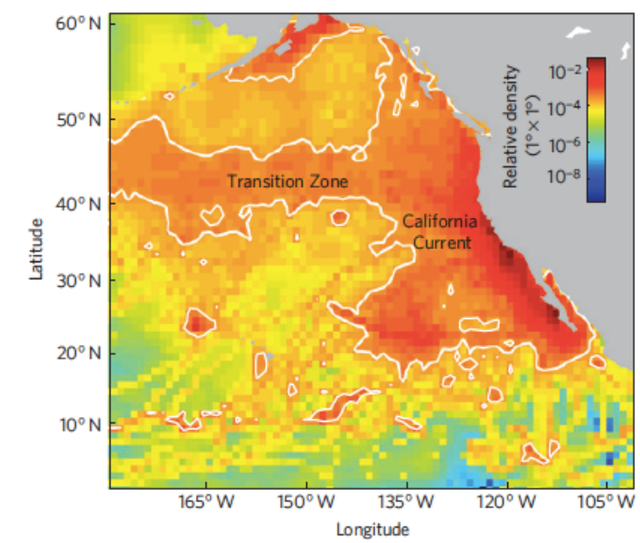


Albacore

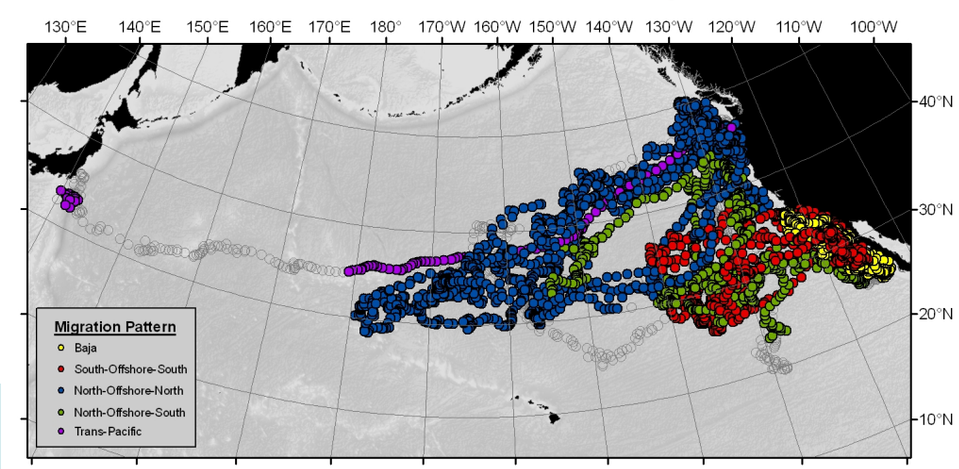


Conservation Information:

"… NPALB is **not experiencing overfishing**. Although no biomass-based reference points have been developed for this stock, there is little evidence from the assessment that fishing has reduced *SSB* below reasonable candidate biomass-based reference points, … and the stock is likely **not in an overfished condition** at present."



1. Many pelagic species have environmental thresholds and preferences that limit the spatial distribution of a species (O_2, T & S).
2. Because these factors generally exhibit persistent space-time patterns, the general distribution of pelagic fishes is known.
3. Knowledge of these relationships allows for the incorporation of climate change into stock assessments, which forms the basis for fisheries management.

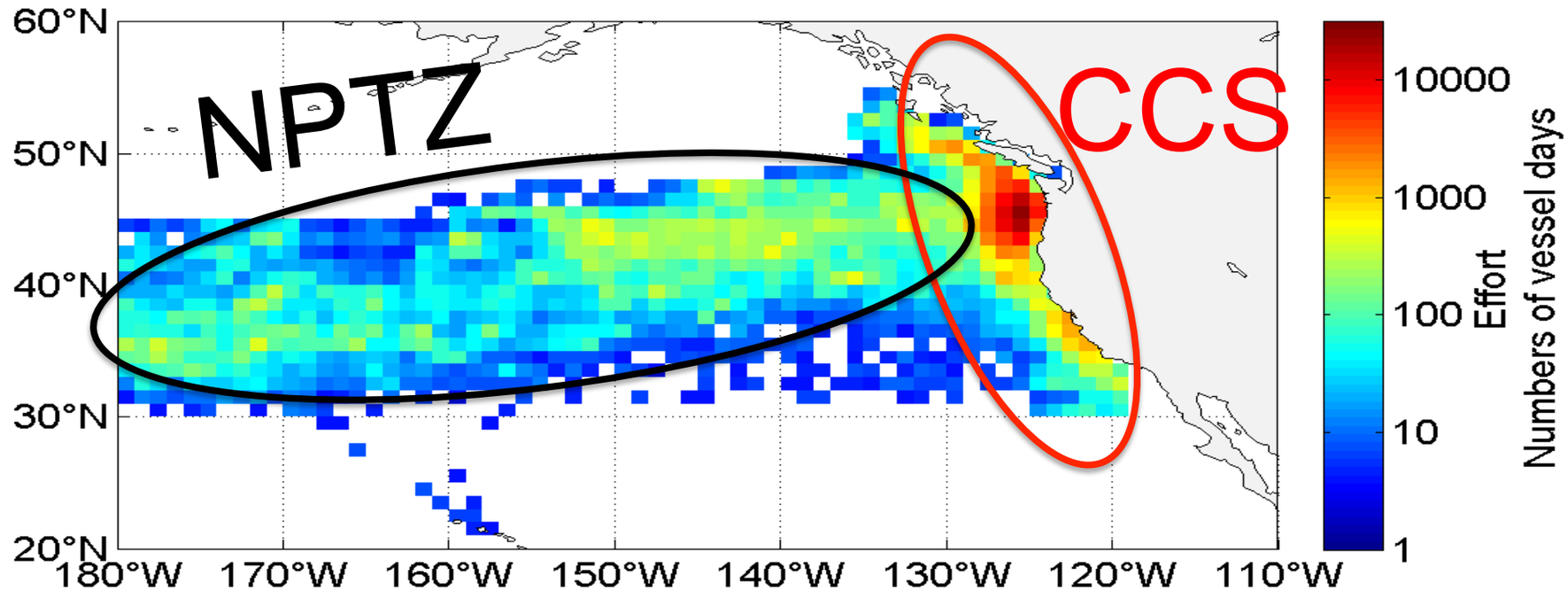


Fisheries Data:
US-CA Troll and Pole-and-Line

Effort

1982-2011

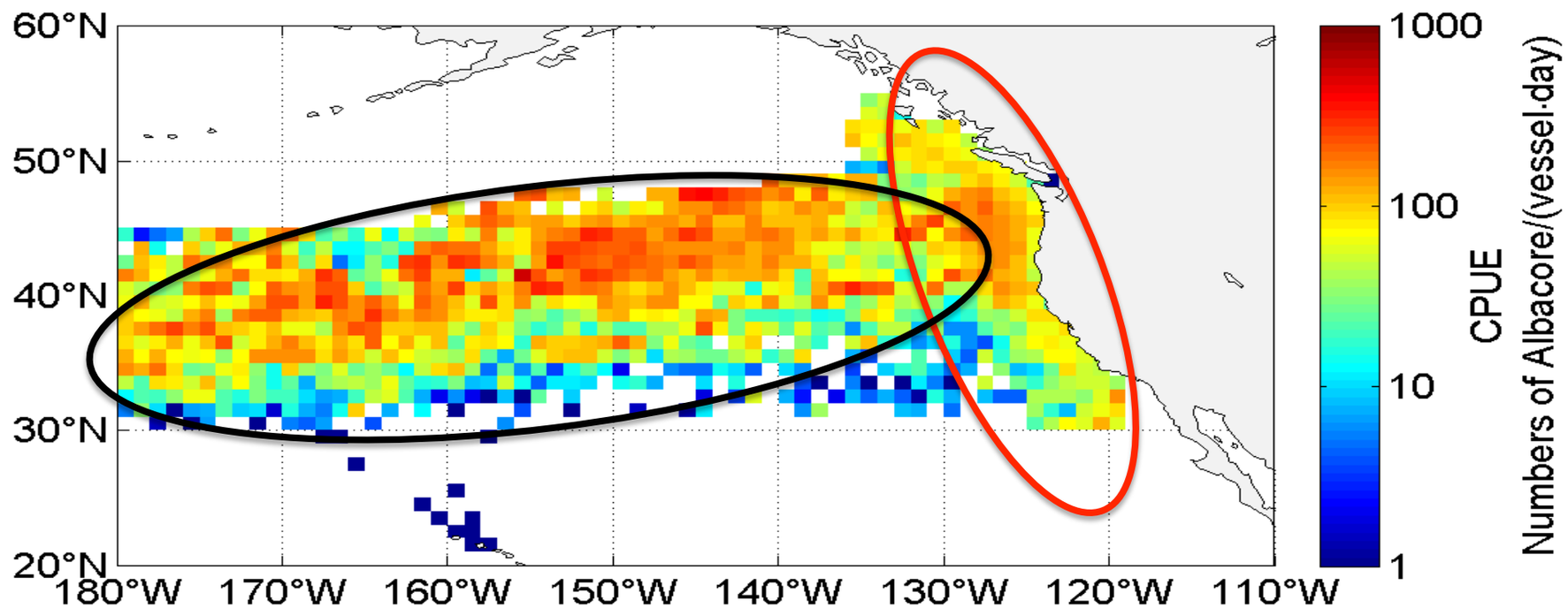
1x1 degree



CPUE

1982-2011

1x1 degree



NOAA FISHERIES

US and Canada albacore logbooks (NOAA Fisheries and DFO Canada)

Top predators and climate change

Predicted changes in species richness in the next century

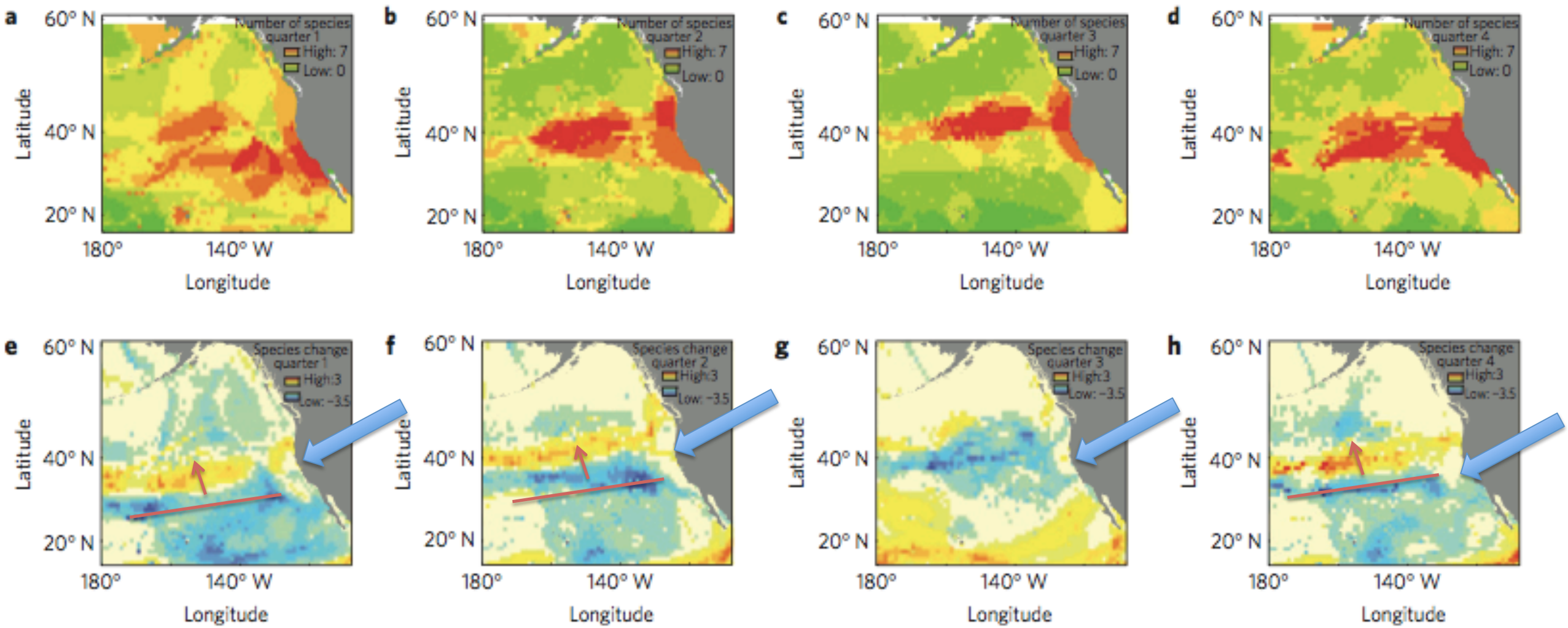


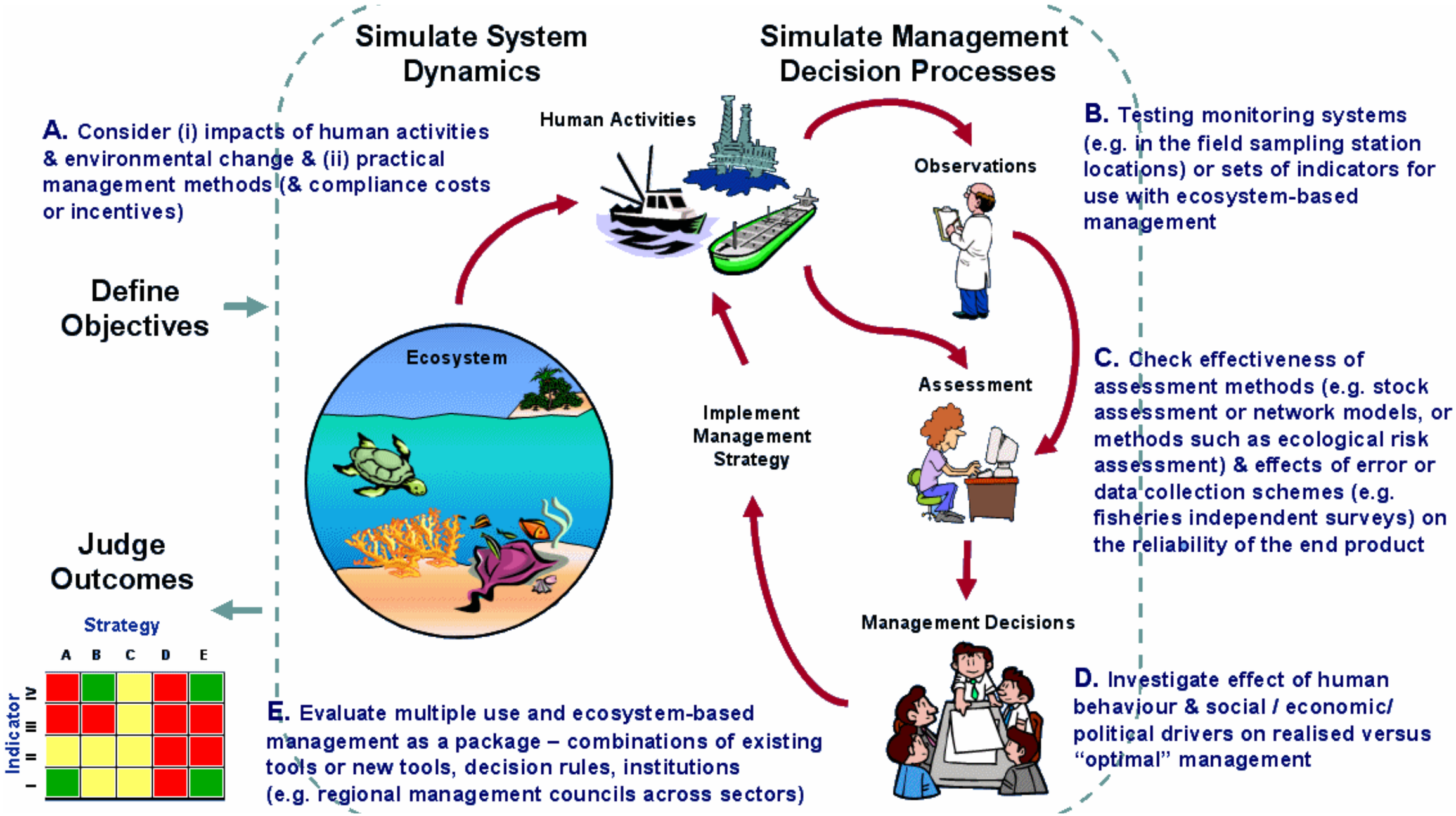
Figure 3 | a–h, Quarterly modelled species richness for 2001–2010 from 15 top predator species (**a–d**) and predicted changes in species richness over the next century (2001–2020 compared with 2081–2100) (**e–h**).

- **Premise: Δ (delta) in oceanographic habitat suitability → Δ in species distributions**
- **Conclusions: northward shift of biodiversity, CC remains a hotspot**

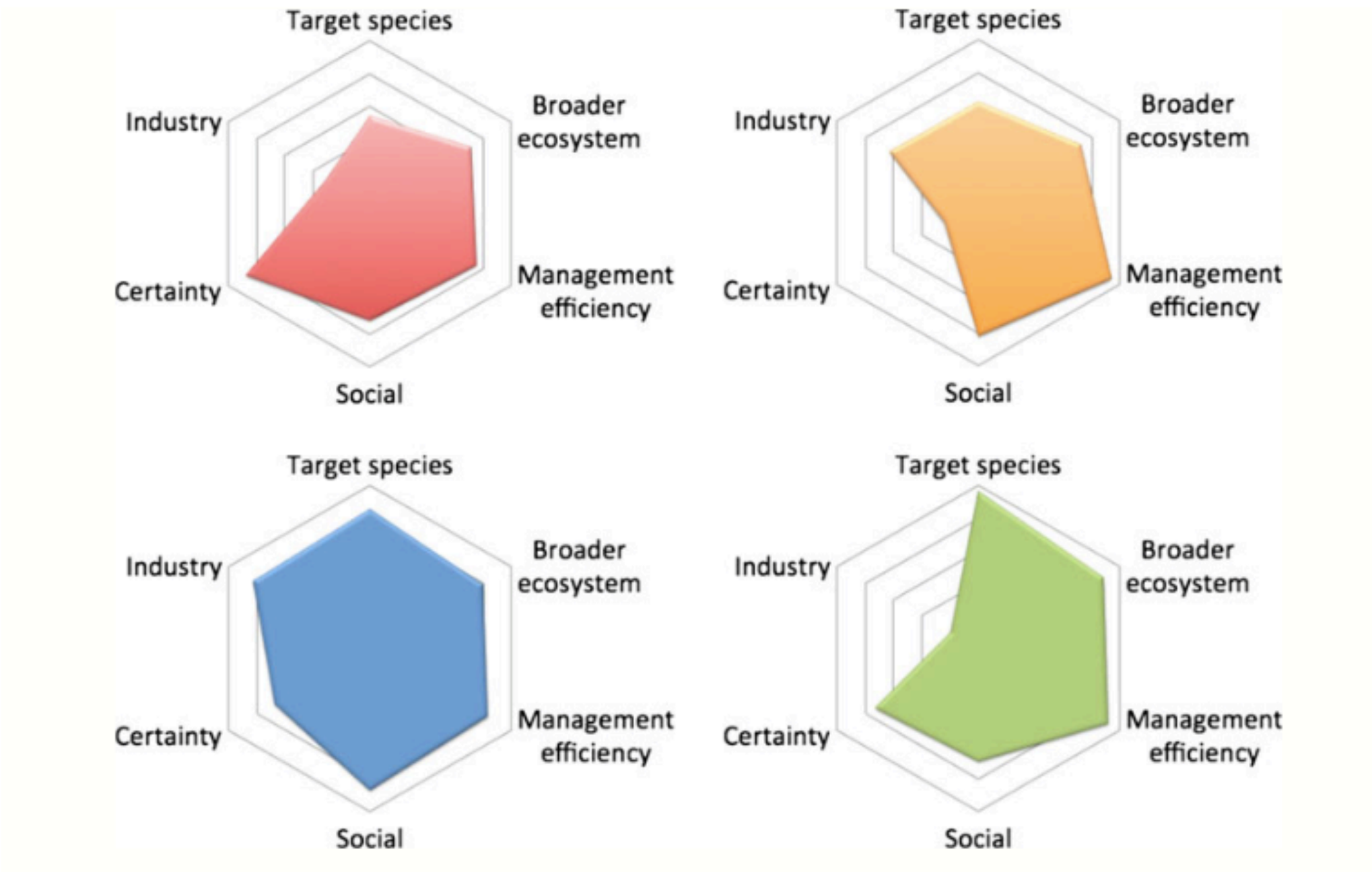
Hazen et al. 2013 *Nature Climate Change*

Implementation of MSE

(interface between science and decision-making)



Example of management strategies across six general areas of mean performance for a large multi-sector, multispecies fishery in SE Australia:



Punt et al. (2014)

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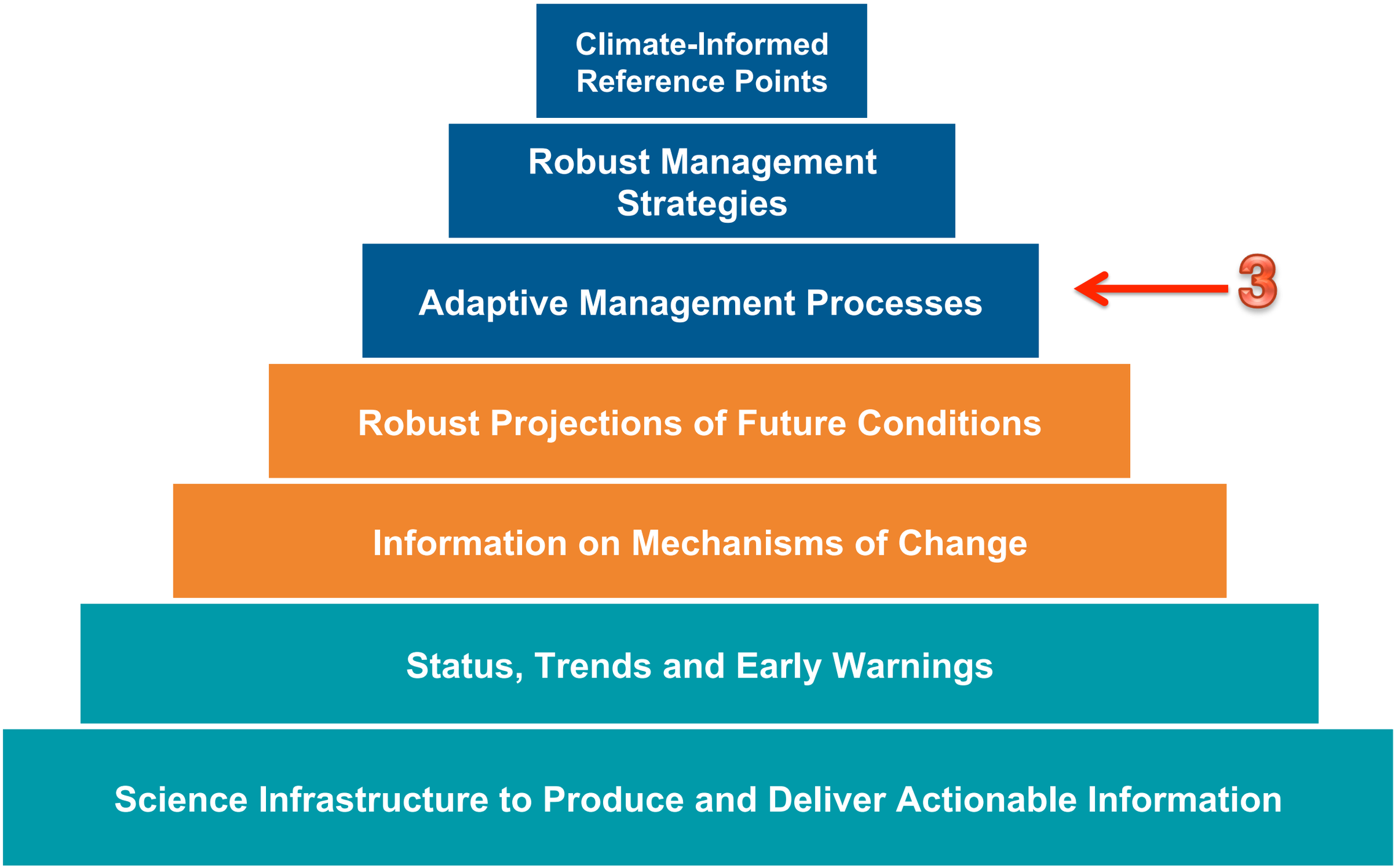
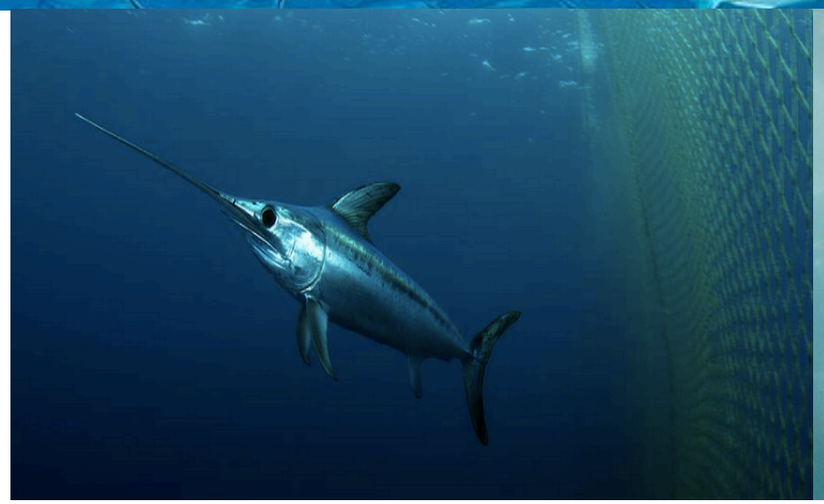
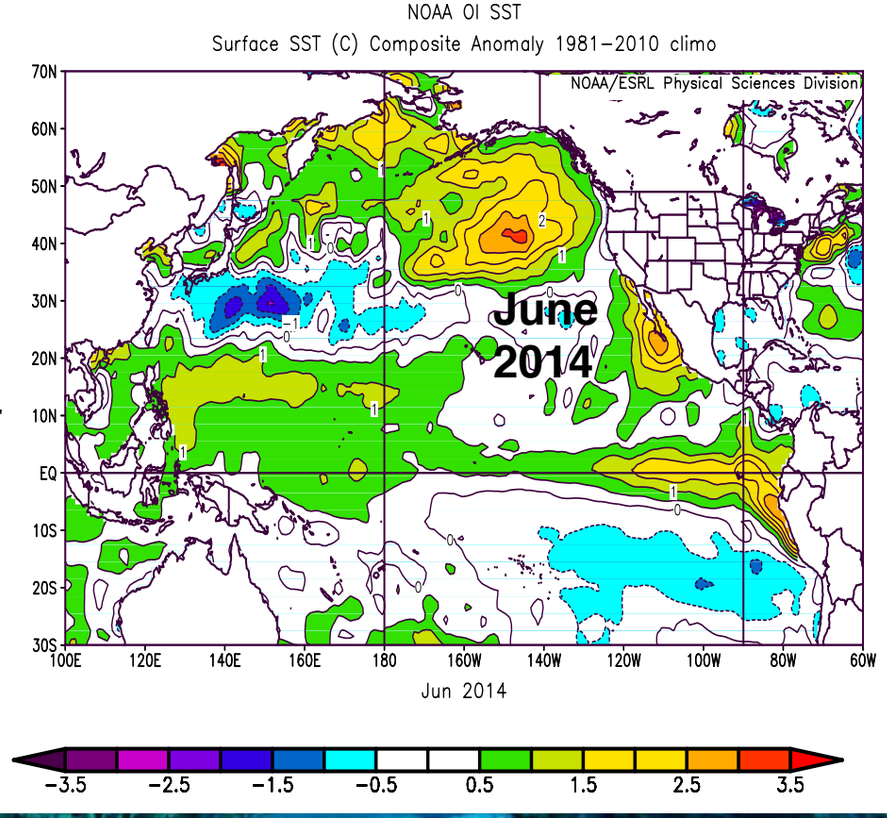


Objective 3. Design **adaptive decision** processes that can incorporate and respond to changing climate conditions.

Swordfish and loggerhead turtles



- In 2014 the WCRO proposed closing the swordfish drift gill net fishery east of 120°W and anticipating increased interaction with Pacific loggerhead turtles
- The decision was based on expectations of persistence of warm waters; not on the possibility of a tropical El Niño coming
- The drift gillnet fishery regulations revisited?
  - –The present language keys to El Niño. Note that 2014's warming was not due to El Niño.



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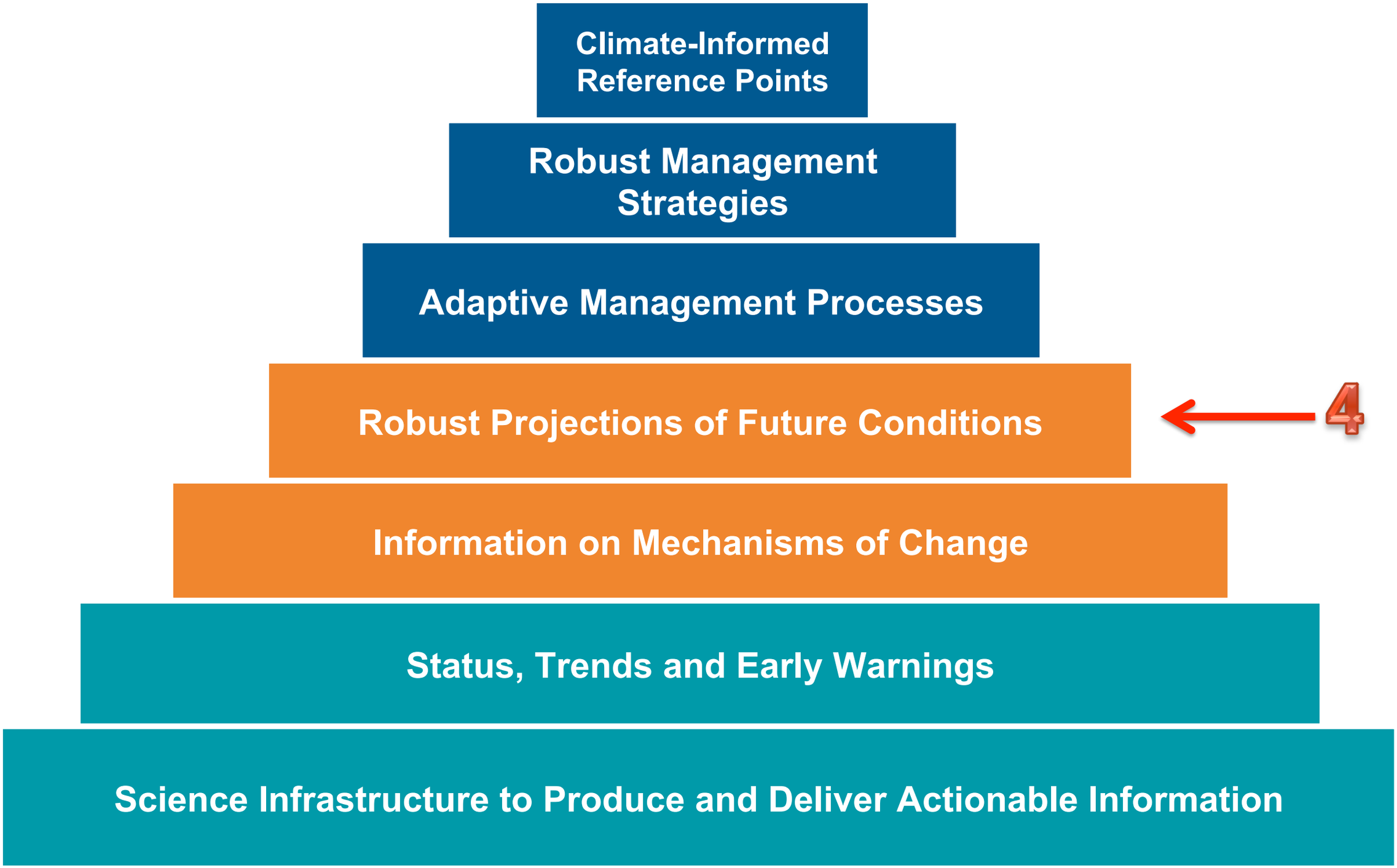
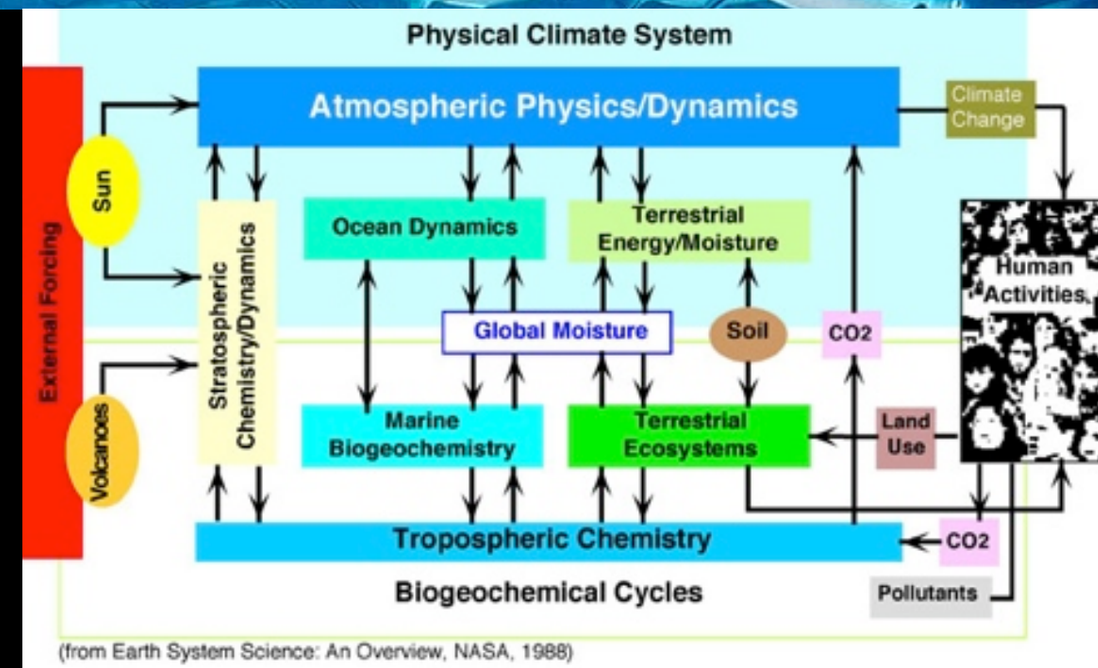
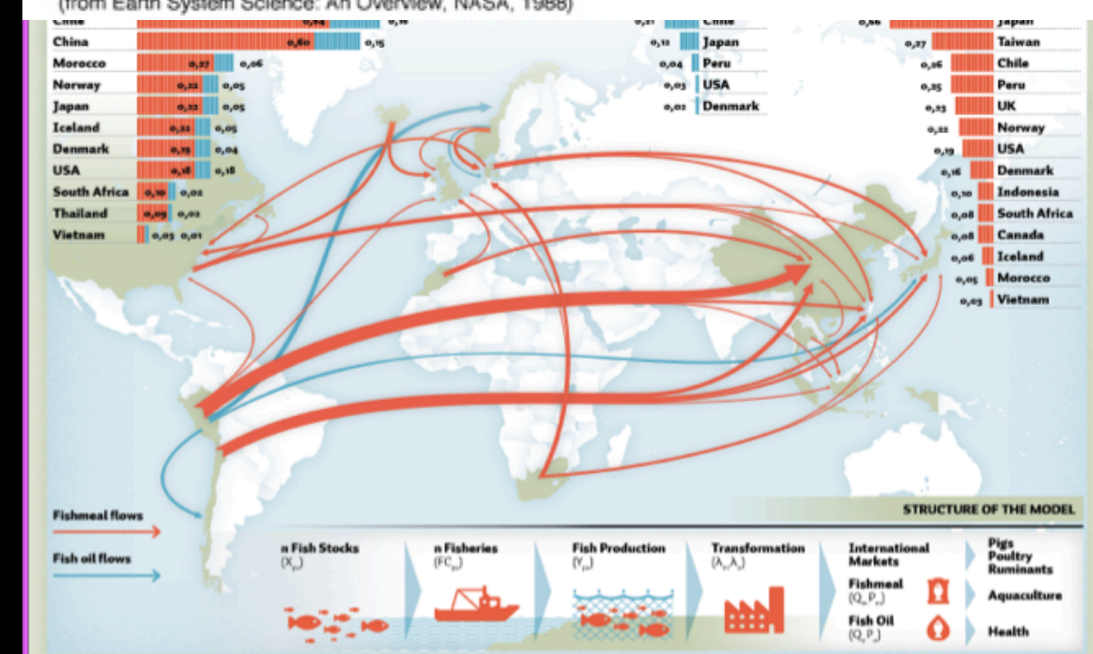


Objective 4. Identify **future states** of marine, coastal, and freshwater ecosystems, LMRs, and LMR-dependent human communities in a changing climate.

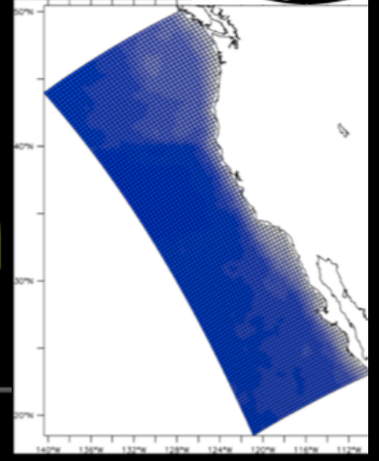
California
Current
Future
scenarios
and steps
toward
Earth System
Models



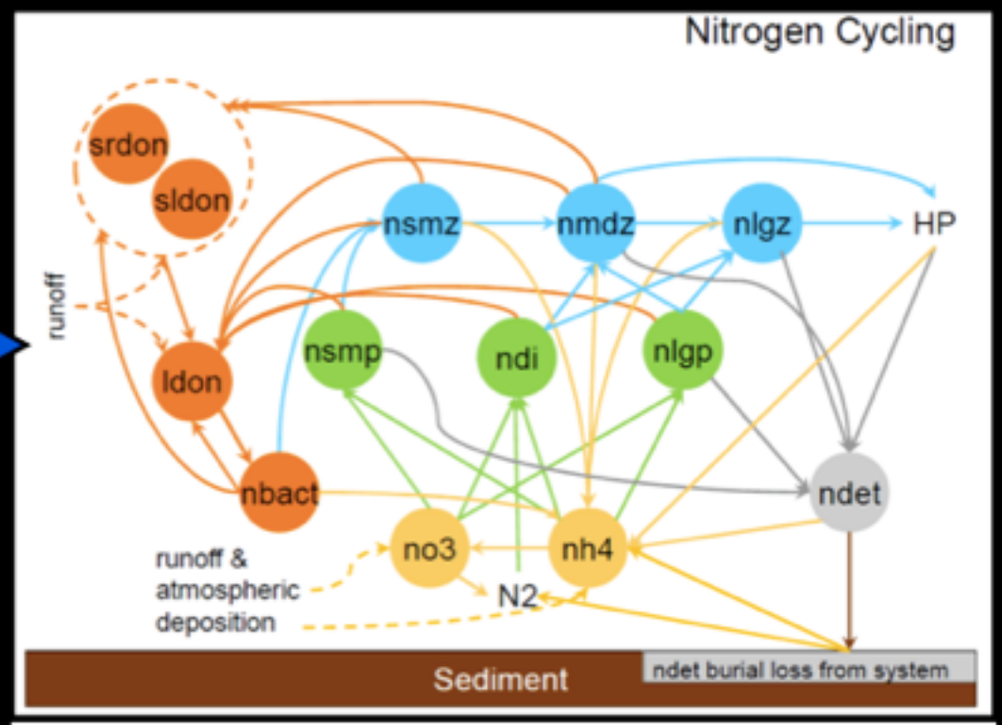
(from Earth System Science: An Overview, NASA, 1988)

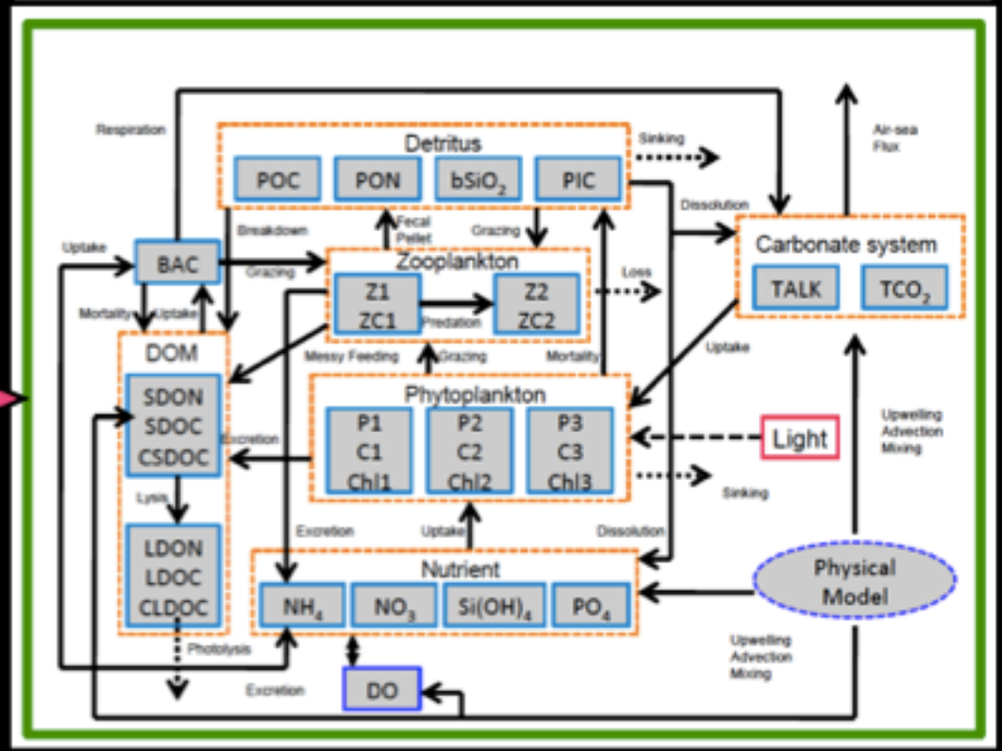


CC-IEA (one way downscale) simulation

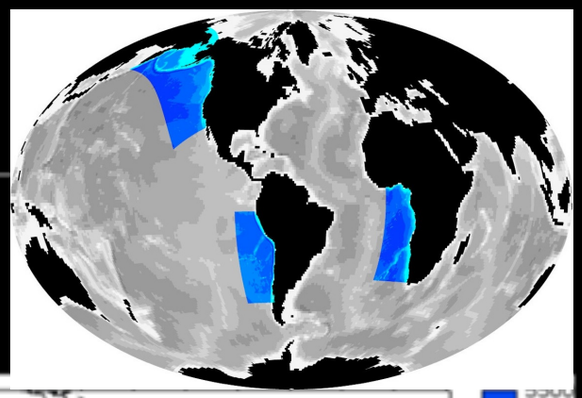


- Global model: GFDL **CM2.1mESM**
  - Atmosphere at 1°, ocean (MOM) at 1°
  - BGC is **COBALT** (Carbon, Ocean Biogeochemistry And Lower Trophics)
- Regional model:
  - Physics: **ROMS** (7 km or ~1/12th deg), 40 vertical layers)
  - BGC: Enhanced **CoSINE** (C, Si, N Ecosystem model), including oxygen and full carbonate chemistry.

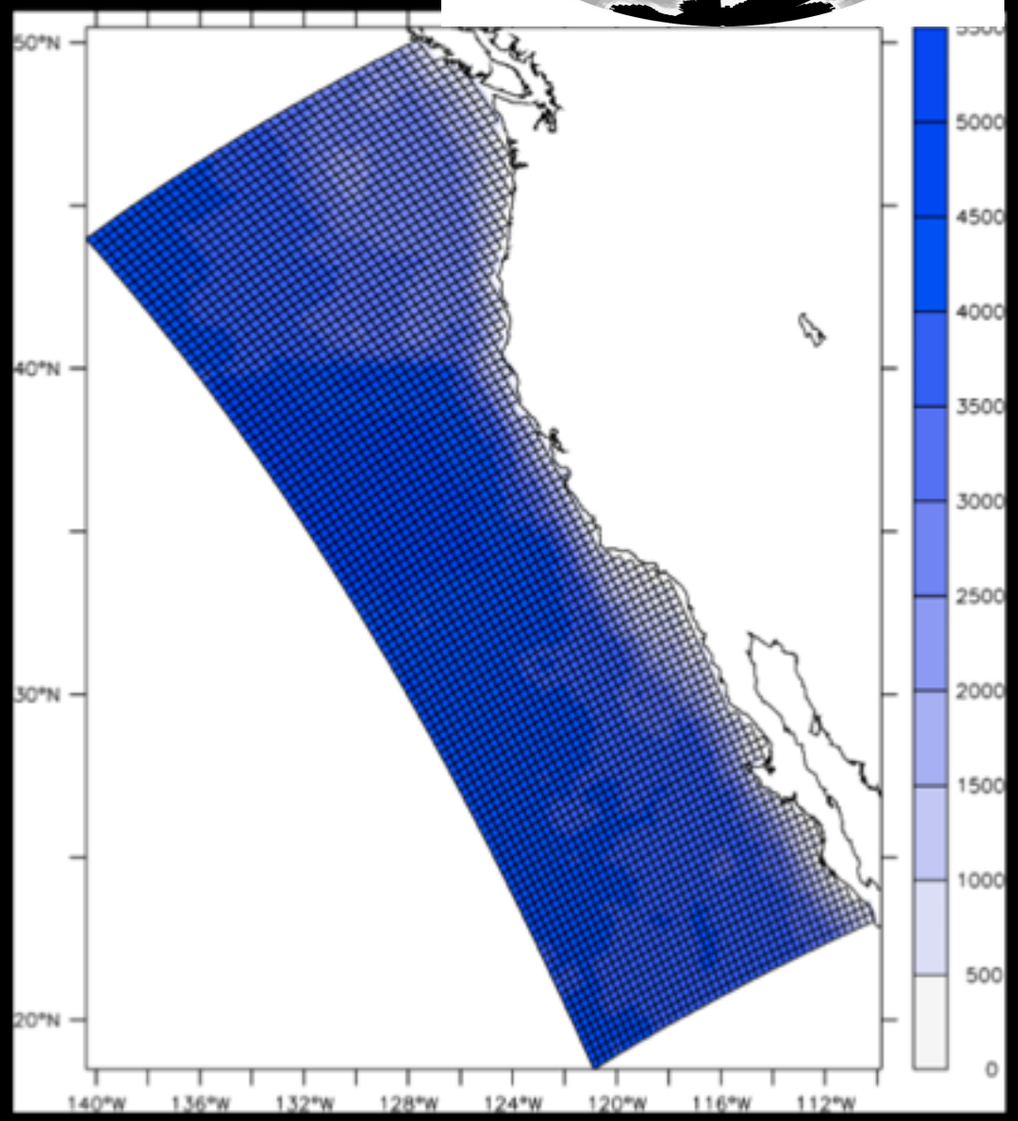




California Current Integrated Ecosystem Assessment (CC-IEA) simulation



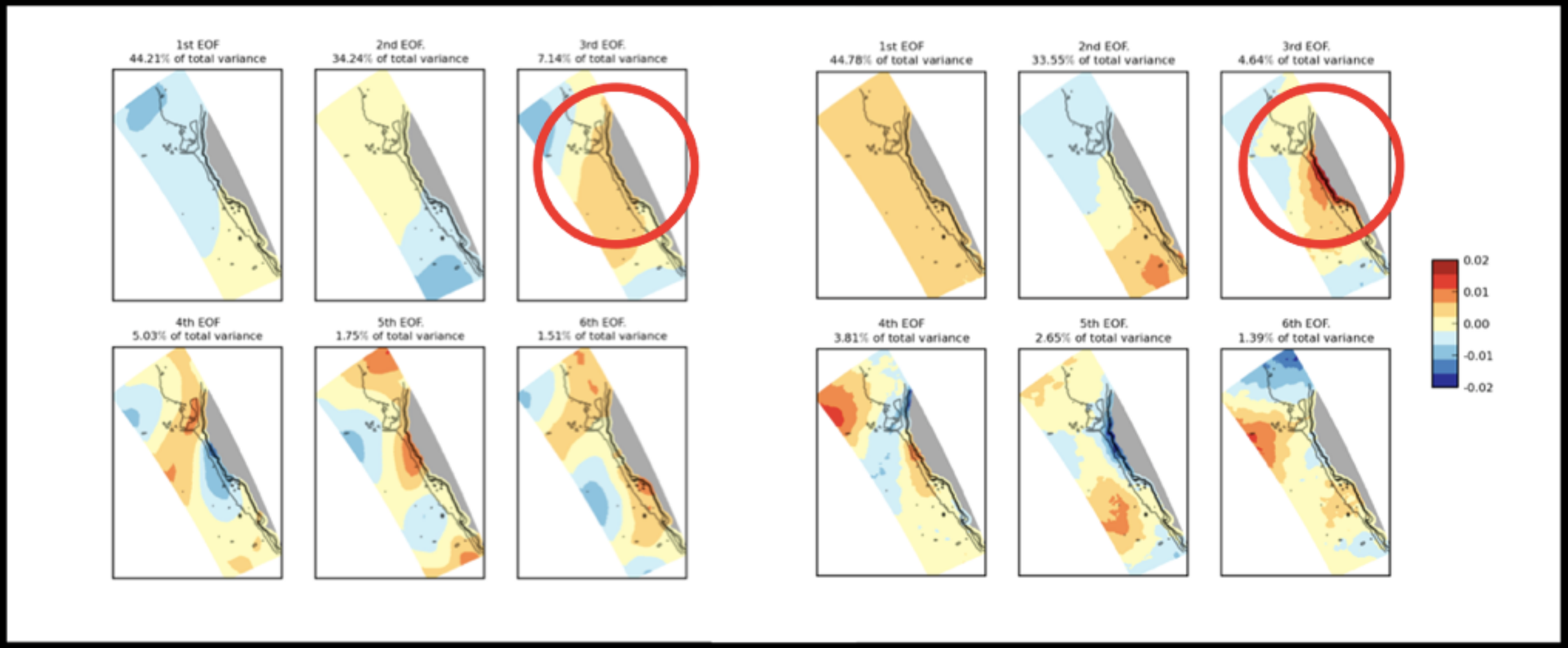
- Simulation
  - 1970-2050 using 20th century climate (emissions) transitioning to RCP8.5
  - One way physical and BGC downscaling of CCS
  - Global to regional boundary conditions for both physics and BGC.



One-way downscaling: Physics and biology

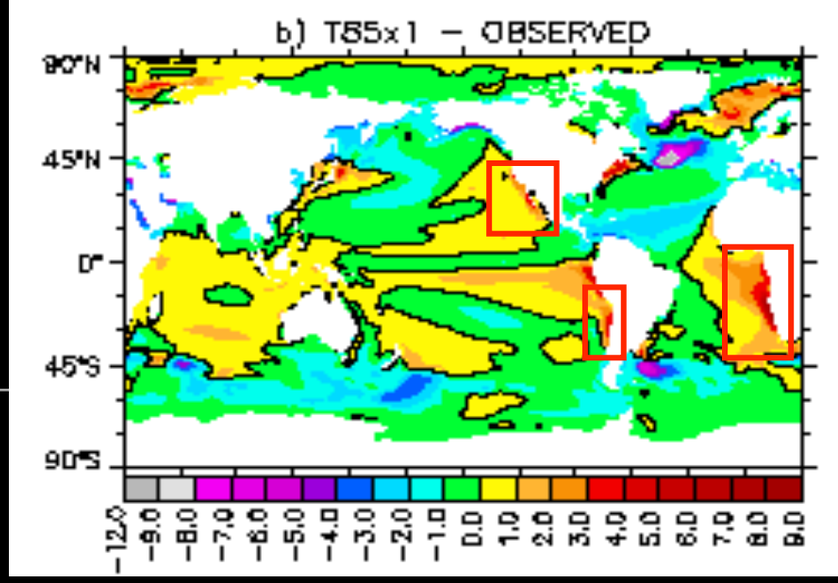
GFDL

GFDL-->ROMS

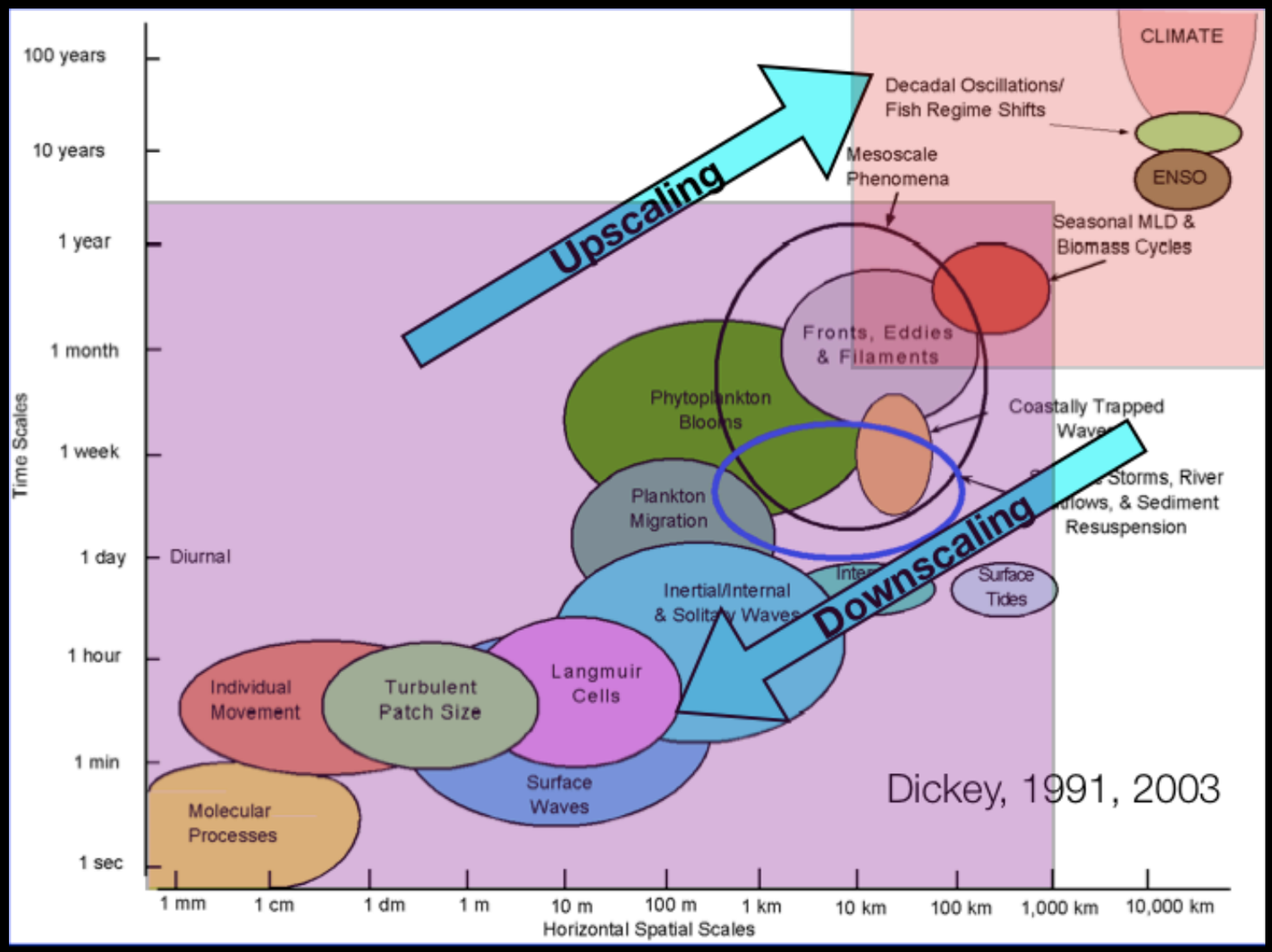


EOFs of summer SSTs

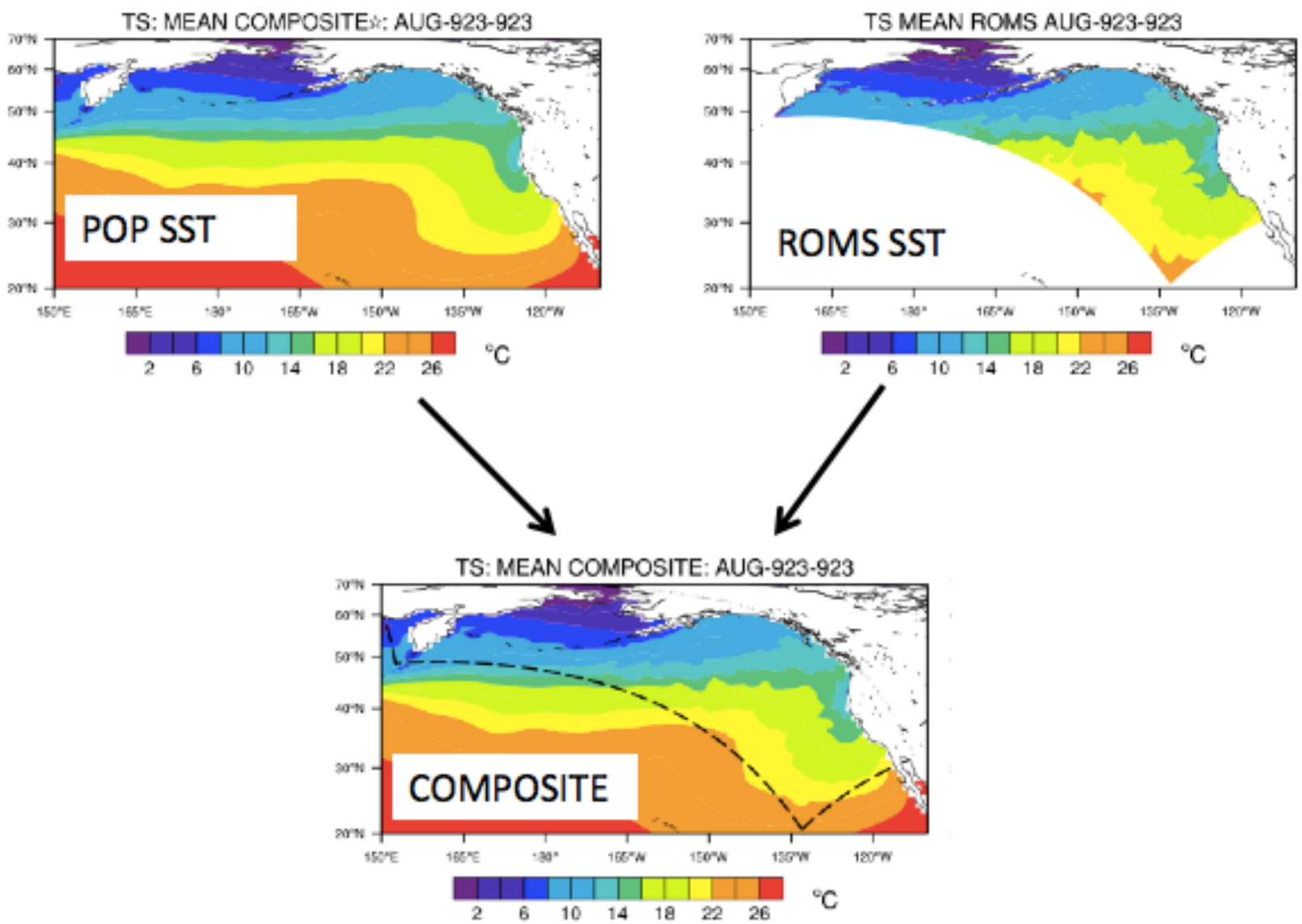
And full-physics "two-way nesting", i.e., down- and upscaling



- Impacts basins on EBUS regions (downscaling) *and on* basin scales (upscaling)
- Correct for climate model biases
- Steps to forecasts/ projections in the sense of full Earth System Models



Where the fully-coupled implementation looks something like this...



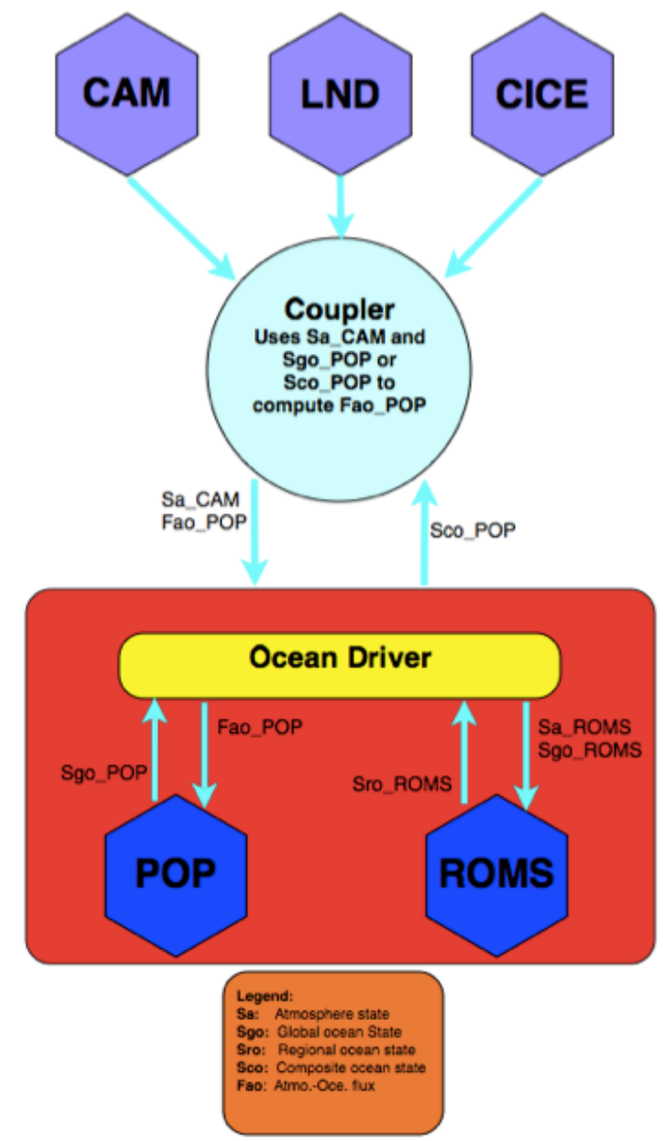


Fig. 2-1. Monthly mean SST from August, year 60 of integration. Top left: from POP part of nRCM. Top right: from ROMS component of nRCM. Bottom: the merged (composite) SST. *Replace with CCS example.*

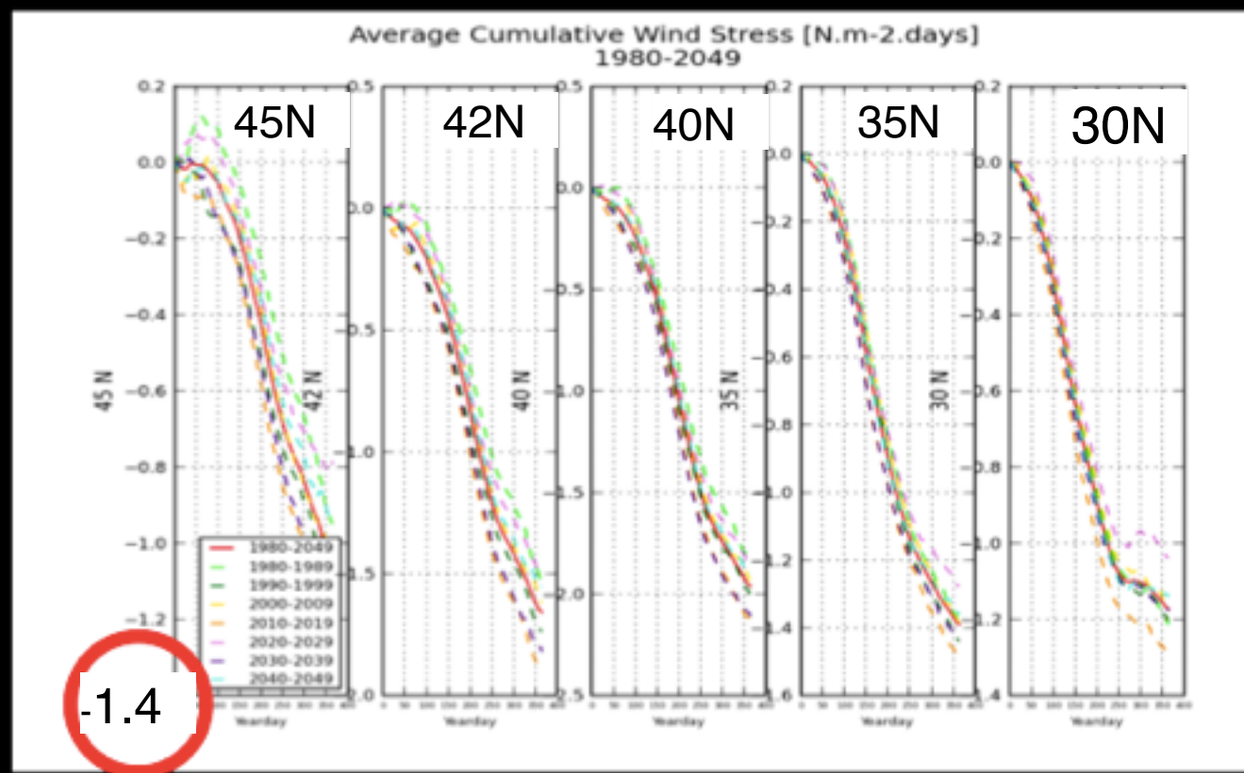
Cumulative wind stress

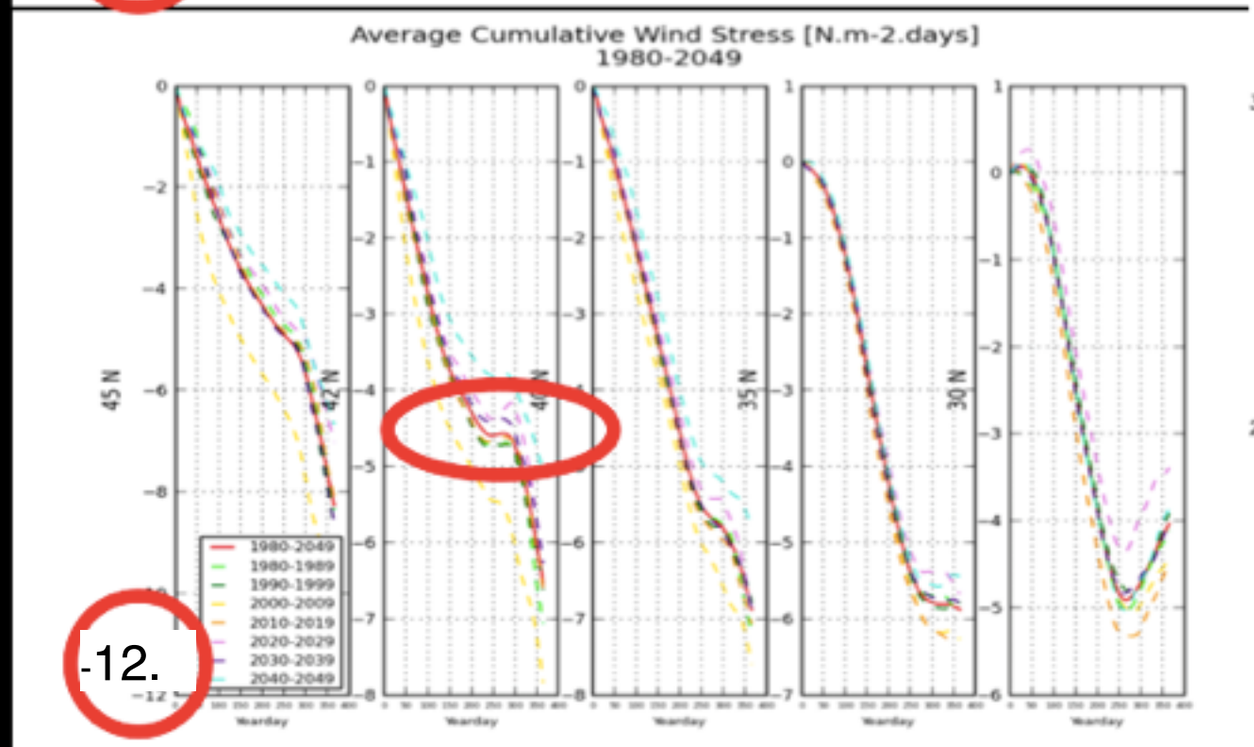
Stronger winds in the downscaled solution and greater spatial structure

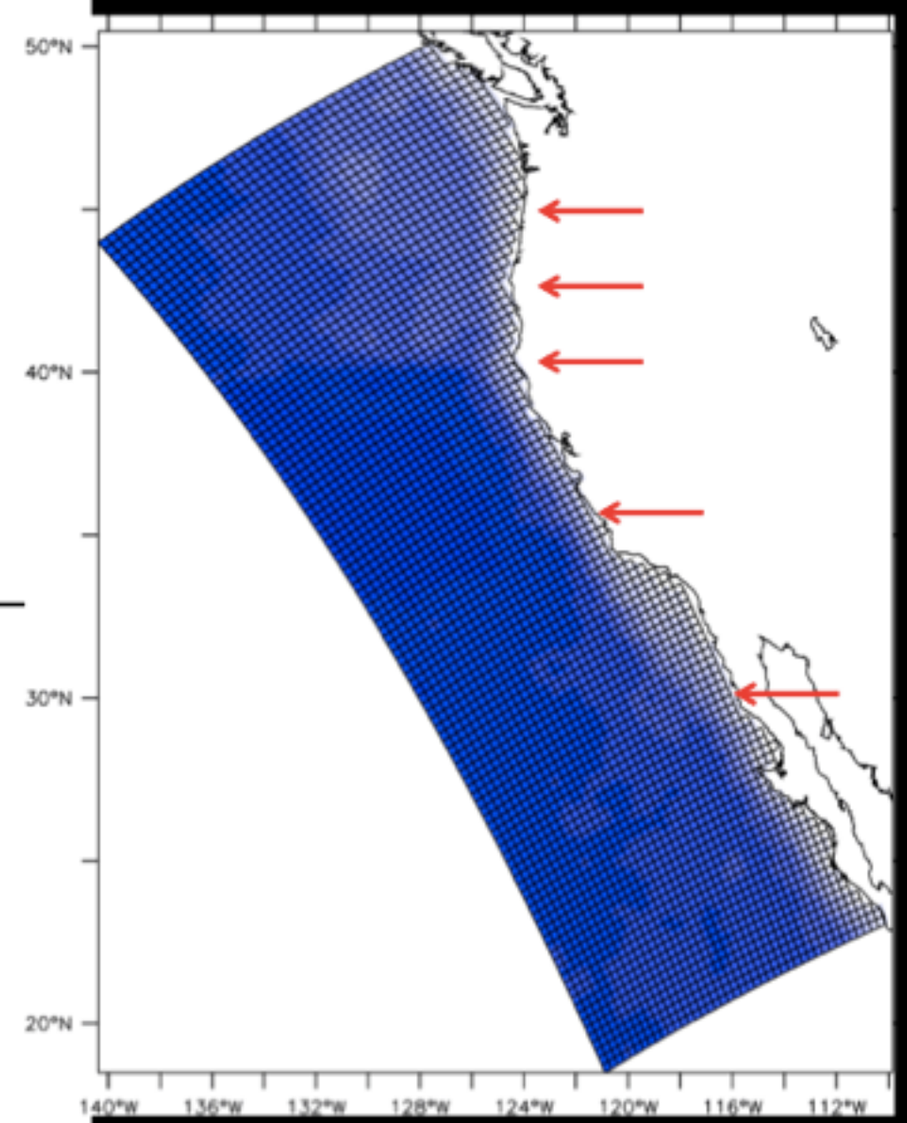
GFDL

Preliminary comparisons of global vs. 2-way coupled wind stress estimates

GFDL--> ROMS

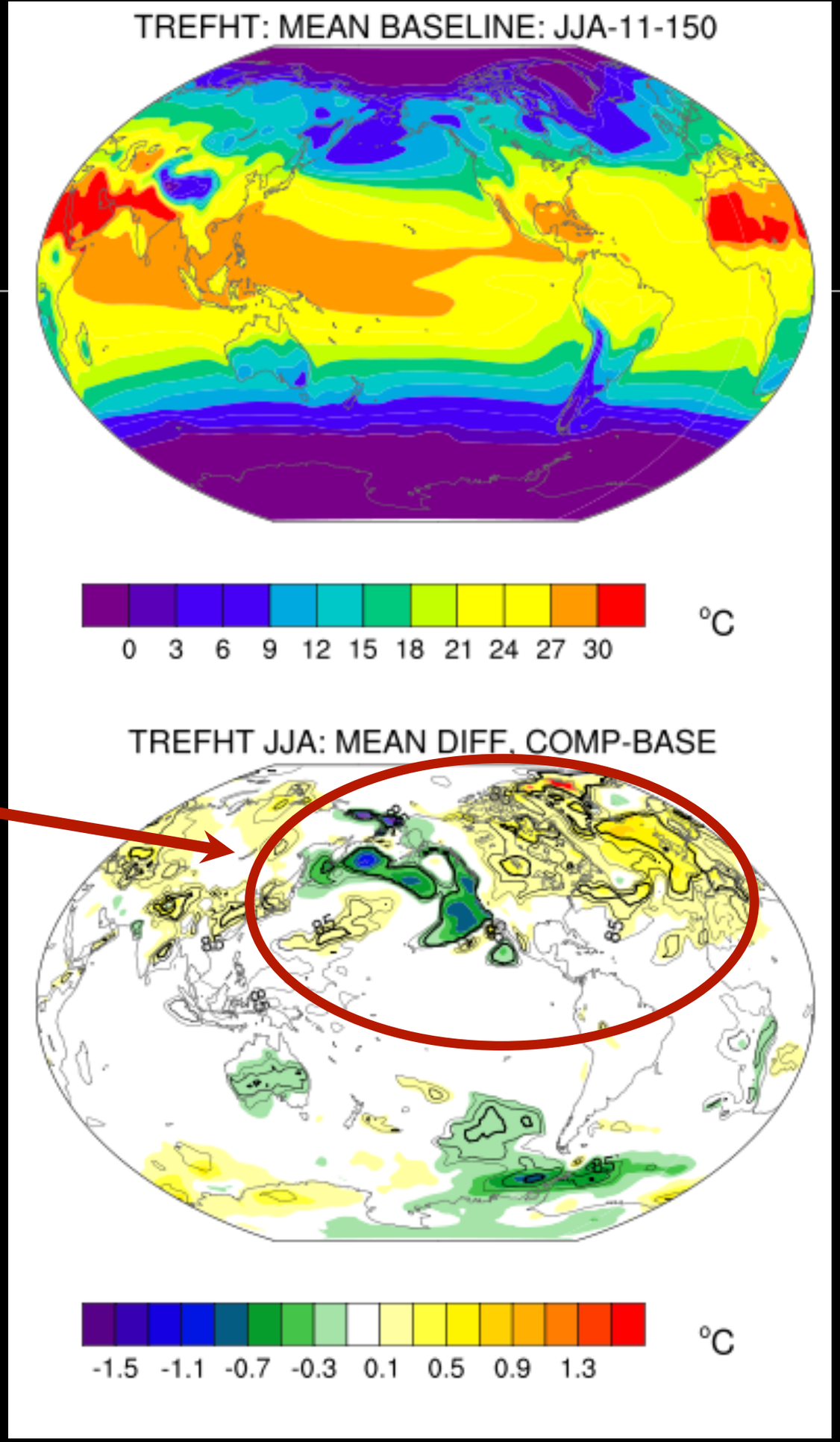






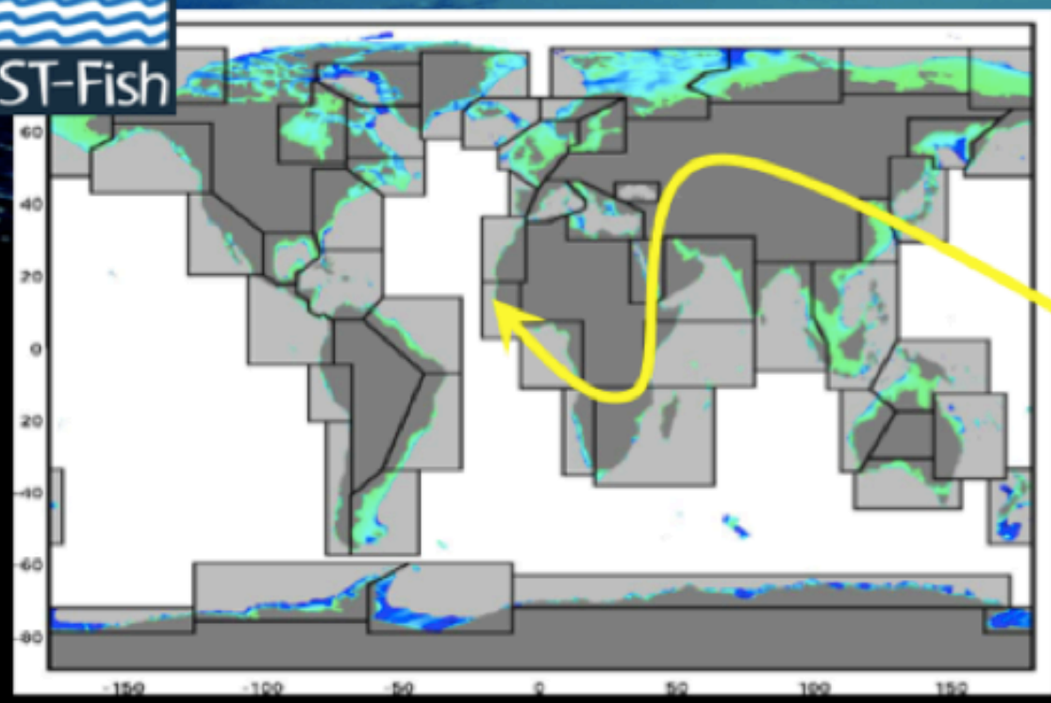
Global Jun-Jul-Aug Surface air temperature

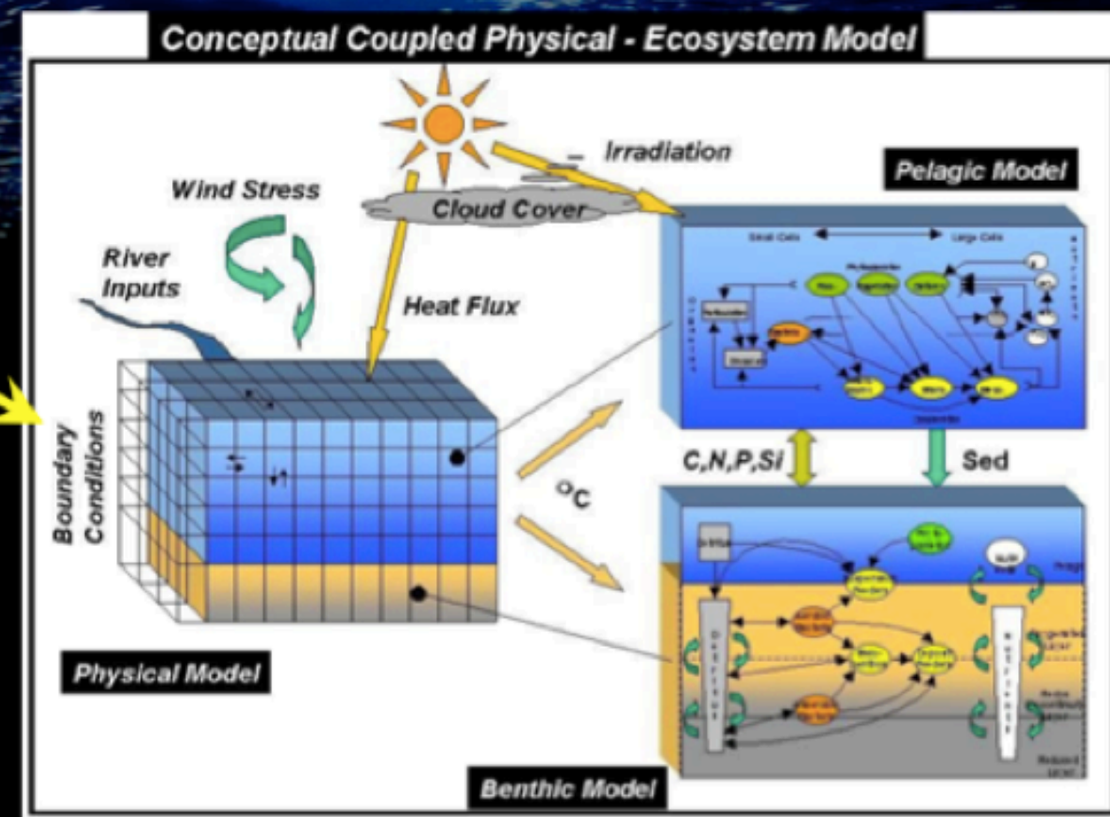
Areas where the effects of the regional solution are significant at larger scales



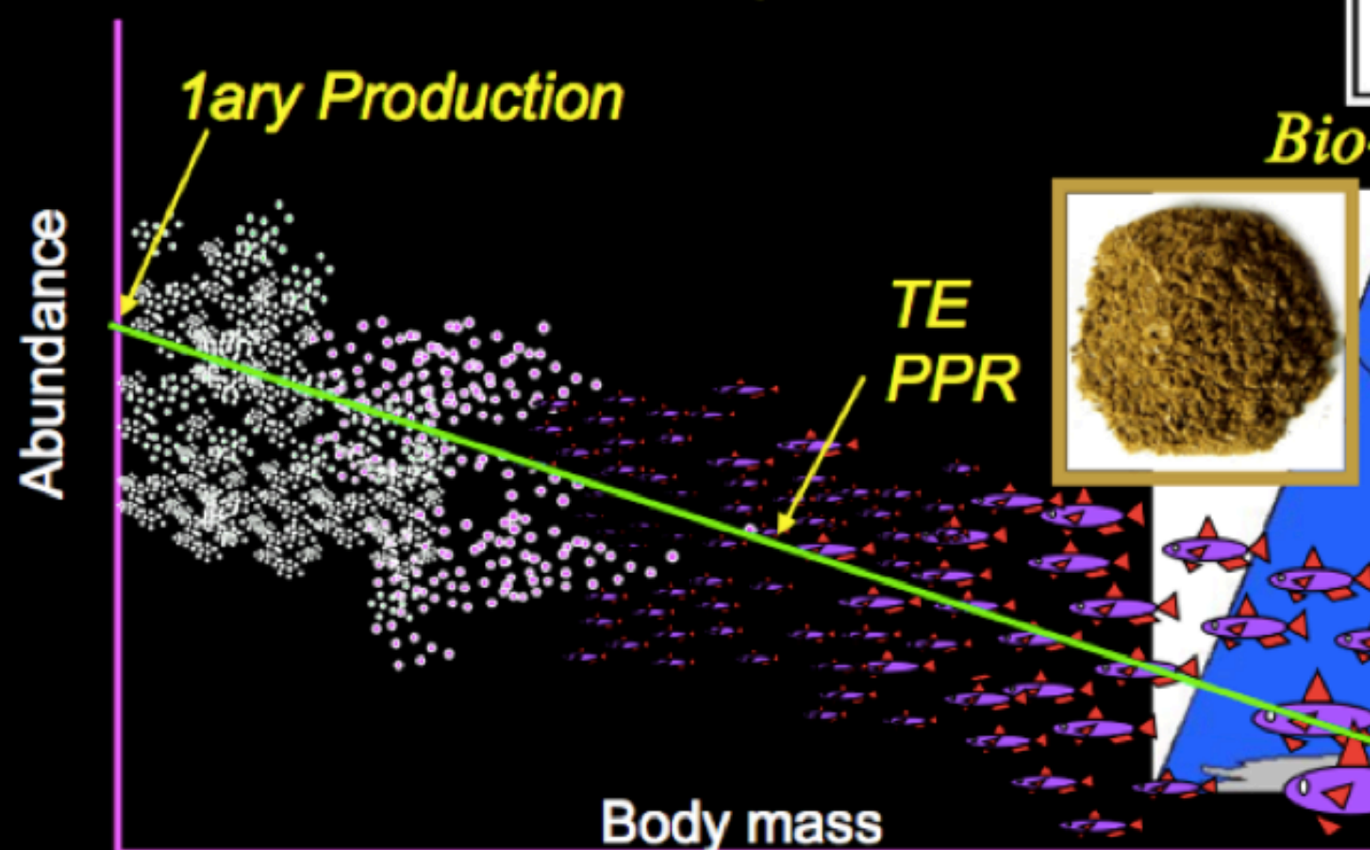
Climate Change forcing scenarios and global markets

Model pelagic/ benthic dynamics as driven by regional hydrodynamics





Couple the shelf seas to the global ocean

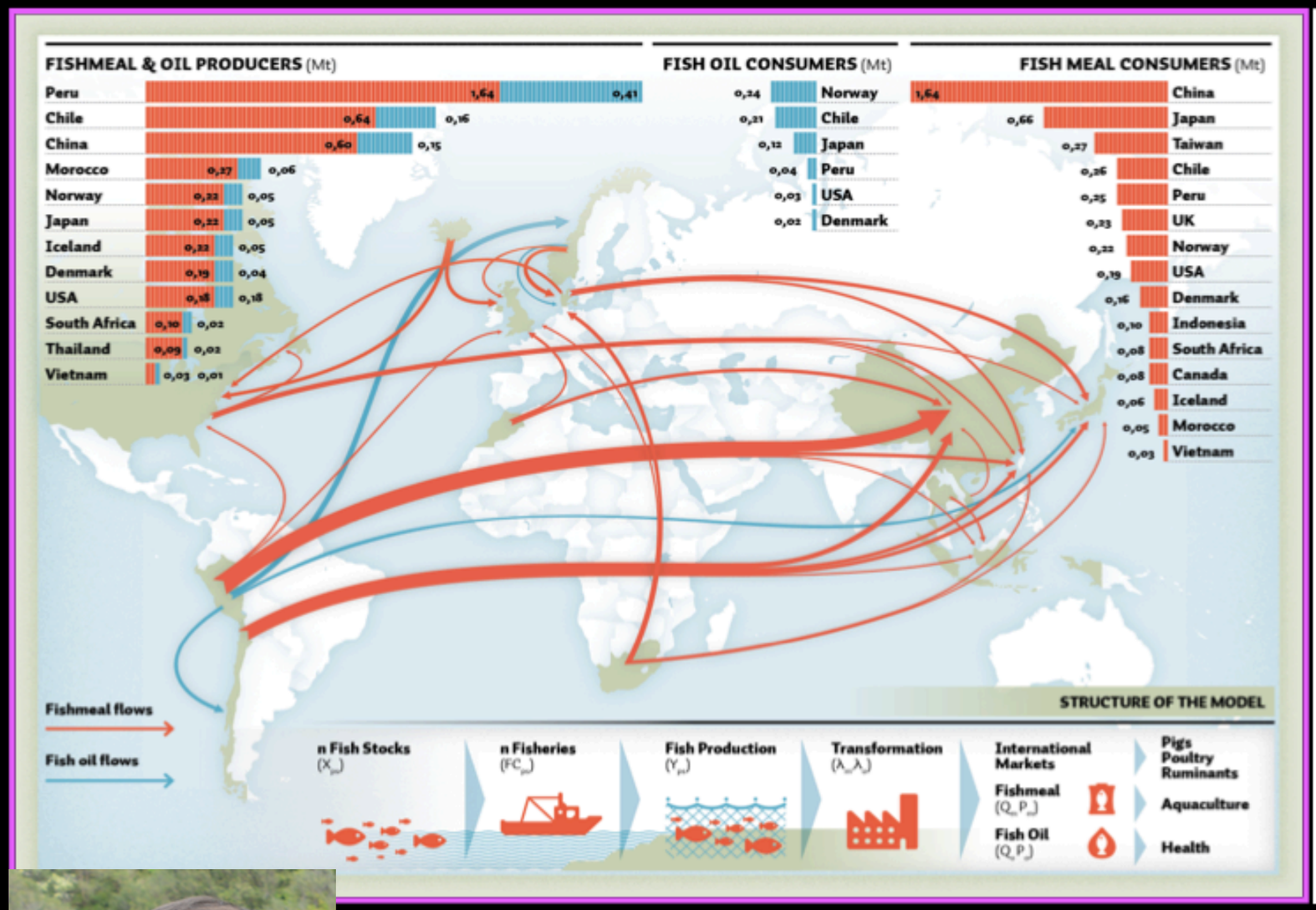


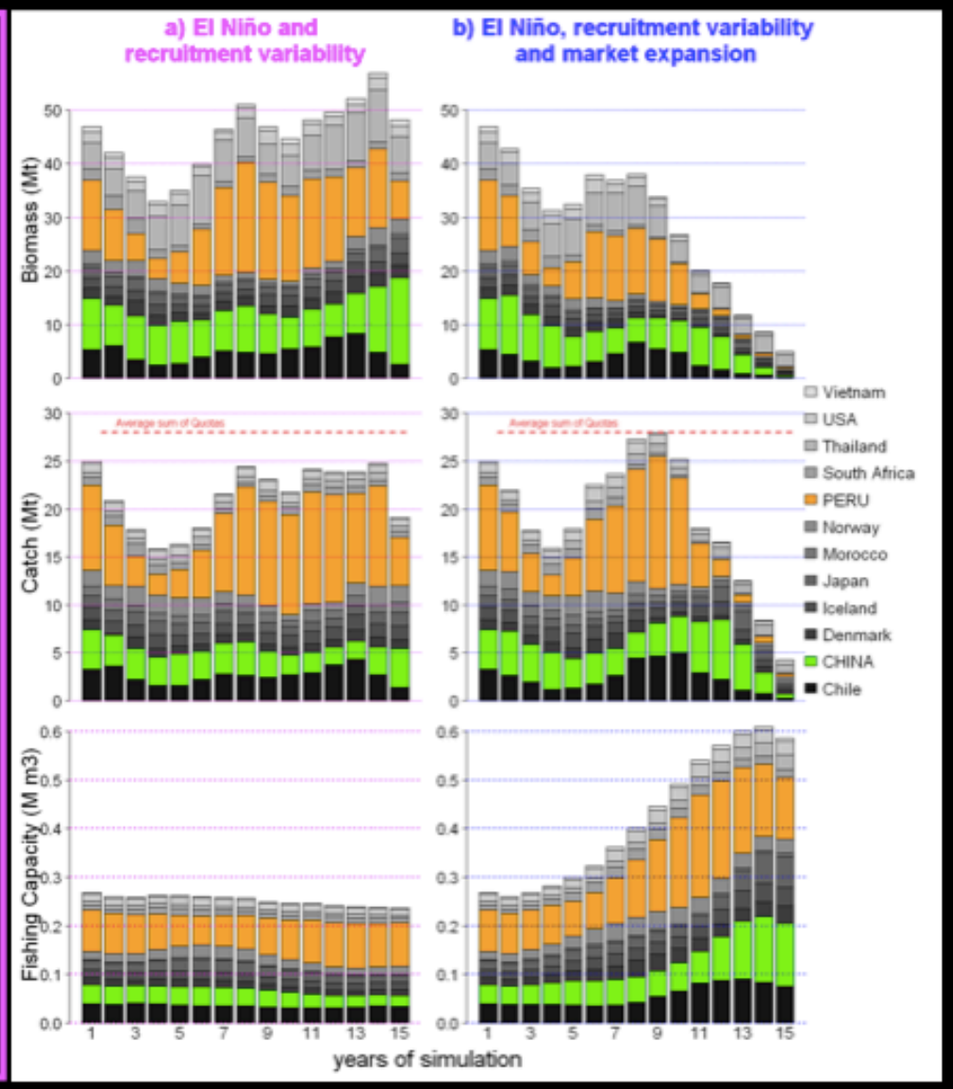
(Barange et al.)

Bio-economic models

Driven by changes in the price of fishmeal…

Bioeconomic simulation models





… and combined with expected environmental variability (e.g., El Niño occurrences), predicted changes in Biomass, Catch and Fishing Capacity.

(Barange et al.; Merino et al.)

Draft Climate Science Objectives

Climate-Informed Reference Points

Robust Management Strategies

Adaptive Management Processes

Robust Projections of Future Conditions

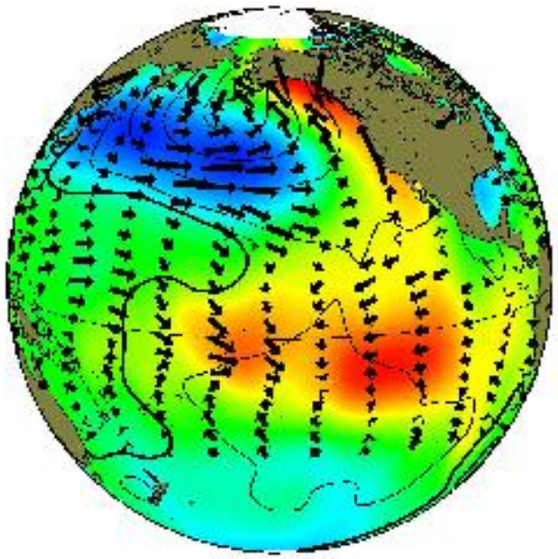
Information on Mechanisms of Change ← 5

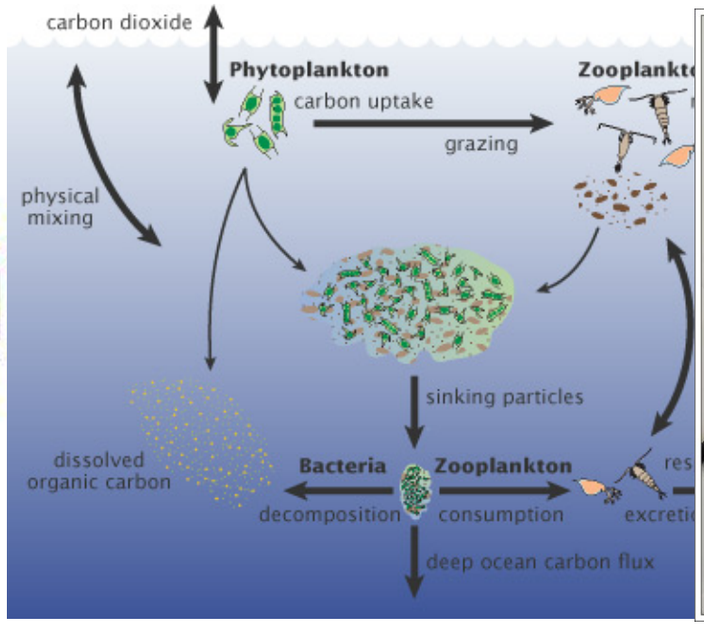
Status, Trends and Early Warnings

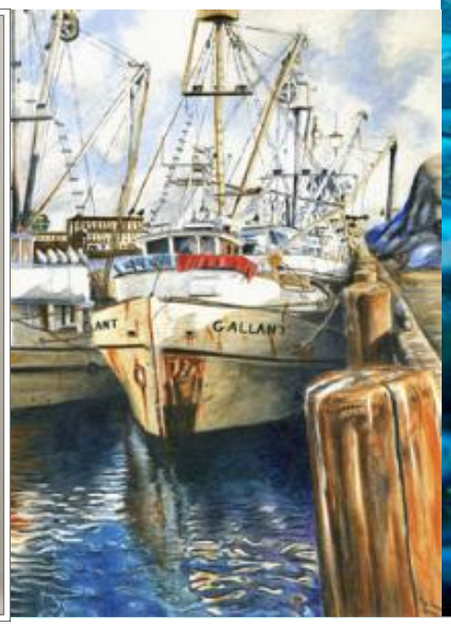
Science Infrastructure to Produce and Deliver Actionable Information

Objective 5. Identify the **mechanisms** of climate effects on ecosystems, LMRs, and LMR dependent human communities.

From physics and lower trophic levels
to sardine, anchovies and fishing fleets



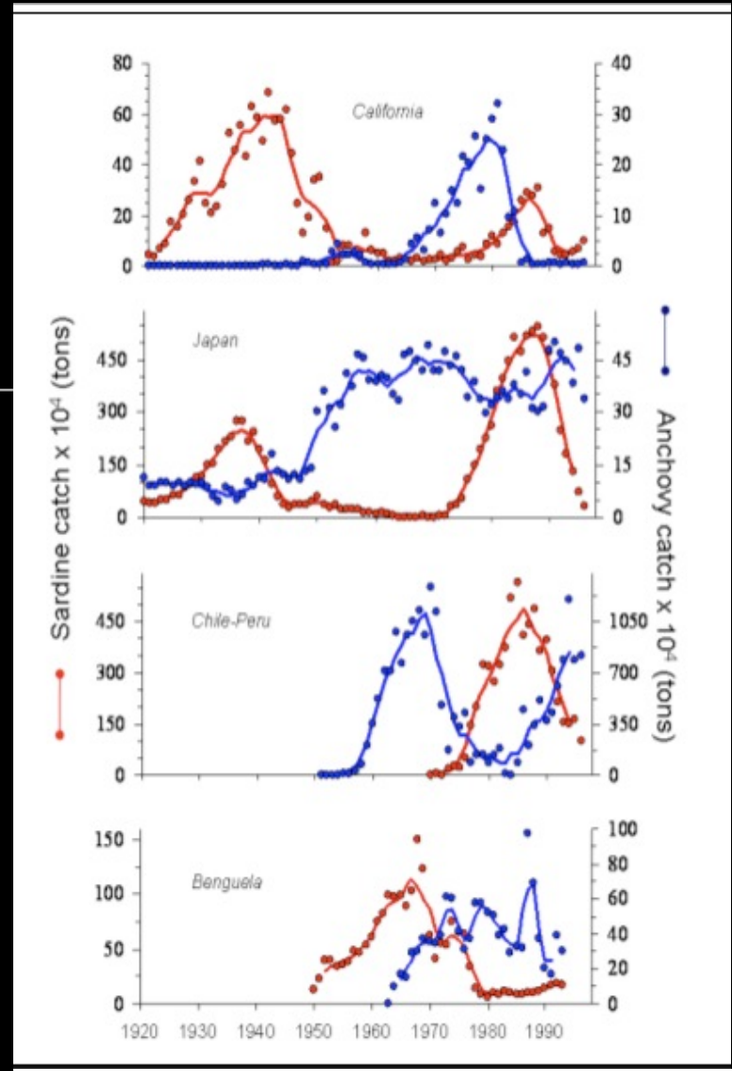


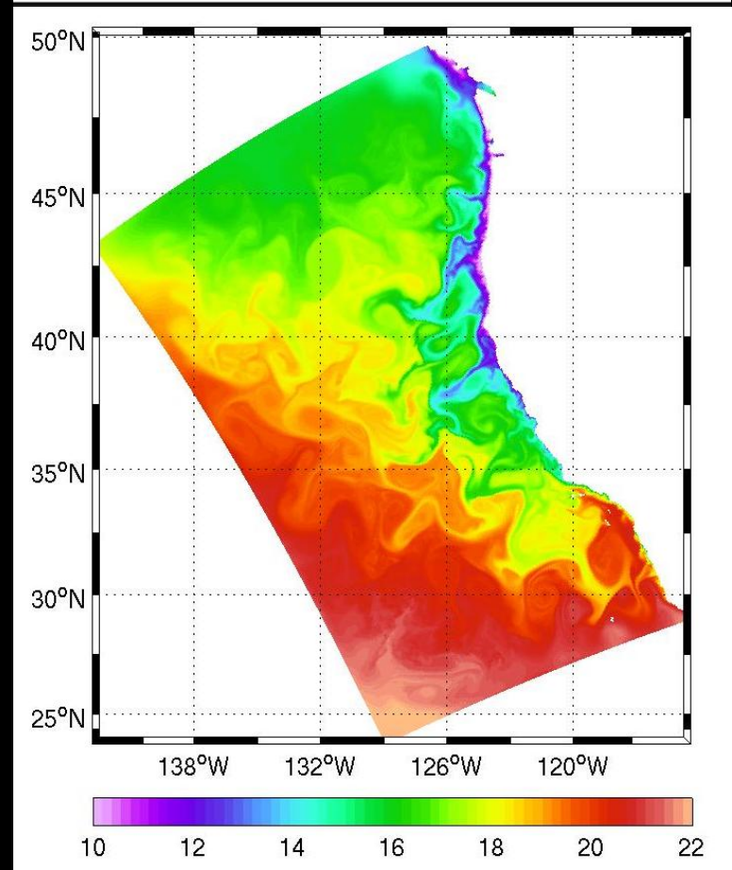


Hypotheses for low-frequency variability

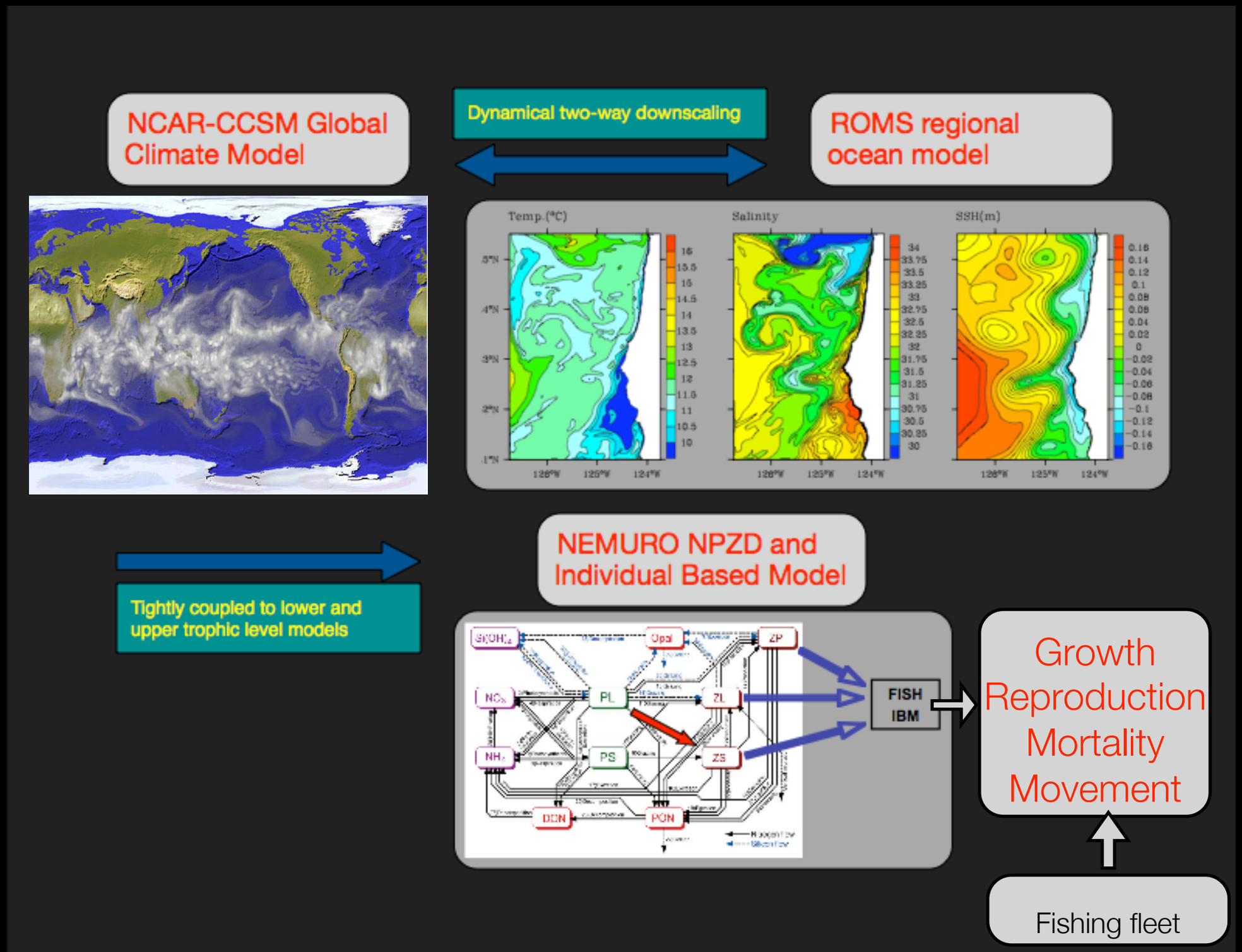
- **Environmental conditions (bottom up)**
  - Temperature controls population expansions and contractions via spawning behavior (e.g., Lluch-Belda et al., 1991).
  - Reproduction success linked to mesoscale features (MacCall, 2002).
  - Food availability and composition determines population success (e.g., Van der Lingen et al. 2001).

- **Fishing pressure (top down)**
  - Affects longevity--affects survival in adverse conditions.
  - Differentially preserve more fecund older fish and their migratory behavior.
  - Productivity depends on learned migratory behavior (Petigas et al. 2006).





Our approach: coupled climate-to-fishers model

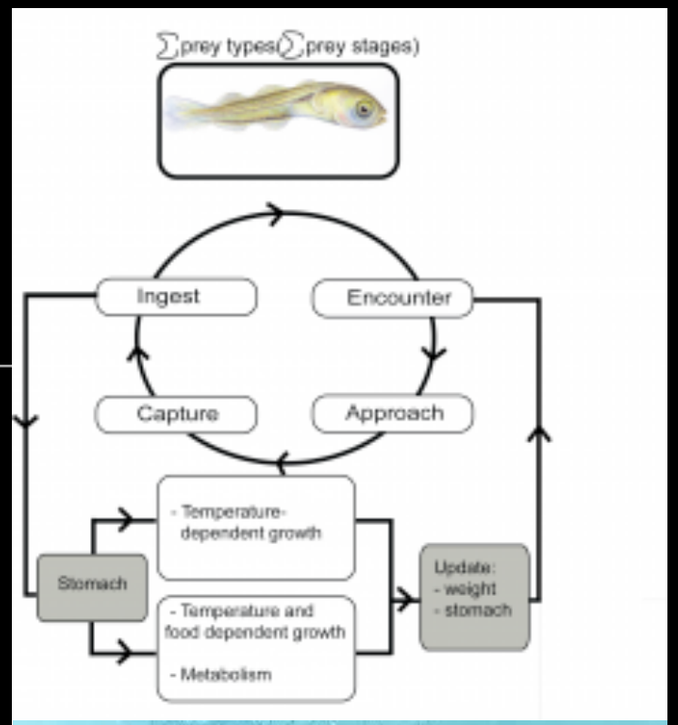


Climate-to-fishers: Multi-species fish model

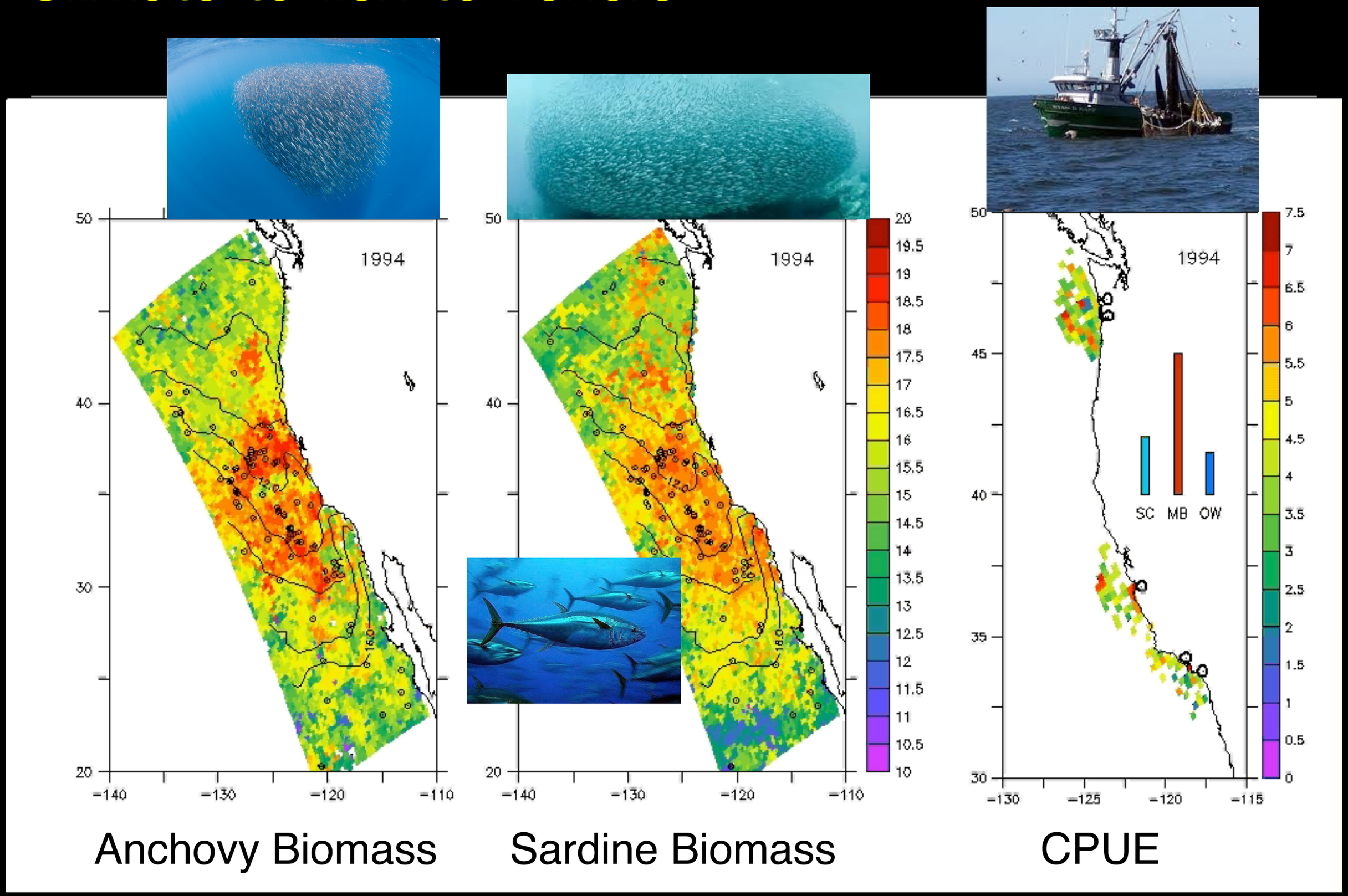
- Simulate multiple species with an *individual based modeling* approach.
- General food web: Species can compete for common prey and eat each other.
- Explicitly model *growth, mortality, reproduction and movement.*
- One species can represent a *fishing fleet* as individuals.

Climate-to-fishers:
Why an IBM (Individual Based Model)?

- Natural unit in nature
- Allows for local interactions and complex systems dynamics
- Complicated life histories
- Plasticity and size-based interactions
- Conceptually easier movement

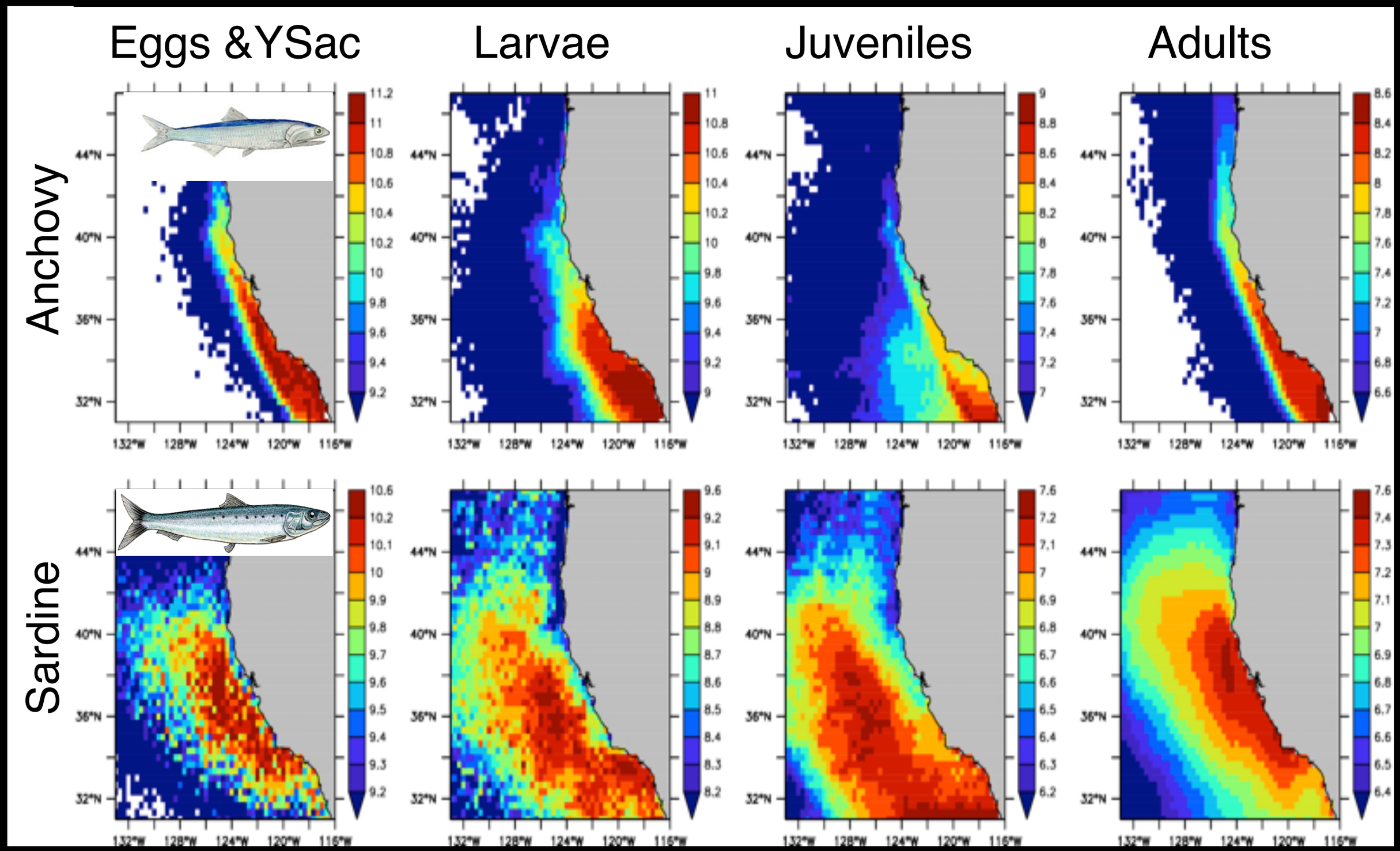


Climate-to-fish-to-fishers



Rose et al. and Fiechter et al., Progress in Oceanography, in press.

Mean (1964-2008) abundance by life stage (log_{10} of individuals); Anchovy (top) and sardine (bot.)

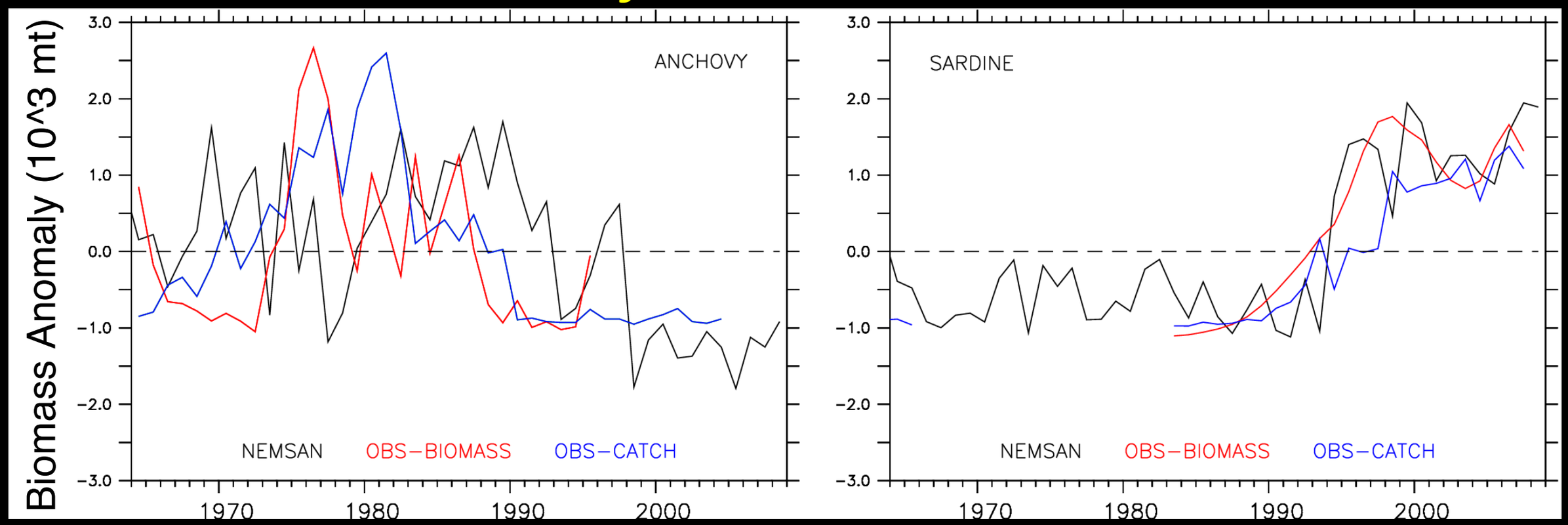


Rose et al. and Fiechter et al., Progress in Oceanography, in press.

Population biomass
(shows encouraging resemblance to observations)

Anchovy

Sardine

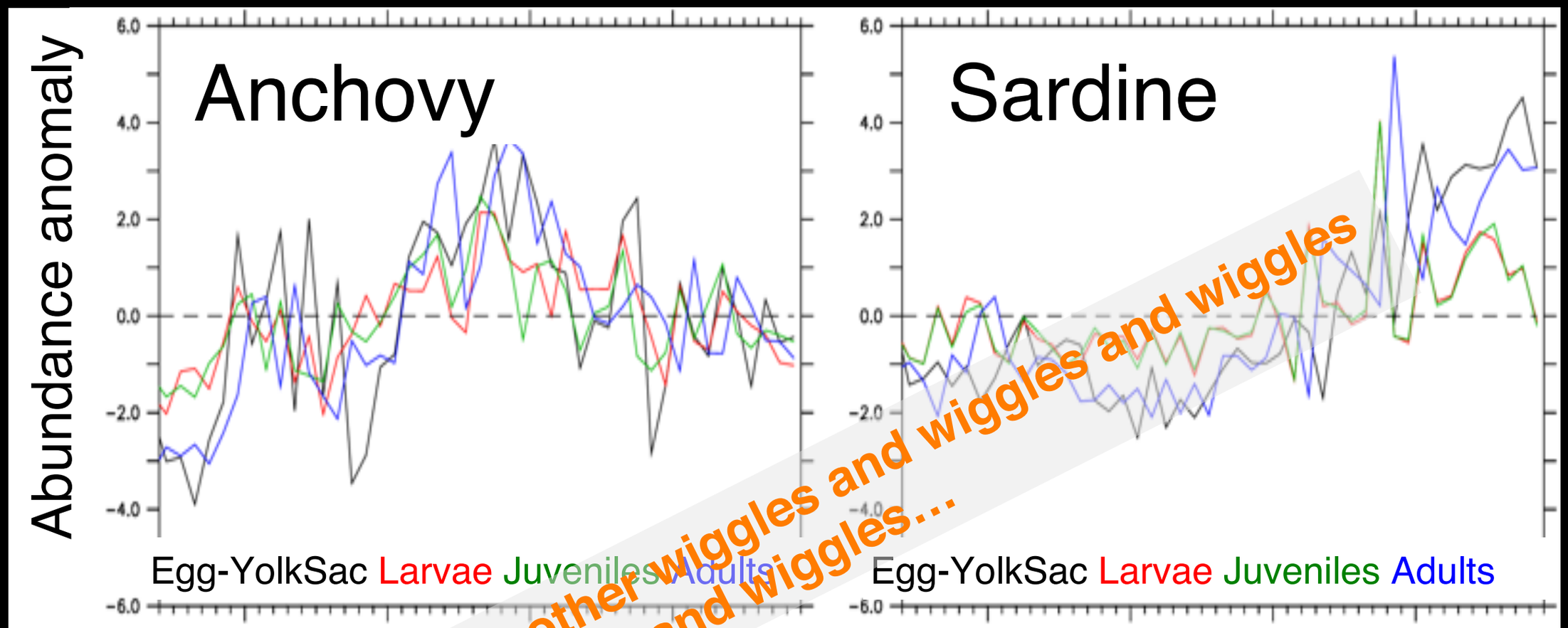


We've put a rather complex set of models including a wide range of processes, biological/physiological traits, and results of two species have emerged showing differences at various scales, e.g., anchovy at higher frequency, decadal variability in both …

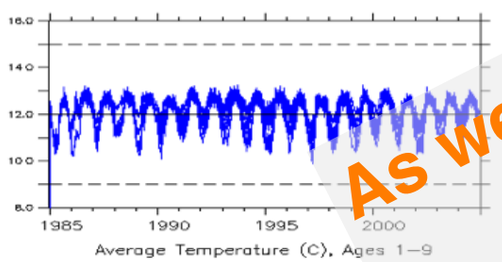
Rose et al. and Fiechter et al., Progress in Oceanography, in press.

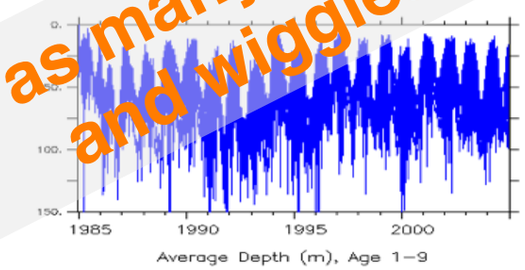
The models allow for examination of annual abundance anomalies at various life-stages

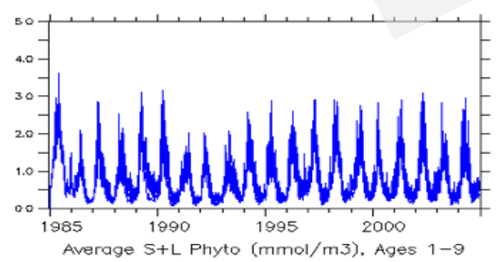
Rose et al. and Fiechter et al., Progress in Oceanography, in press.

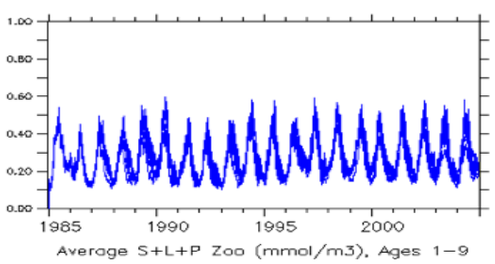


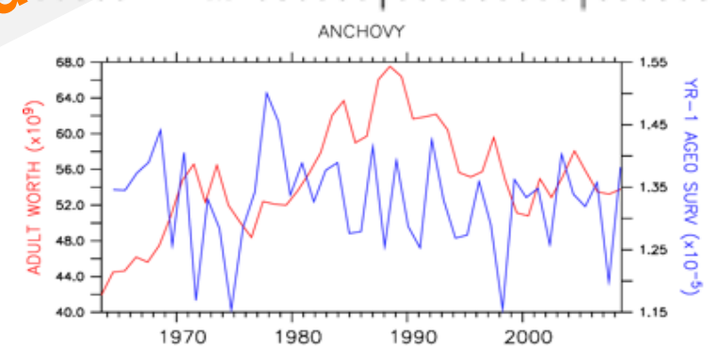
As well as many other wiggles and wiggles and wiggles and wiggles…

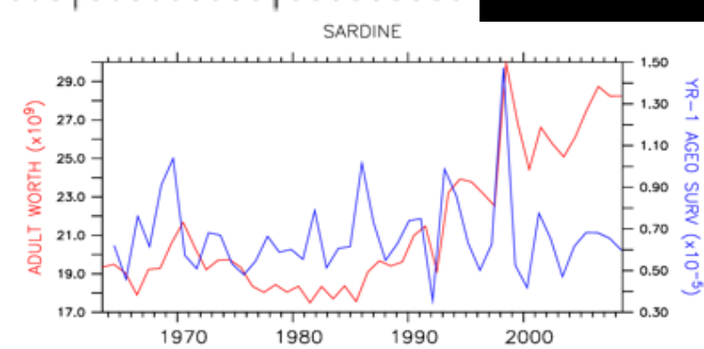


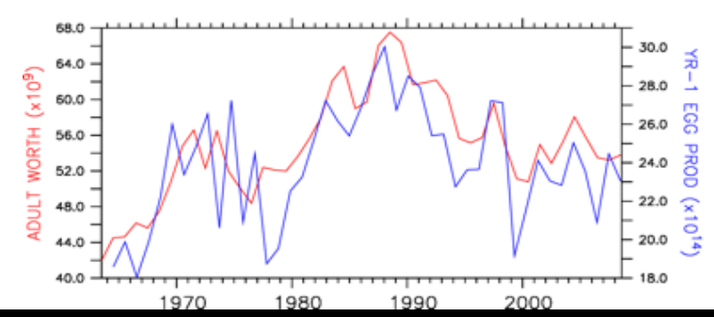


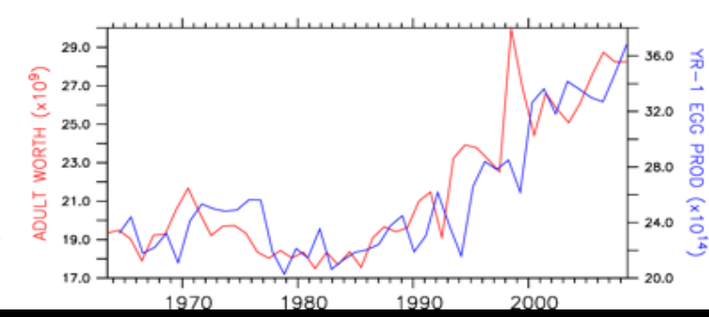










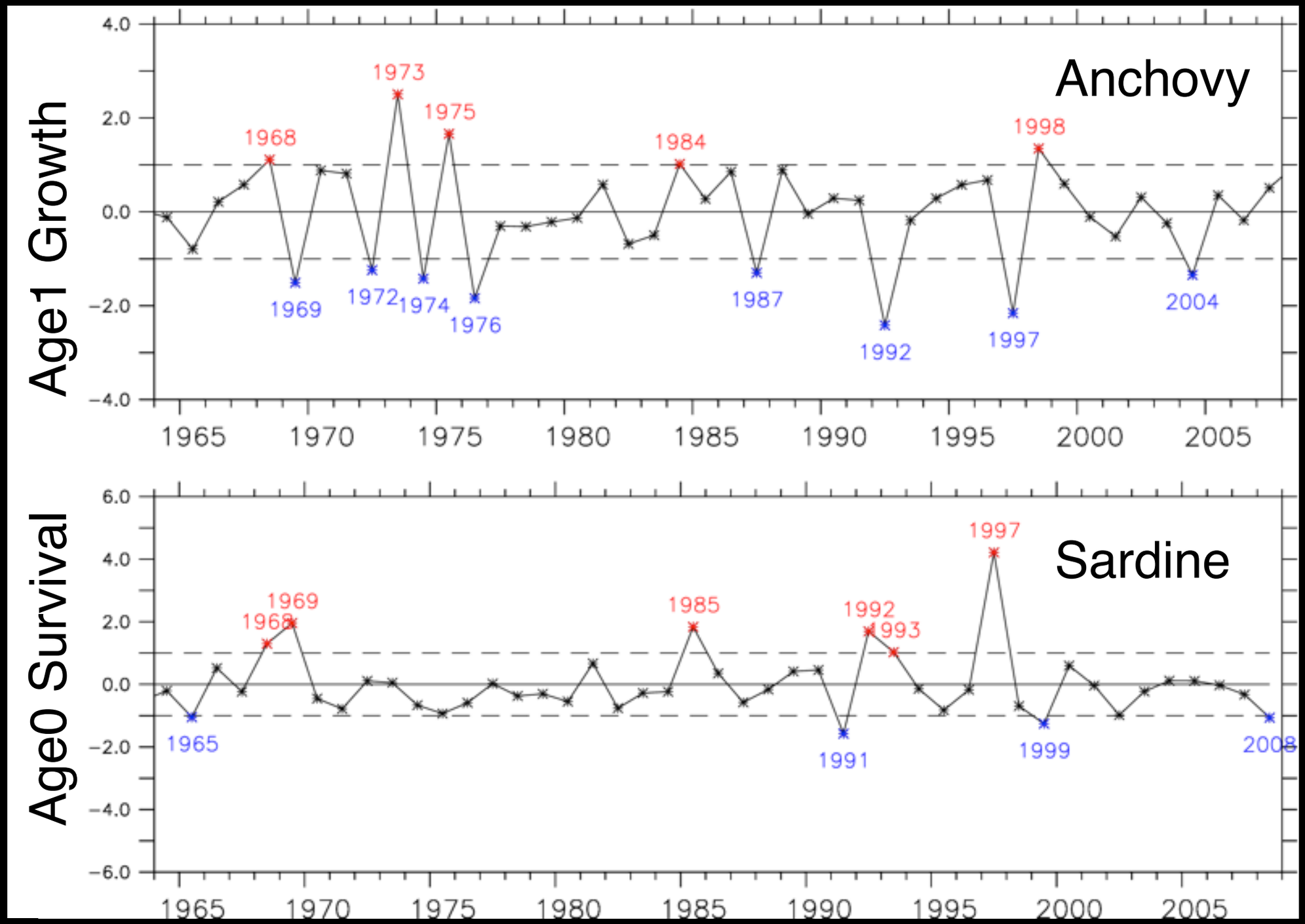


Lots of “wiggly” information…
three steps to tease out the drivers

- Step 1: establish the biological processes that control adult sardine and anchovy population dynamics
  - Anchovy: adult population fluctuations are associated with age-1 growth and prey availability.
  - Sardine: adult populations correlated with temperature and age-0 survival.
- Step 2: link changes in processes to variations in environmental conditions
  - Anchovy: years of high growth related to enhanced upwelling in the southern CCS (more productive lower tropic levels)
  - Sardine: years of high age-0 survival related to high temperatures
- Step 3: correlate environmental conditions experienced by the individuals in the model to regional and climate-scale variability in the CCS using ROMS and NEMURO output directly.

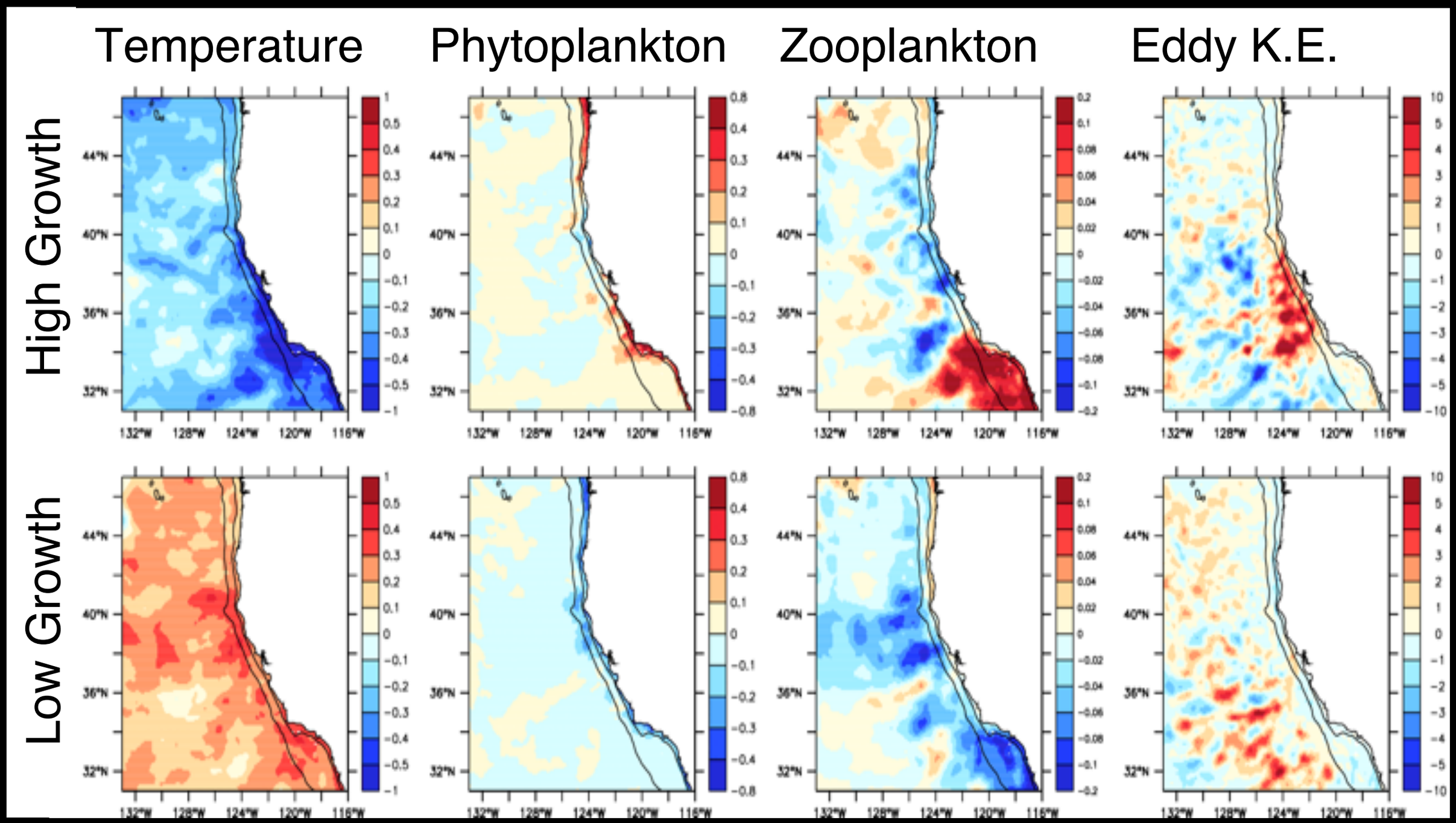
Annual anomalies

Top: Age-1 growth. Bot.: Age-0 survival



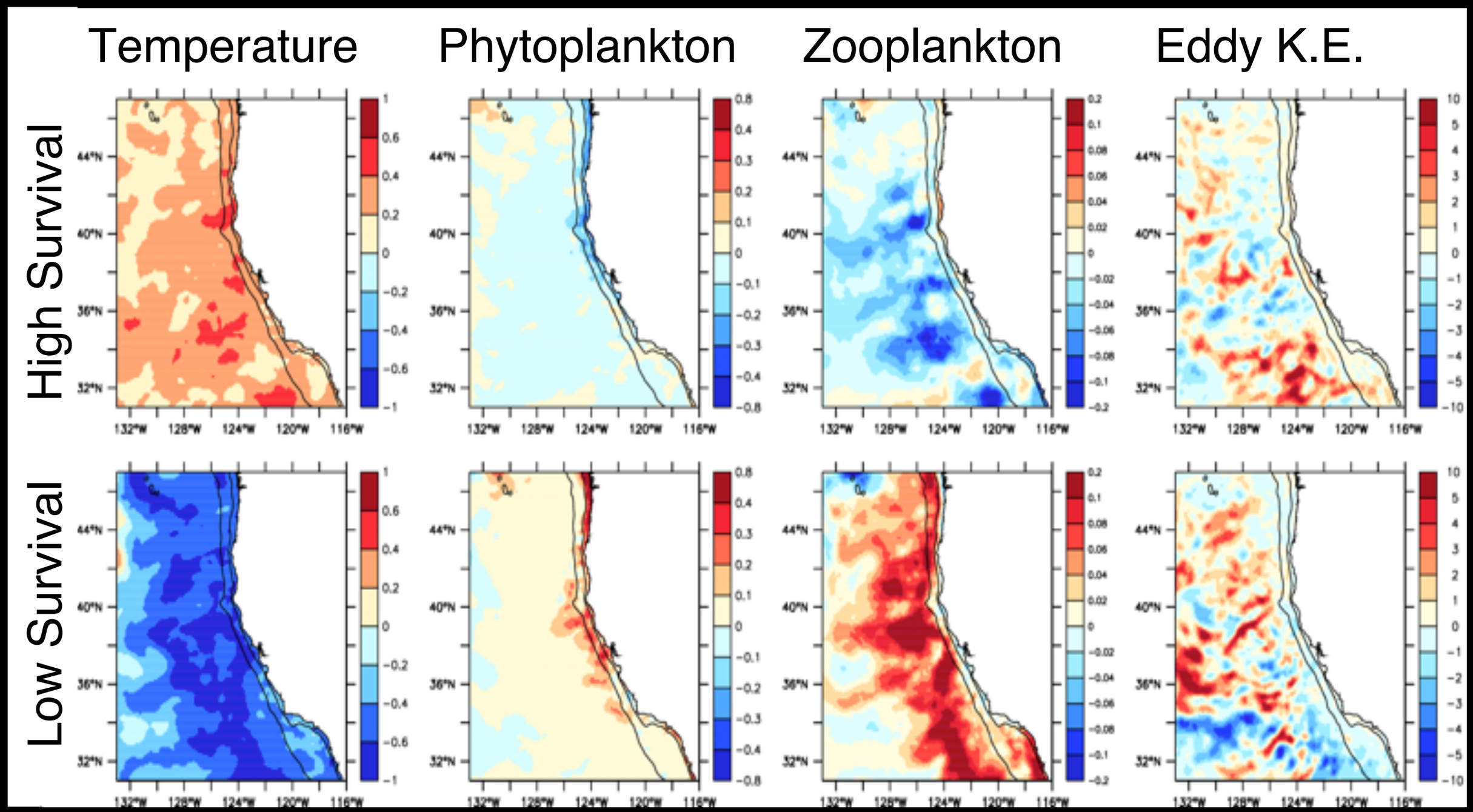
Rose et al. and Fiechter et al., Progress in Oceanography, in press.

Environmental drivers: Anomalies for high- and low-years of anchovy age-1 growth



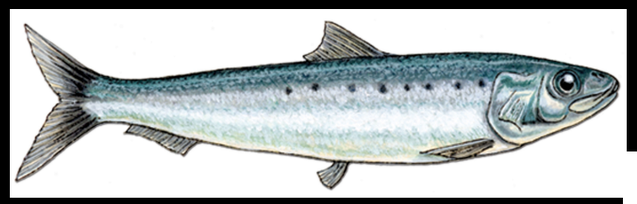
Rose et al. and Fiechter et al., Progress in Oceanography, in press.

Environmental drivers: Anomalies for high- and low-years of sardine age-0 survival



Rose et al. and Fiechter et al., Progress in Oceanography, in press.

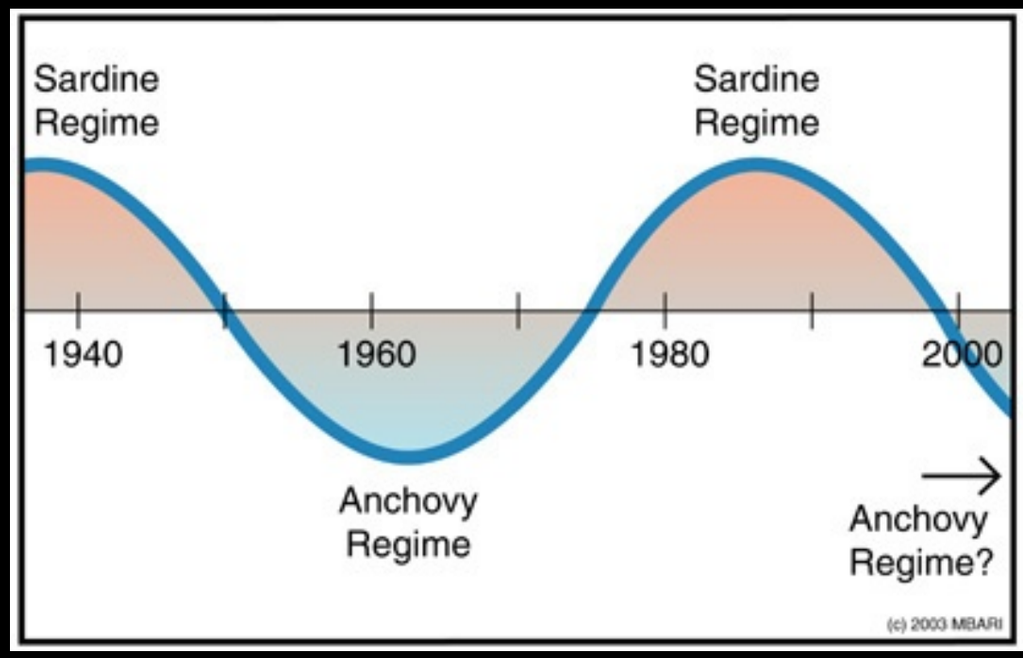
Summary on sardine & anchovy dynamics in the CCS



- Climate-to-fishing: Encouraging proof of concept of the modeling approach

- Slightly different temperature and diet preferences can lead to significantly different responses to environmental variability.

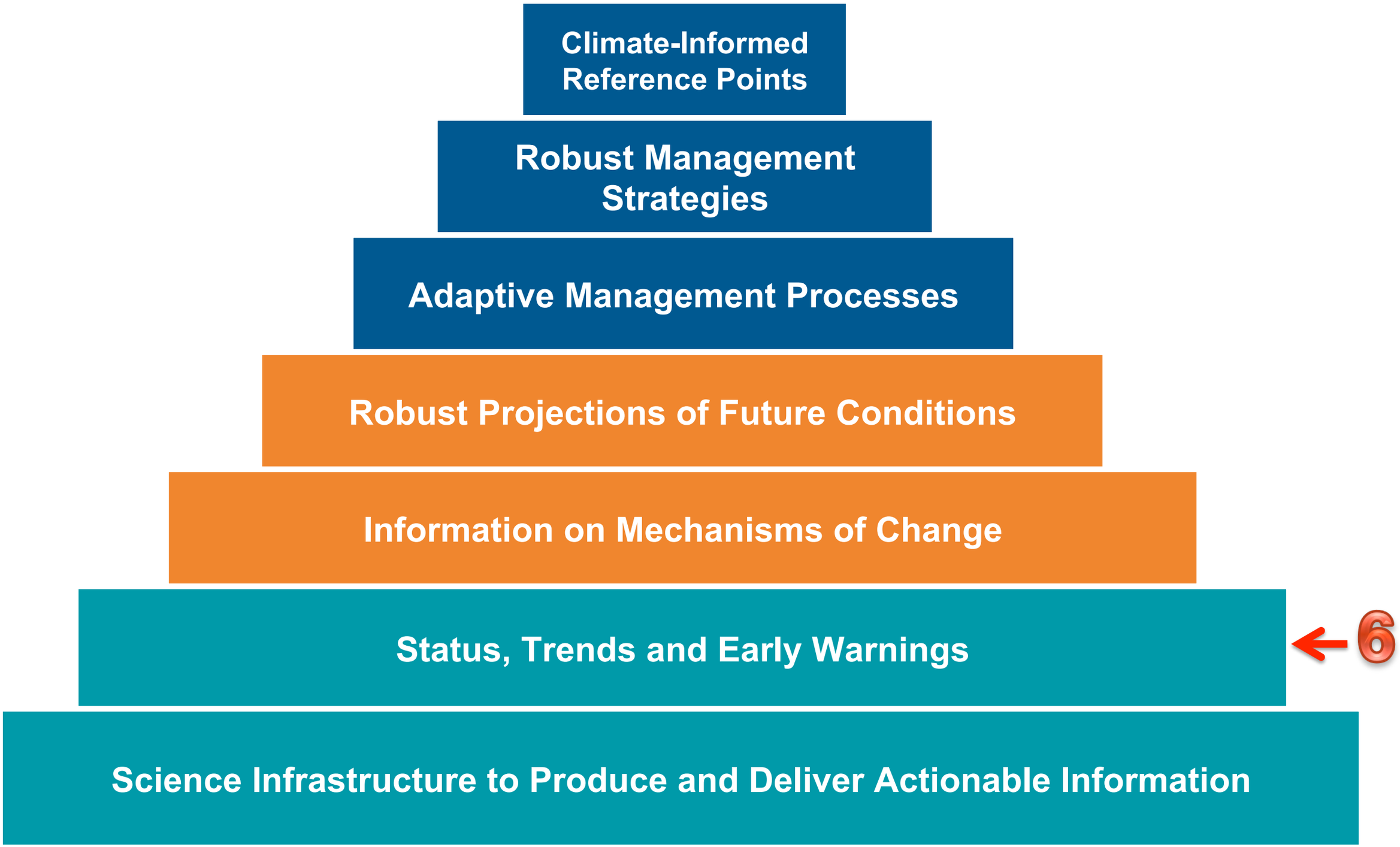
- Results (Step 3 of analysis) hint at potential to known modes of climate variability, responding to ENSO and PDO.



- Sardine vs. anchovy out-of-phase cycles: populations favor prey for anchovy and temperature for sardines and these are out of phase in the CCS. (Caveat: results apply under present, e.g., last ~50-year conditions, paleoclimate may be other matter)

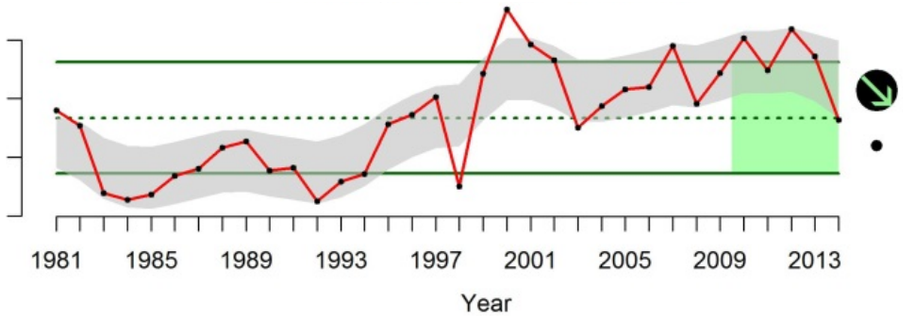
- On-going work: biological realism, alternative hypotheses, climate projections,…

Draft Climate Science Objectives



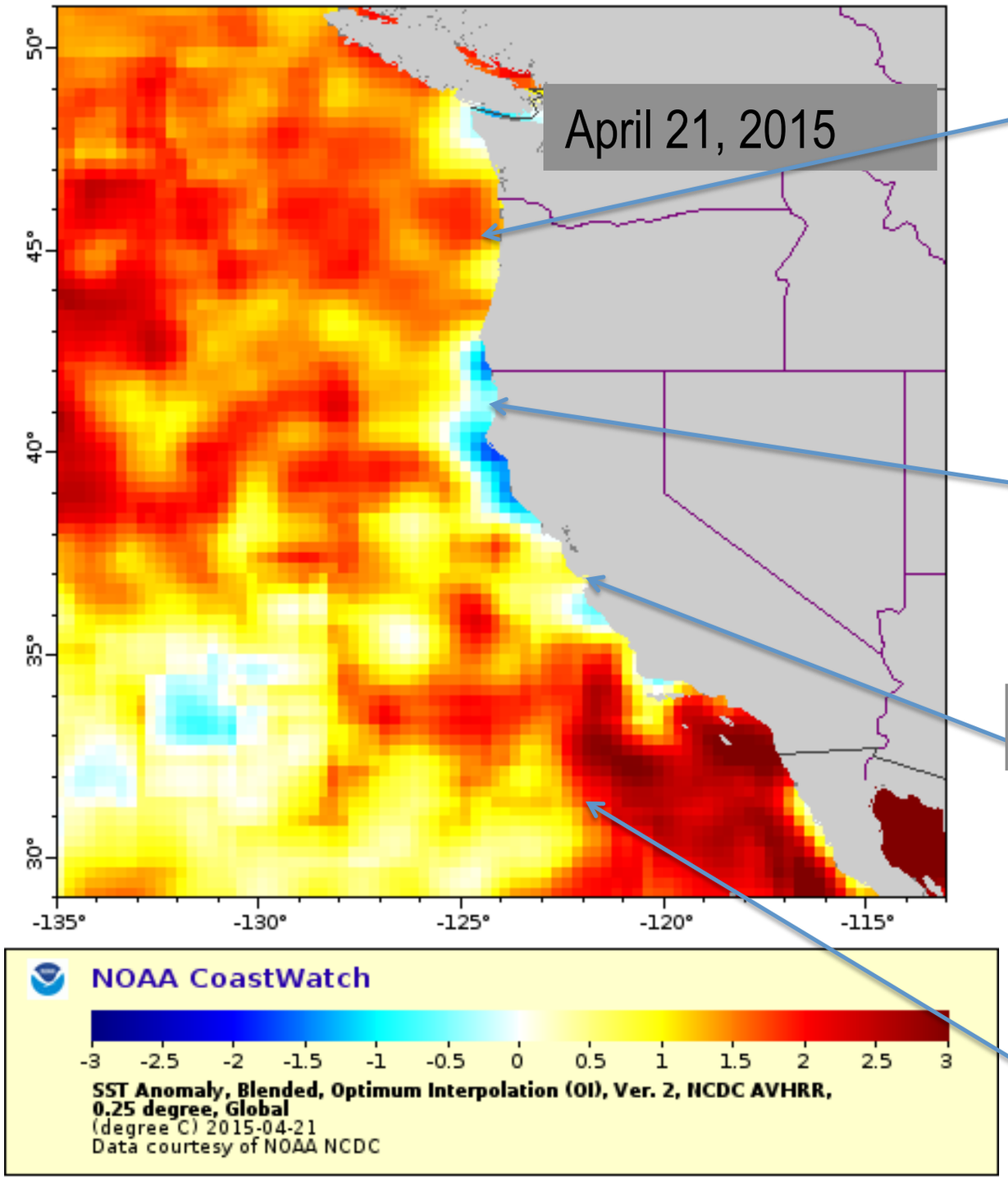
Objective 6. Track trends in ecosystems, LMRs and LMR-dependent human communities and provide early warning of change

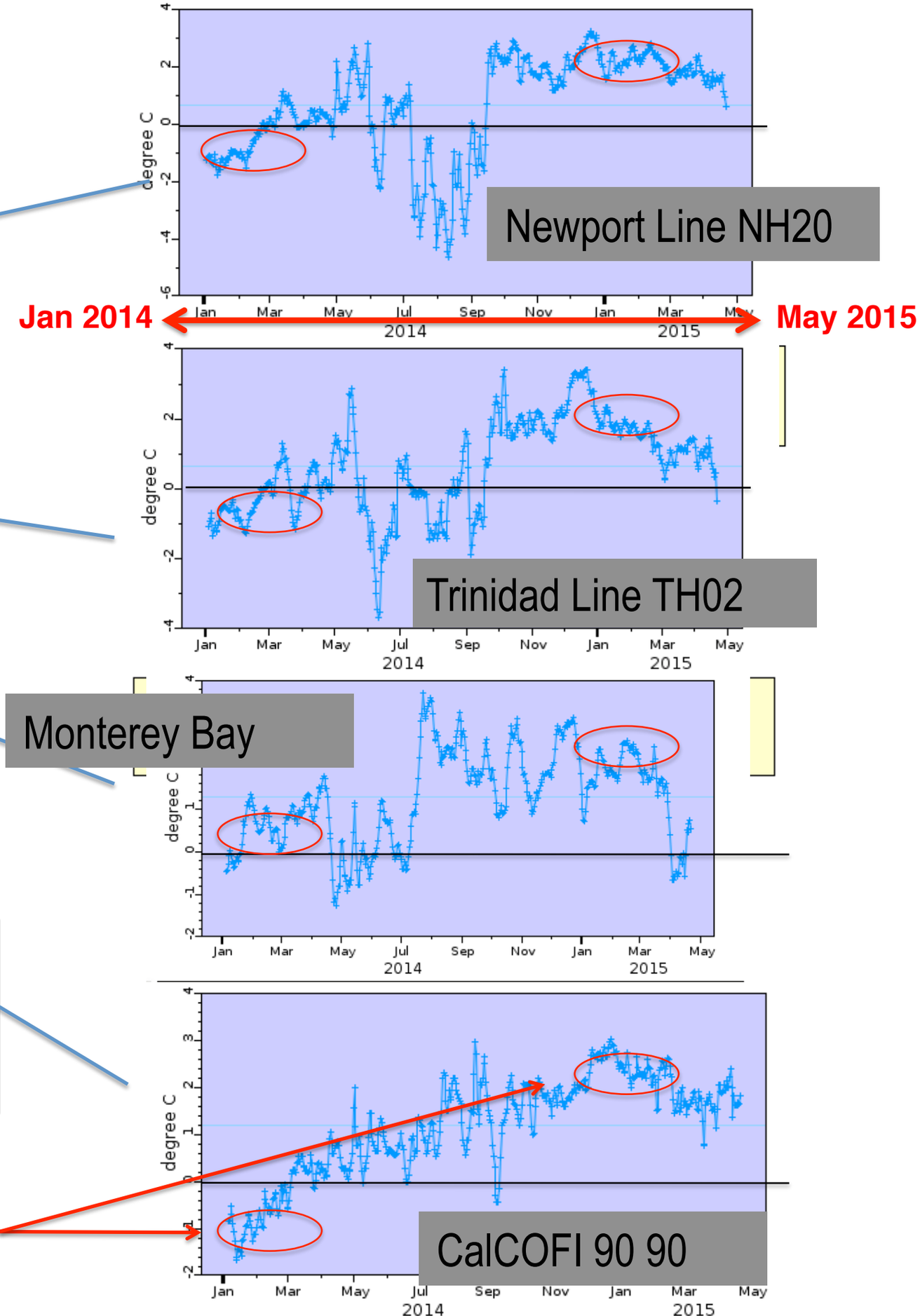
Trends and advance warning?



- **NOAA's California Current**
- **Integrated Ecosystem Assessment**

2014/15 SST anomaly



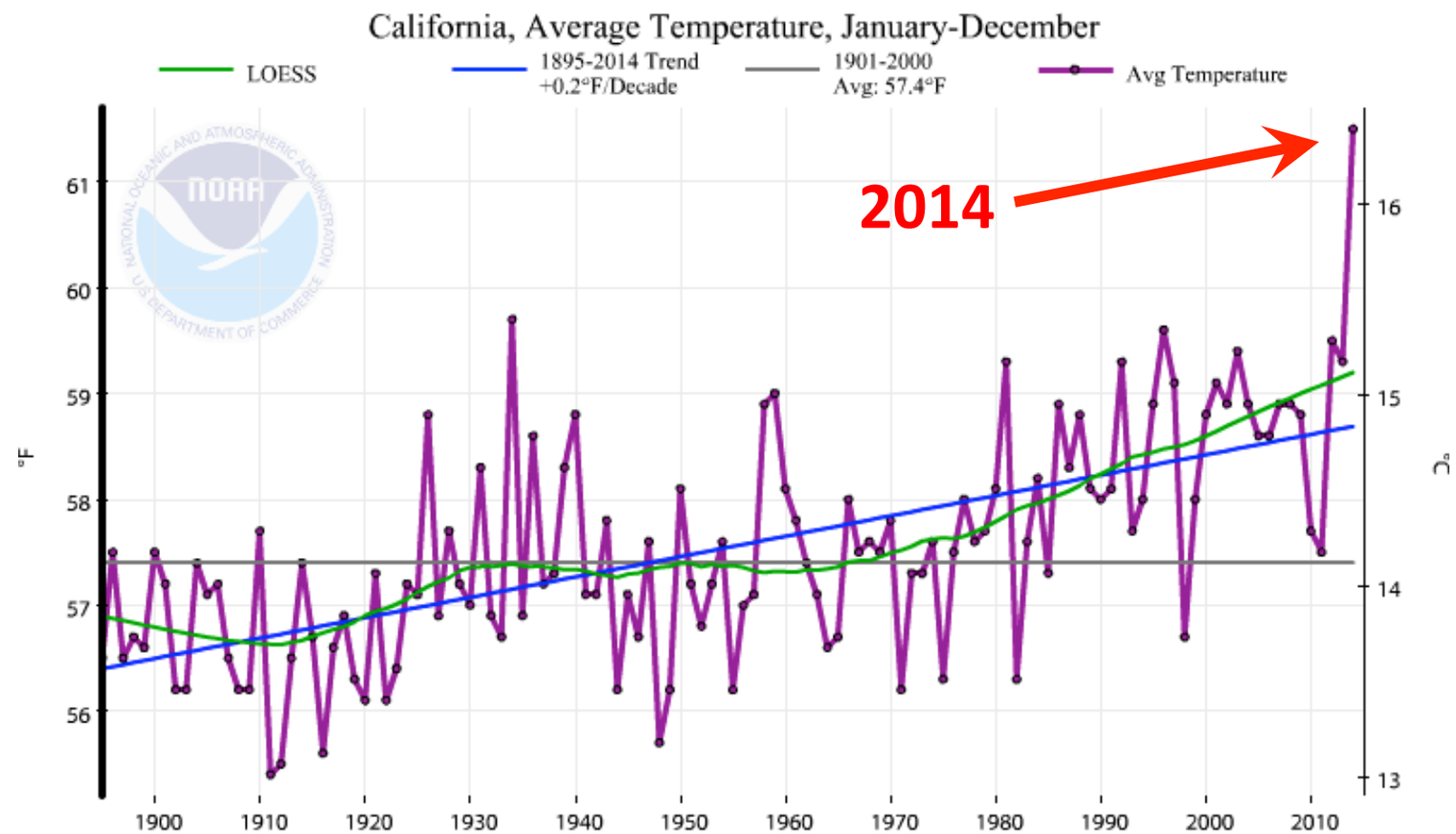


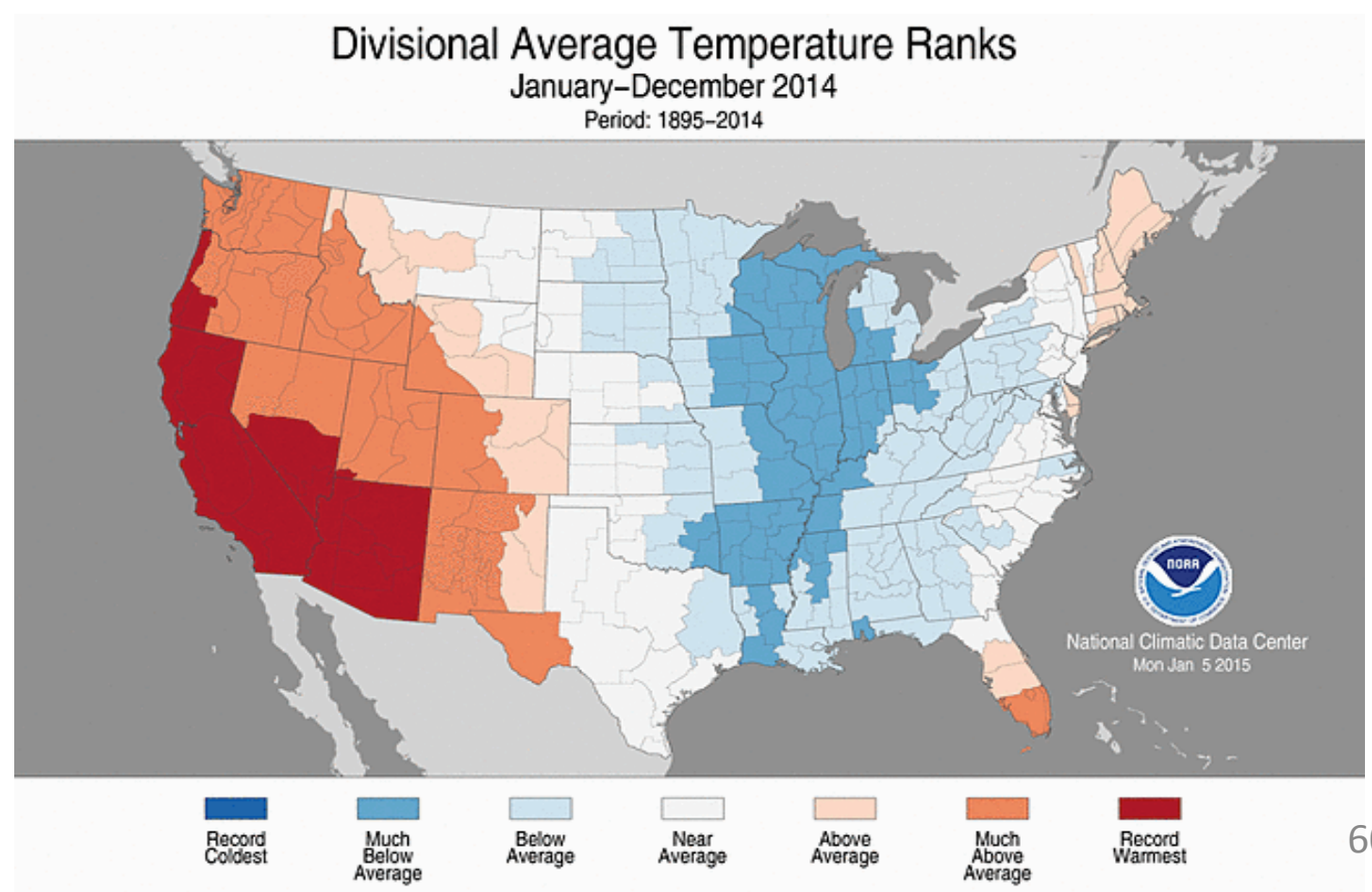
It's early to describe this spring's upwelling, but the winter ocean was much warmer.

It wasn't just the ocean that was warm.

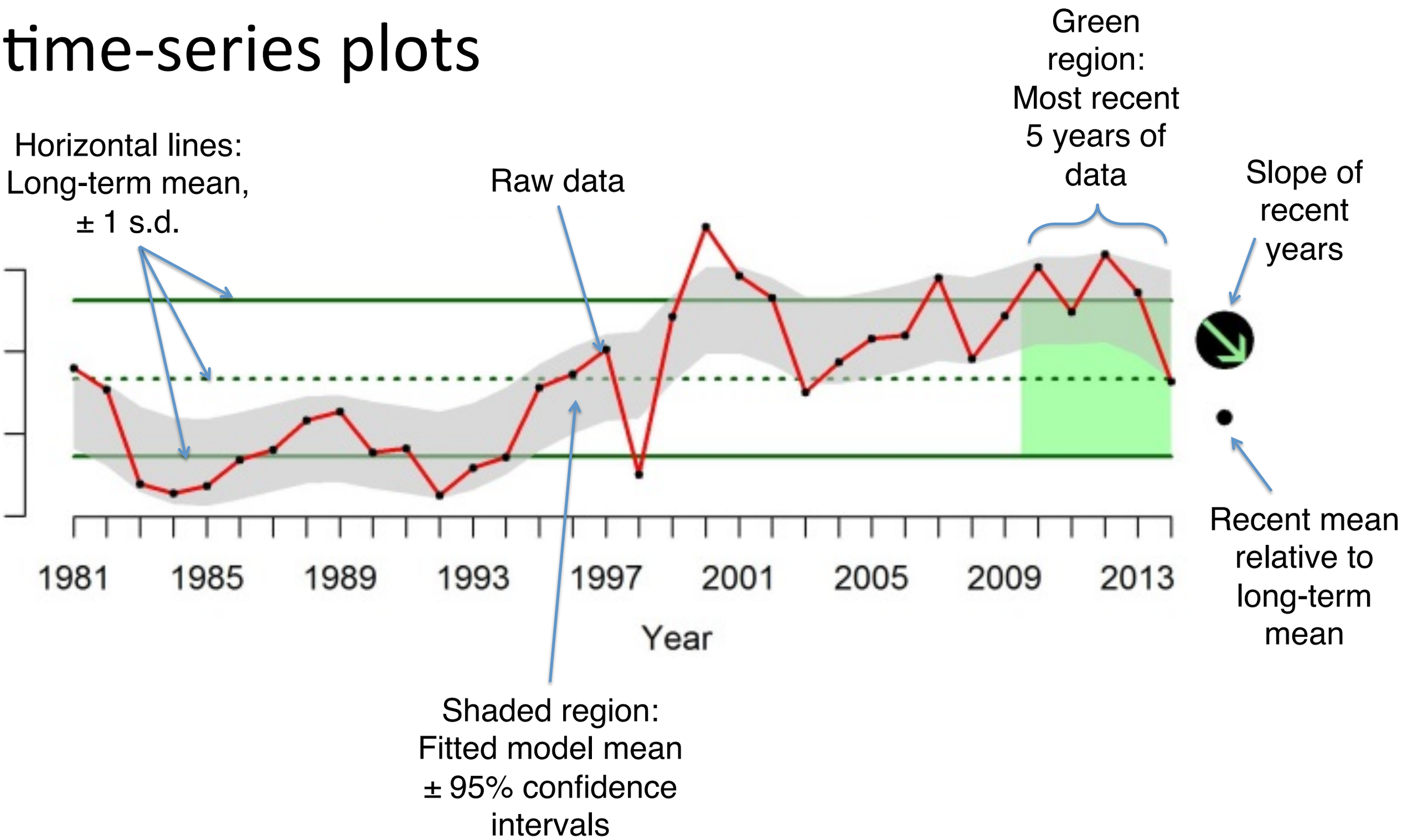
In California, 2014 weather was not only dry, but it was also extraordinarily hot

- Surface air temperature record was almost off the charts, ~ 1 °C warmer than the previous record
- Extraordinary warmth was confined to the southwest, centered in California





Interpreting upcoming time-series plots

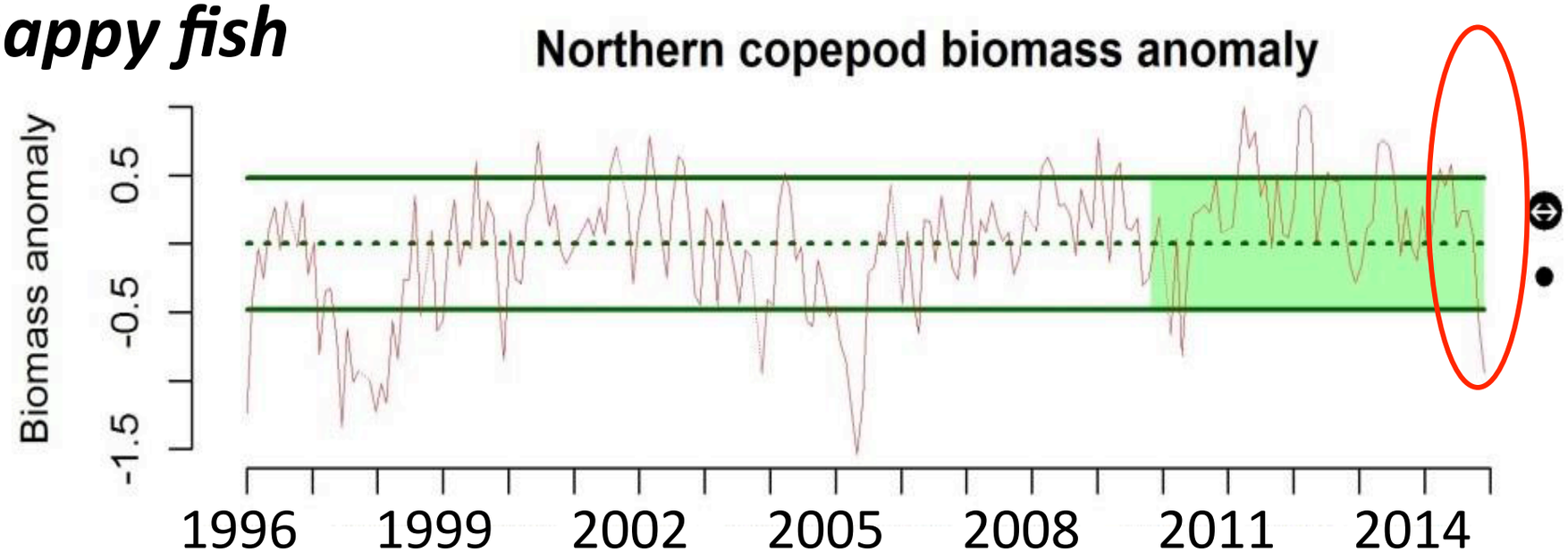


There are northern and southern copepod assemblages:

≈

northern copepod = happy fish

- **"Northern" copepods are rich in lipids that support fish production**
- **Northern copepods associated with cooler waters in the California Current**
- **In recent years off Newport, OR: northern copepods have been abundant**
- **But, a major shift occurred in late 2014**



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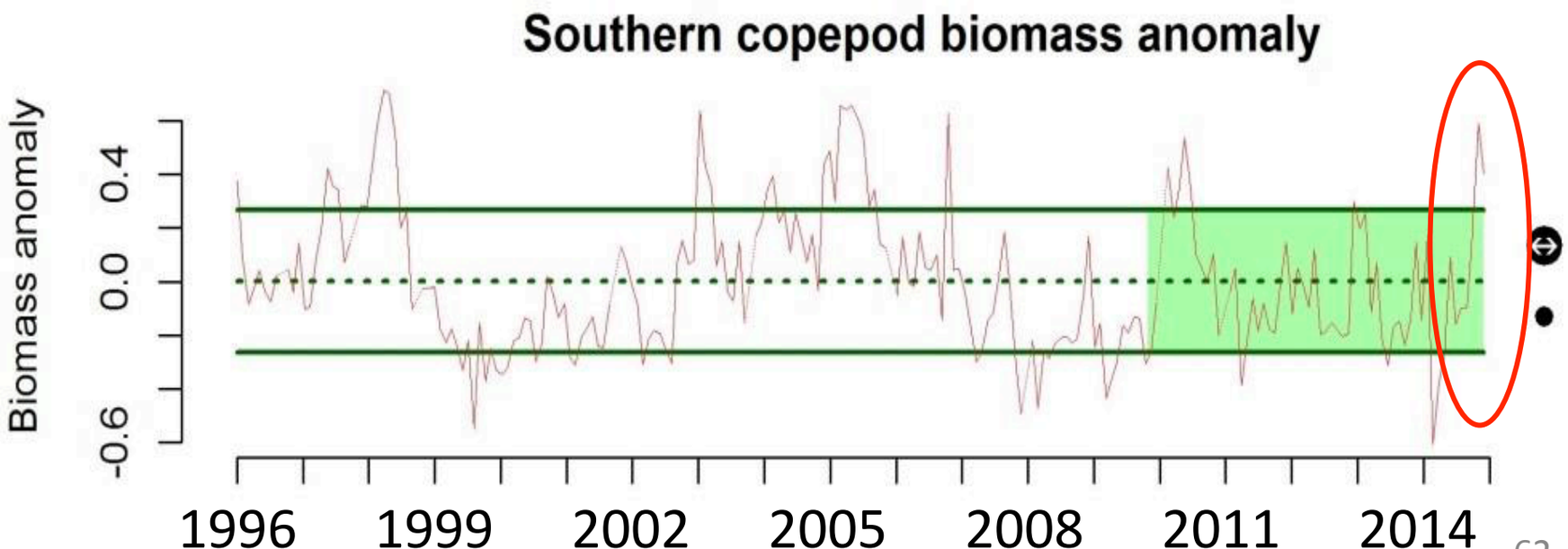
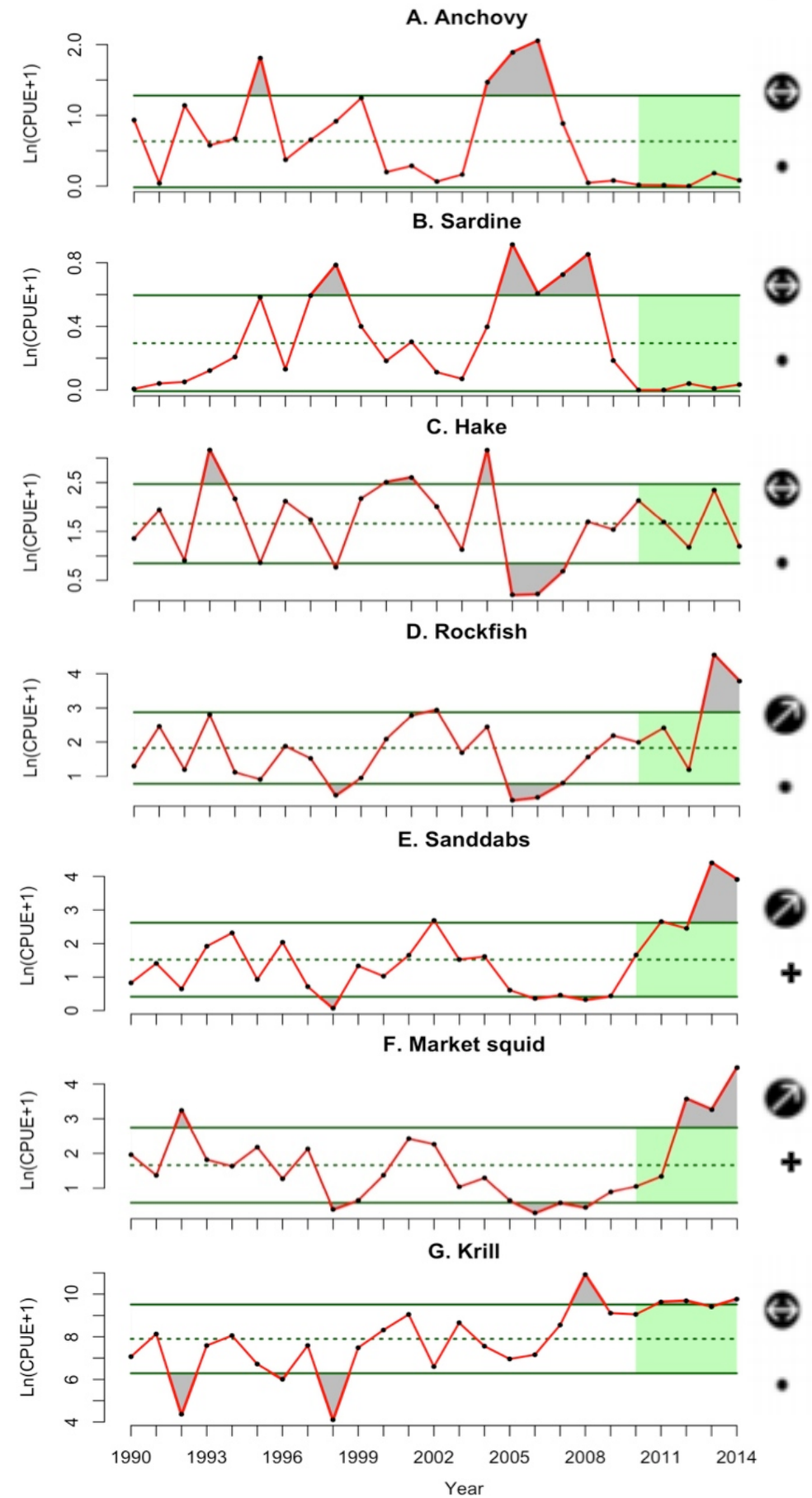


Ecosystem Indicators: Forage Availability

- Assessment of forage available for predators (larger fish, birds, mammals)
- Largely juveniles or young of year (YOY) of finfish groups
- Central California Current, through 2014:
  - Anchovy and sardine catches were relatively low
  - Relatively high catches of YOY rockfish, YOY sanddabs, market squid and adult krill

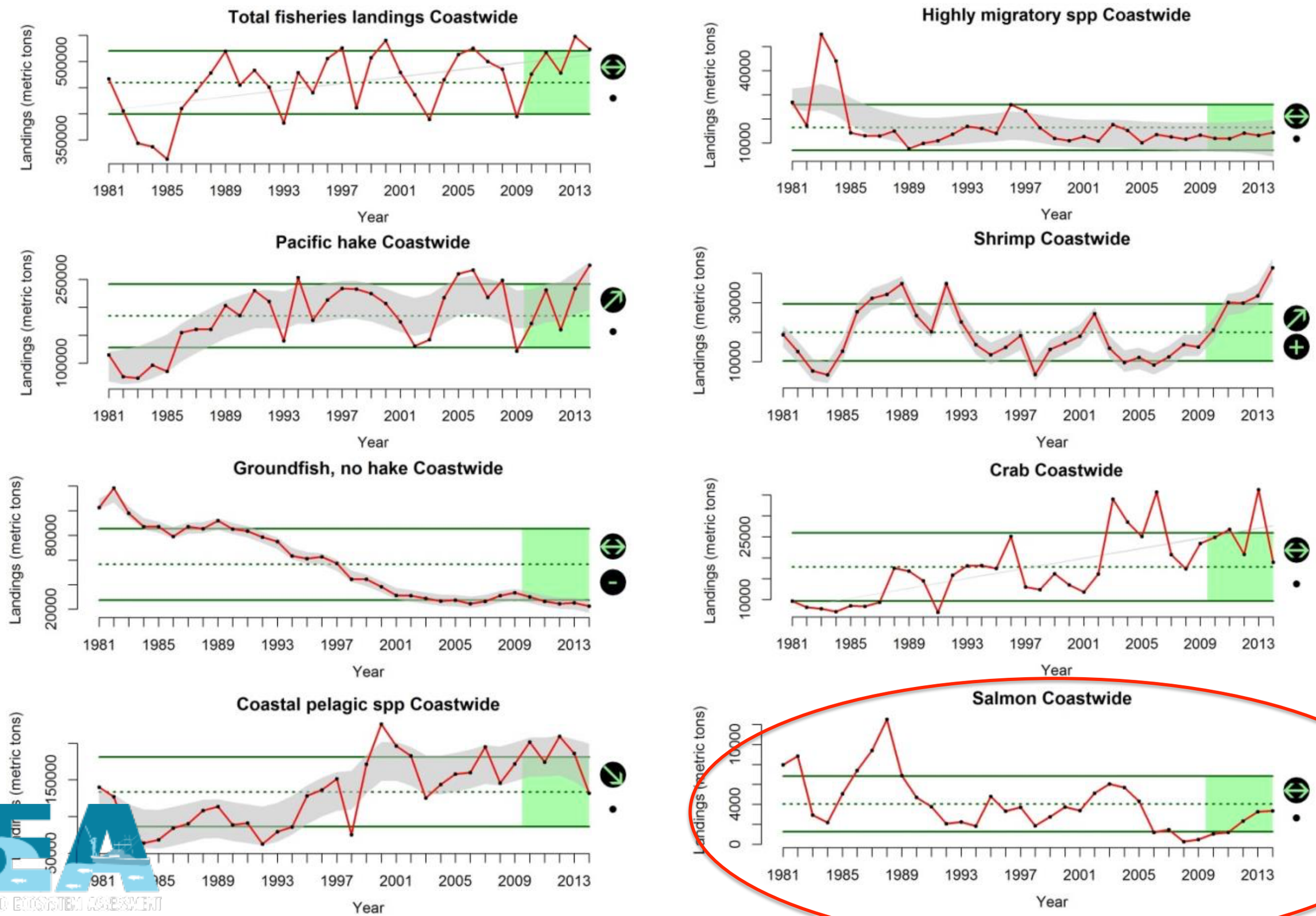
How will these forage groups respond to the warm conditions? We will have to wait and see what the 2015 data tell us.

Central California Current Region



Coastwide U.S. commercial fishery landings

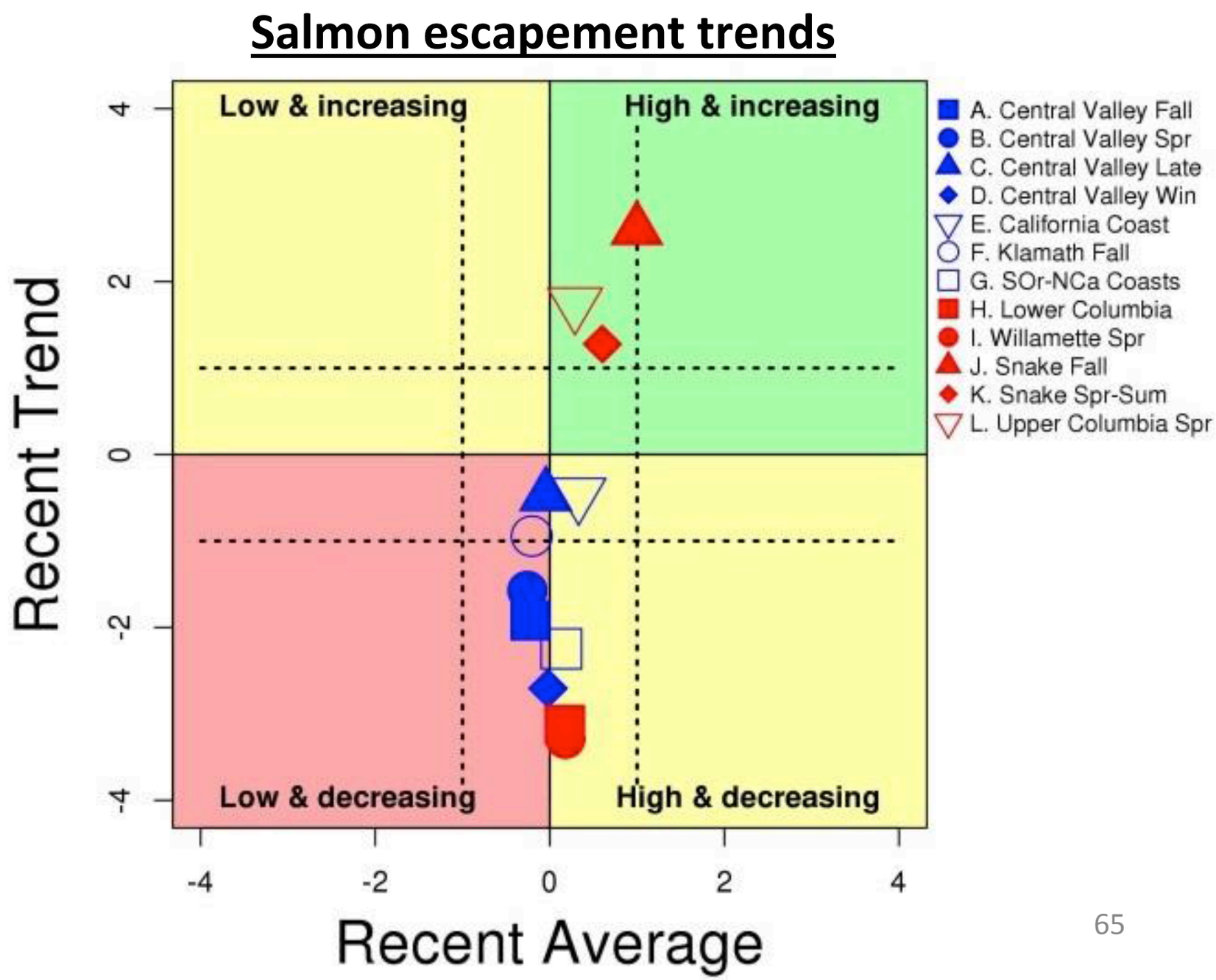
- Total landings just updated; 1981 to 2014



Chinook salmon escapement status and trends

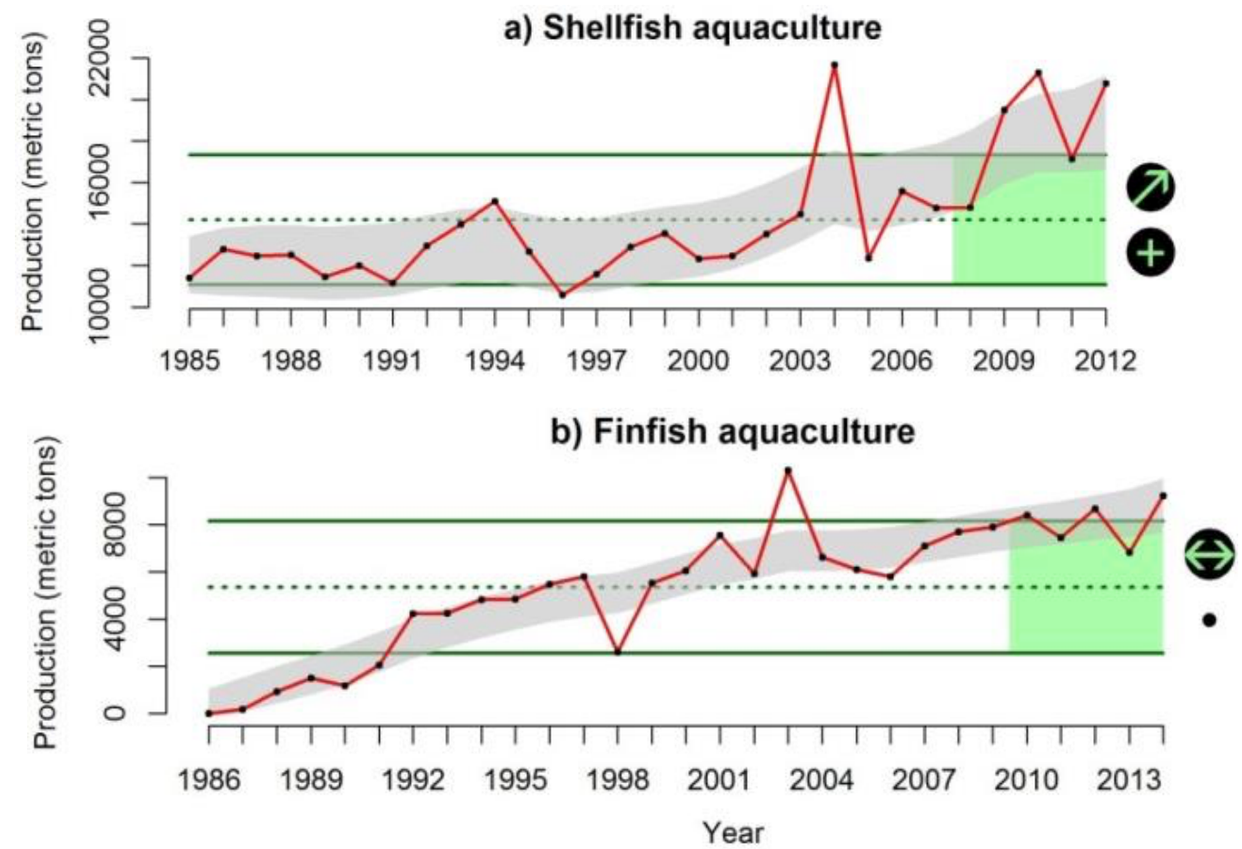
- *Data for river returns for spawning are available only through 2012*
- From 2003-2012, stocks were within "long-term" (20 to 30-yr) averages
- Several stocks have declining trends; returning to average levels following high escapements in early 2000s
- Some stocks with increasing trends

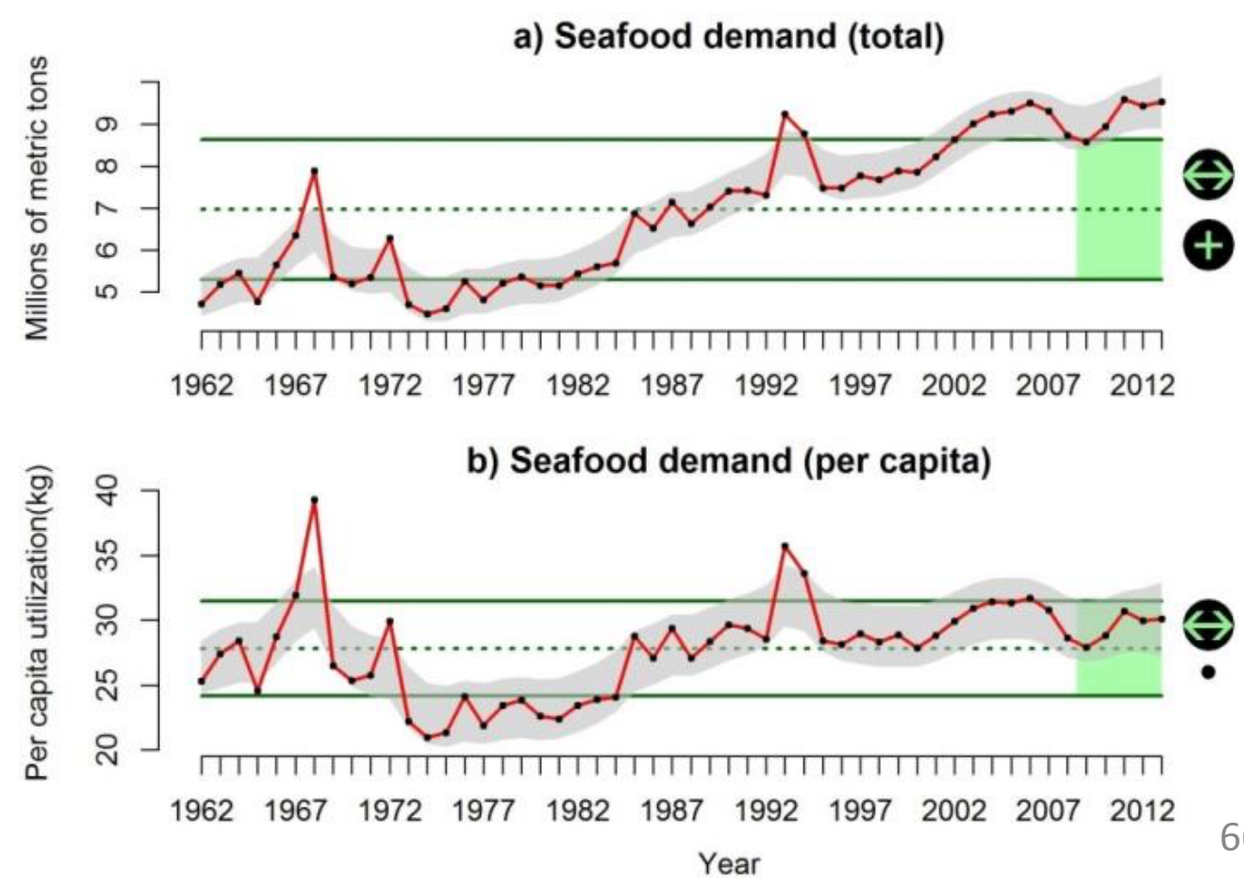
How will salmon stocks be affected by low, warm stream flows and changes in nearshore marine conditions?



Other human activities

- **Sectors related to fisheries:**
  - West Coast shellfish aquaculture (through 2012)
  - West Coast finfish aquaculture (through 2014)
  - U.S. total seafood demand (through 2013)
- **Per capita U.S. seafood demand remains flat**
- **IEA is monitoring other human activities as well**
  - Shipping
  - Energy extraction
  - Coastal development
  - Pollution

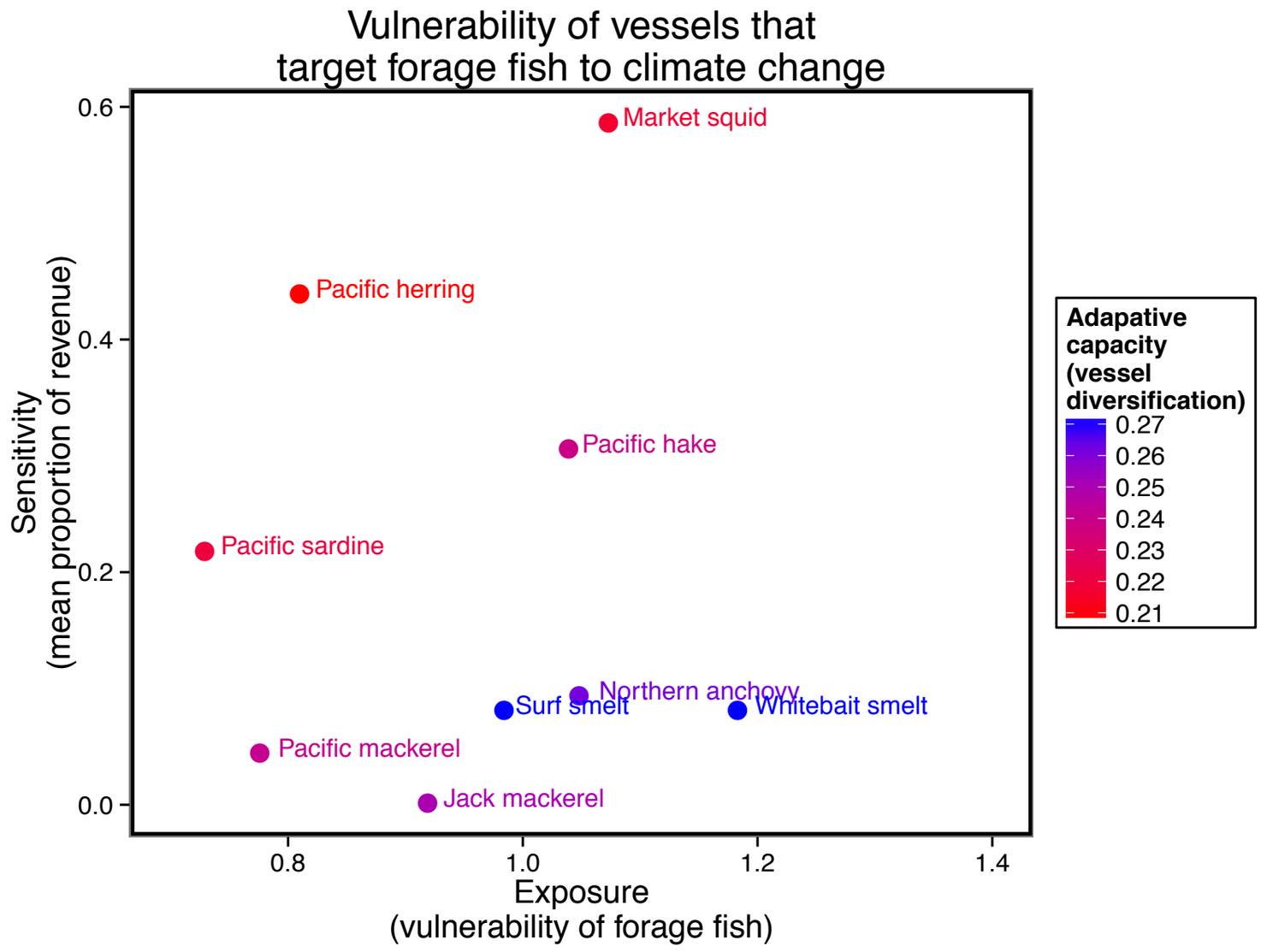




Vulnerability of *people* to climate change

Is a vulnerable fish a vulnerable fishery?

Increased vulnerability of marine resources to expected climatic change, and reduced resilience in human communities → increased vulnerability



Samhouri et al. in review

Draft Climate Science Objectives

Climate-Informed Reference Points

Robust Management Strategies

Adaptive Management Processes

Robust Projections of Future Conditions

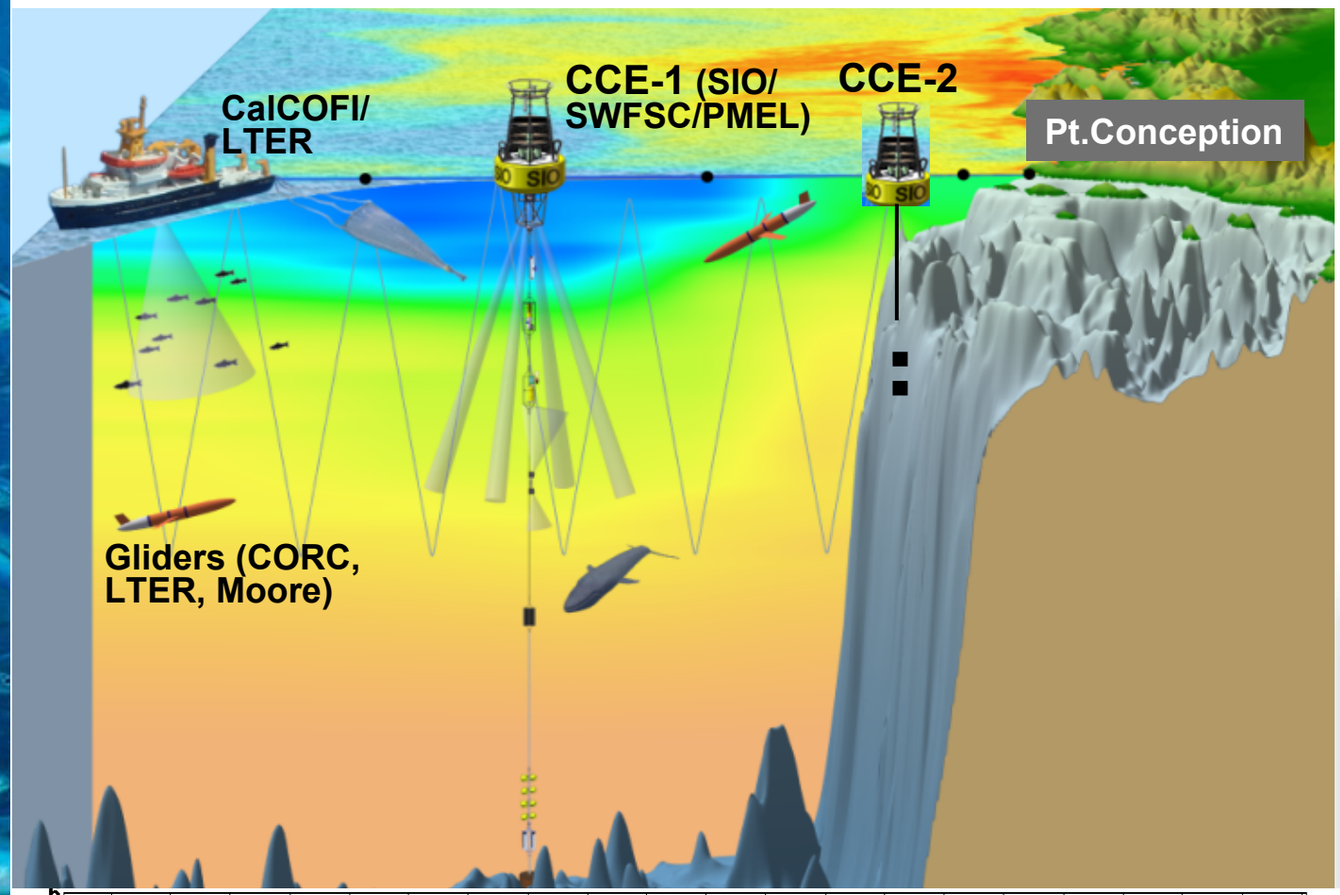
Information on Mechanisms of Change

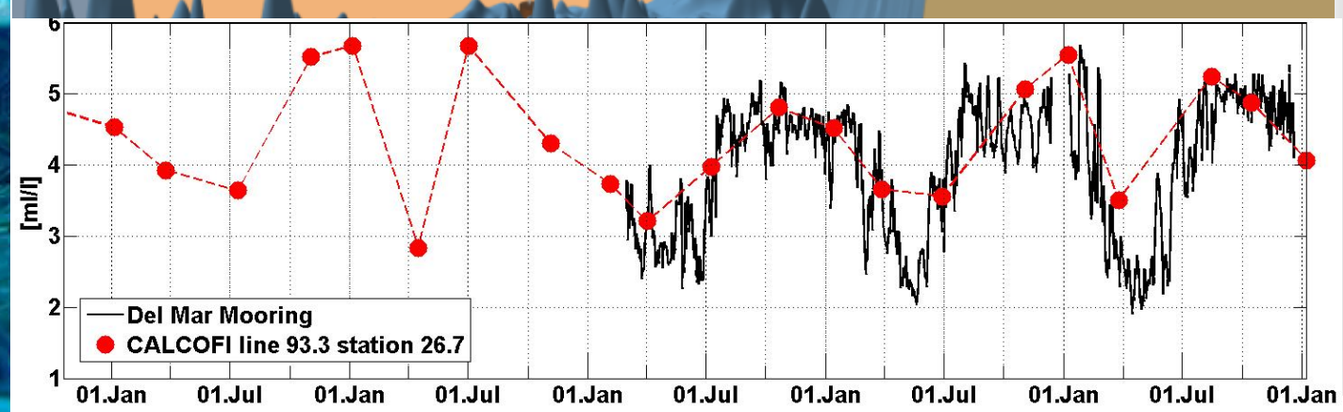
Status, Trends and Early Warnings

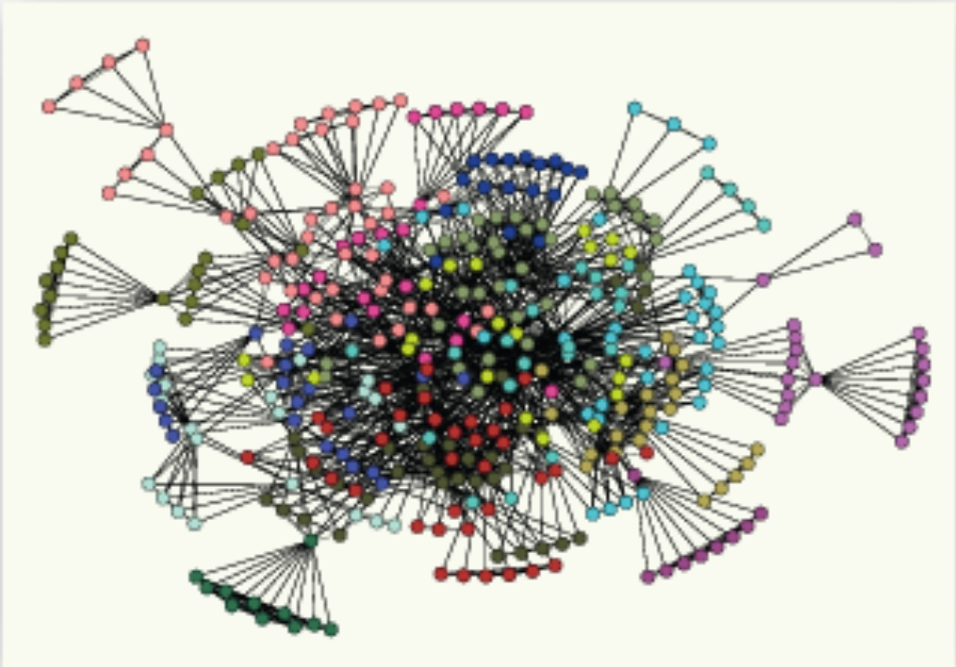
Science Infrastructure to Produce and Deliver Actionable Information

7

Objective 7. Build and maintain the **science infrastructure** needed to fulfill NOAA Fisheries mandates under changing climate conditions.







Final Remarks…
Expected Results from NCSS:

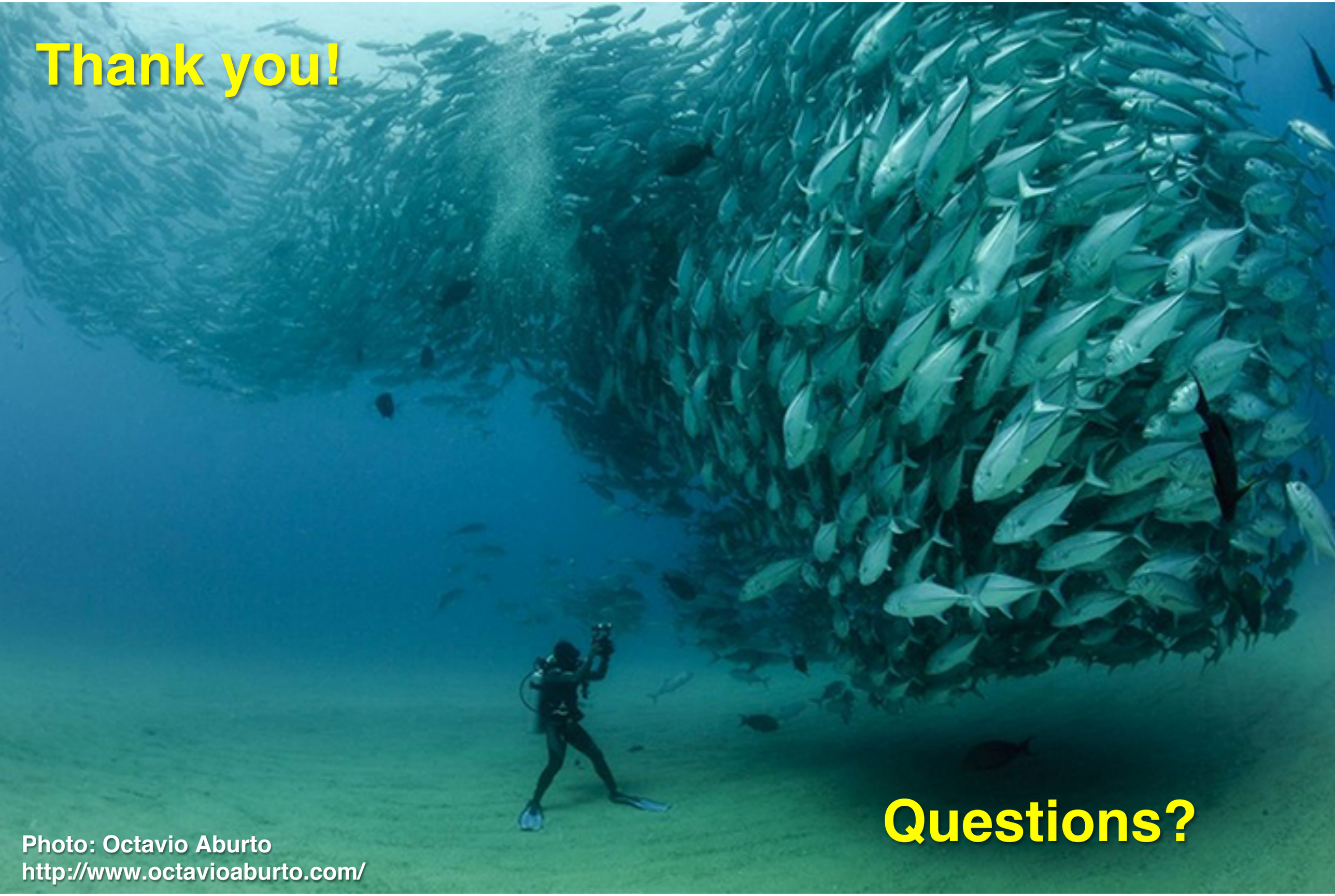
- ***Better tracking*** of ecosystem changes providing early warnings of climate-related changes.

- ***Increased understanding*** of the mechanisms of change and the vulnerability of fish stocks, communities.

- ***Near and long term forecasts*** of ocean & resource conditions.

- ***Climate sensitive*** stock assessments and biological reference points.

- ***Improved management scenarios.***



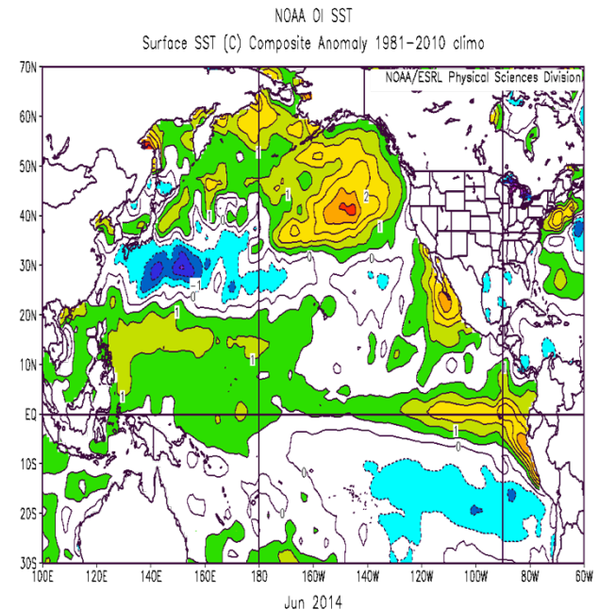
A large group of Bigeye trevallies (bigeye jack) at Cabo Pulmo National Park, Mexico. Thousands of fish forming a ball during the reproduction courtship.

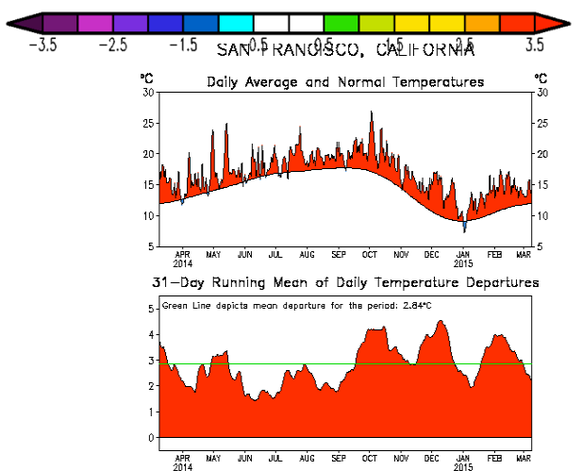
Extra Slides

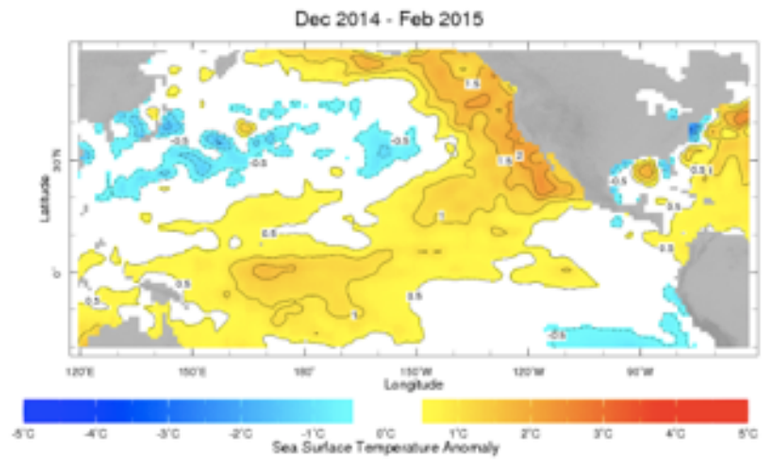
A very unusual year

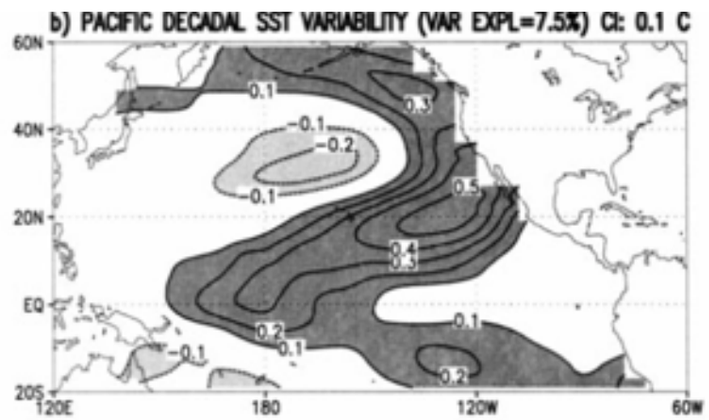
Mild El Niño

Historic "warm blob"

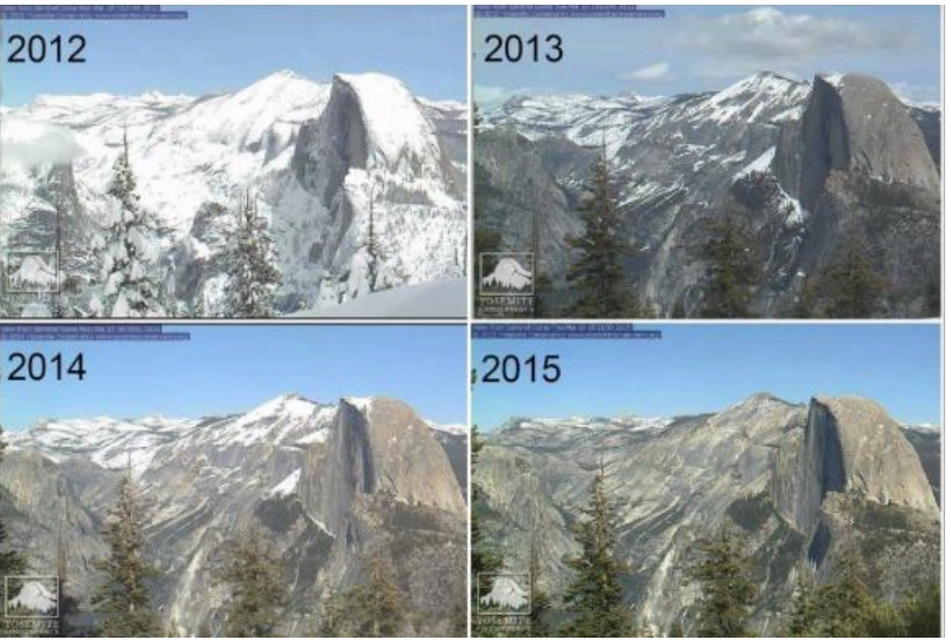


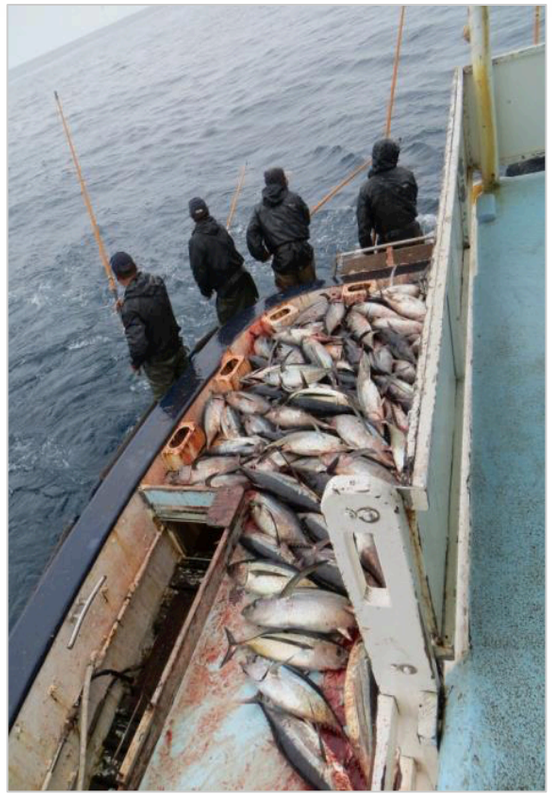






Historic warmth and low snowpack





Environmental Highlights

- The California Current is **a variable system** from year to year and decade to decade
- Recently, **the Northeast Pacific has been dominated by the "warm blob,"** record high sea surface temperatures that developed in the Gulf of Alaska in 2013 and spread to the coast and southward.
- Basin-wide indices trended from ENSO-neutral to **mild El Niño**, and the two north Pacific indices both shifted from conditions promoting high primary productivity to **less productive conditions**.
- After a record strong year in 2013 of **coastal upwelling, conditions in 2014 returned to average** or slightly below average upwelling. Coupled with the basin scale indices, these suggest lower overall primary productivity.
- The west coast, especially California, experienced hot and dry conditions. The annual **snowpack is at historic lows**.

Ecological and Human Dimensions Highlights

- After several relatively productive years, **biomass of energy-rich northern copepod species declined sharply in the fall of 2014**.
- Larval fish and young of the year, along with small coastal pelagic species (anchovy, sardine, etc.) comprise the **forage base** and while many were stable or increasing in 2013-2014, it is **unknown how forage base will respond to recent oceanographic changes**.
- Low zooplankton and absent forage may be causing significant **mortality of Cassin's auklets and California sea lion pups**.
- California Central Valley and Lower Columbia River **Chinook salmon** have negative escapement trends, while trends elsewhere are stable or positive; **low snow pack could be a problem**.
- **Commercial fishery landings remain relatively high**, driven largely by Pacific hake and coastal pelagic species; crab and shrimp landings also increased.

1.c U.S. Fishery Status

Assessment of the Pacific Sardine Resource in 2015 for USA Management in 2015-16

NOAA FISHERIES
SWFSC-FRD

K.T. Hill, P.R. Crone,
E. Dorval, B.J. Macewicz
Fisheries Resources Division
SWFSC, La Jolla, CA 92037, USA

Presented to Pacific Fishery Management Council, April 12, 2015

Objectives of the NCSS

1. Identify appropriate, **climate-informed reference points** for managing LMRs.
2. Identify **robust strategies** for managing LMRs under changing climate conditions.
3. Design **adaptive decision** processes that can incorporate and respond to changing climate conditions.
4. Identify **future states** of marine, coastal, and freshwater ecosystems, LMRs, and LMR-dependent human communities in a changing climate.
5. Identify the **mechanisms** of climate effects on ecosystems, LMRs, and LMR dependent human communities.
6. Track **trends** in ecosystems, LMRs, and LMR-dependent human communities and provide early warning of change.
7. Build and maintain the **science infrastructure** needed to fulfill NOAA Fisheries mandates under changing climate conditions.

Our Changing Oceans

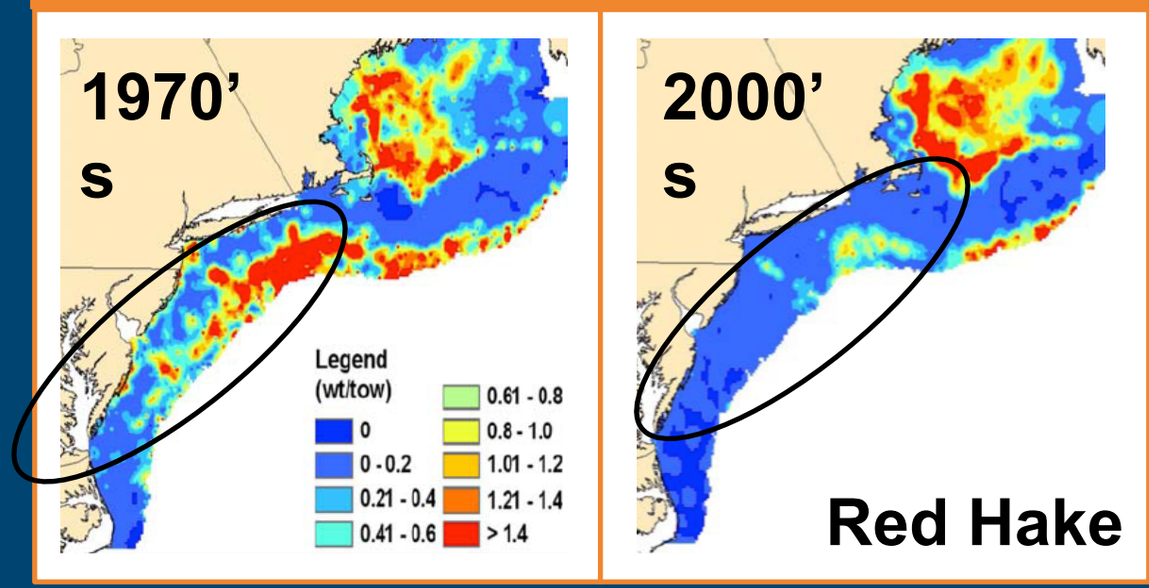
- Climate change, acidification, stratification, deoxygenation… are altering ocean ecosystems.
- Fisheries impacted globally with regional differences:
  - Biogeographic (poleward) shifts
  - Changes in species composition
- Significant challenges expected for fisheries management.

Draft Climate Science Strategy

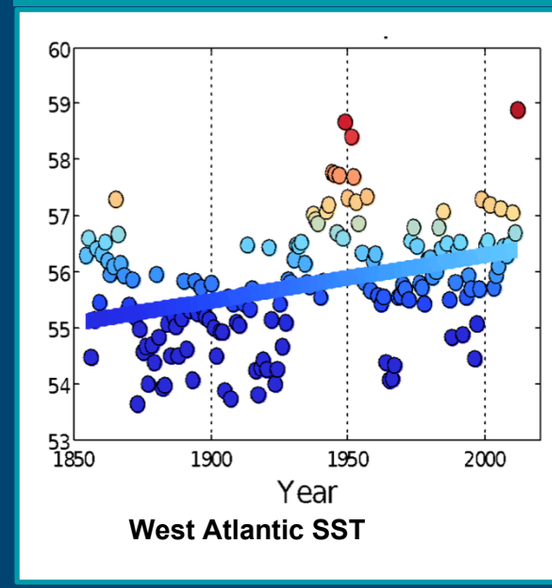
What are the important information requirements?

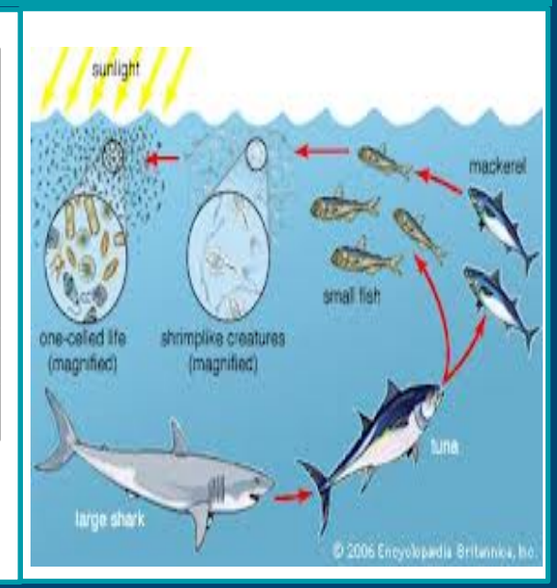
Key Information Requirements

WHAT IS CHANGING?

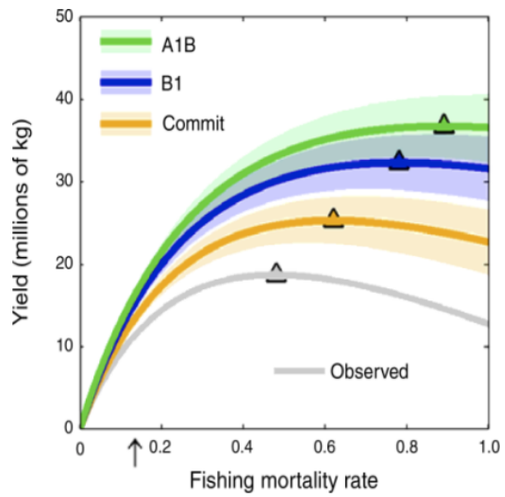


WHY IS IT CHANGING?



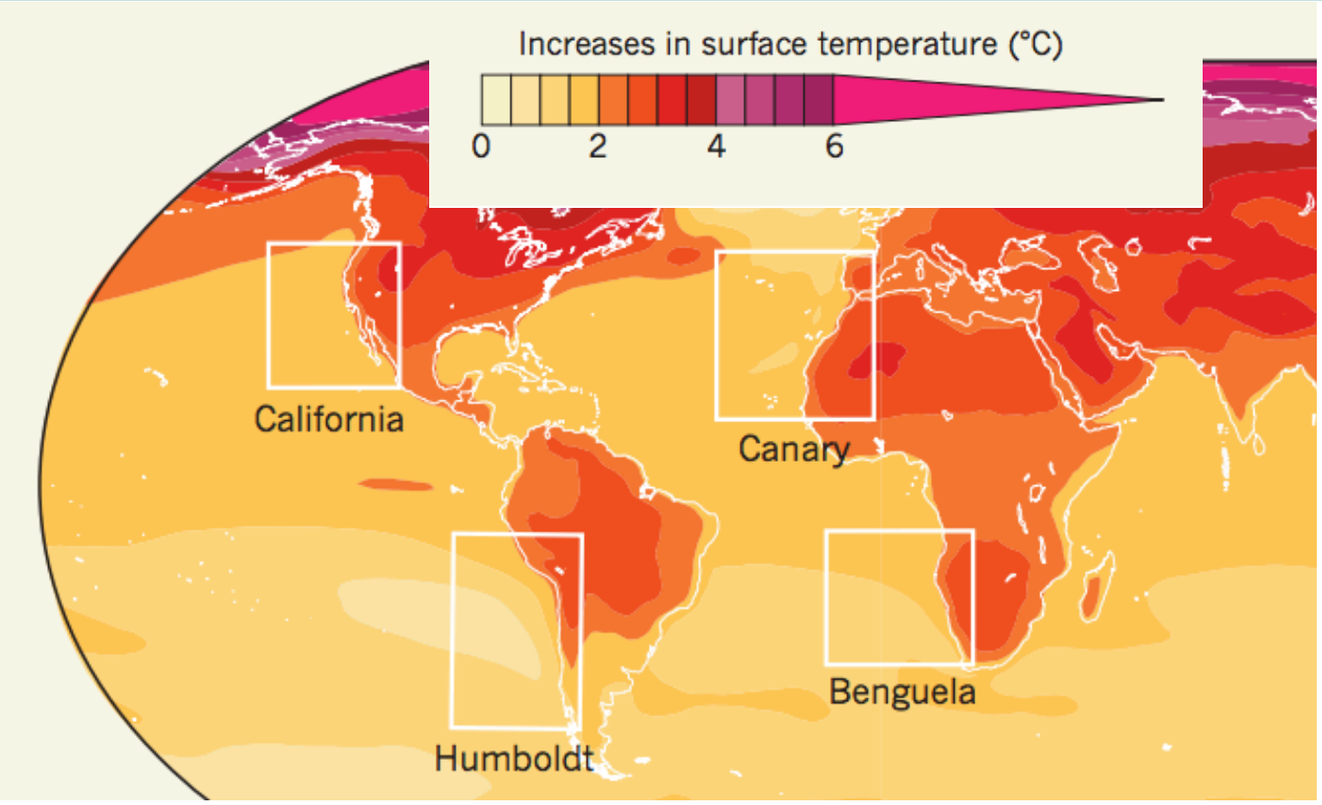


HOW WILL IT CHANGE?

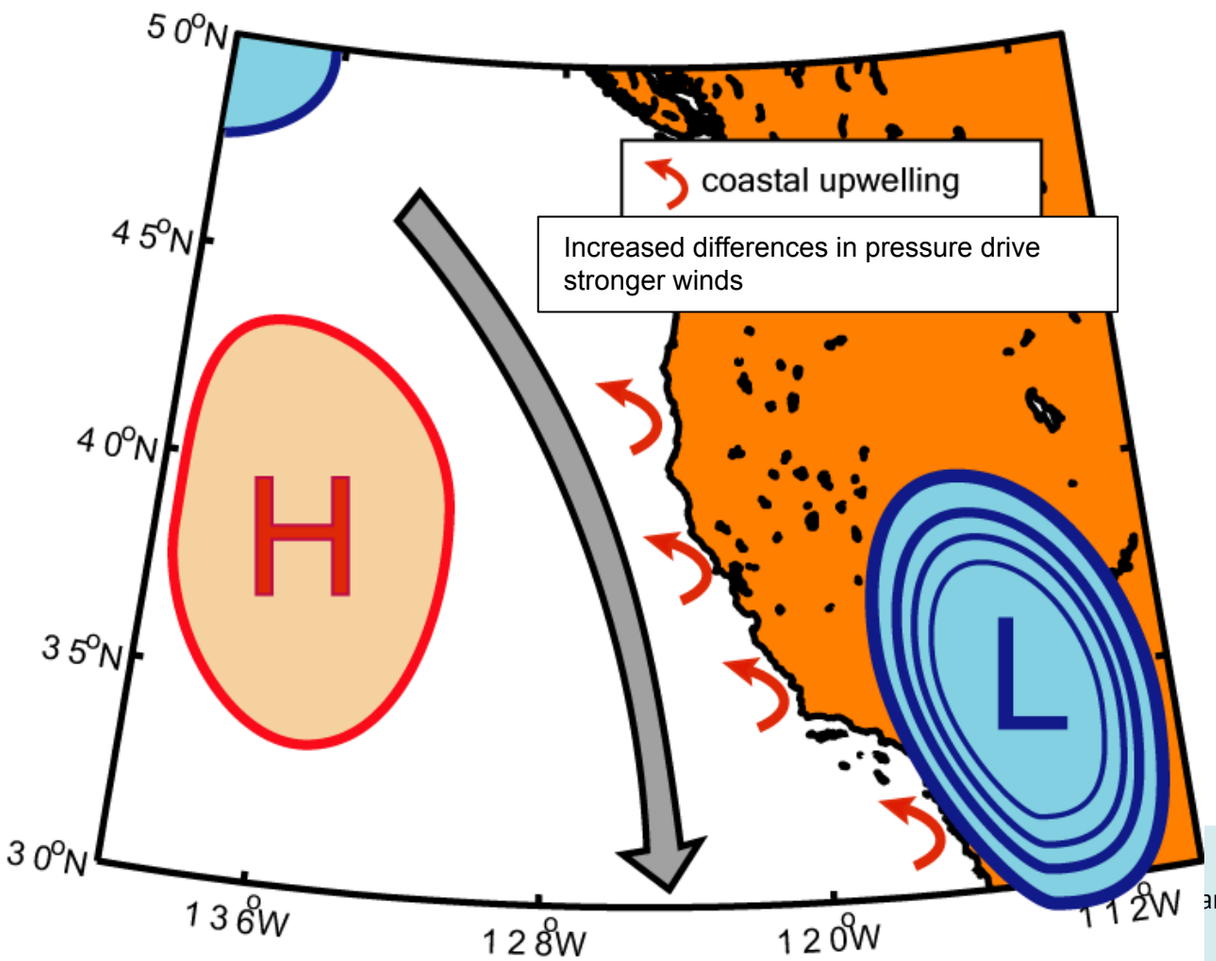


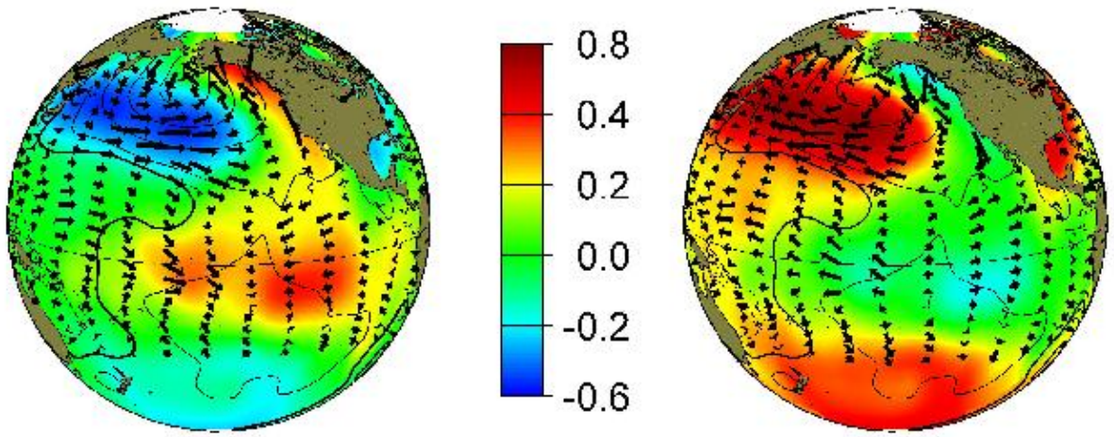
HOW TO RESPOND?

CALIFORNIA CURRENT AND CHANGES IN UPWELLING



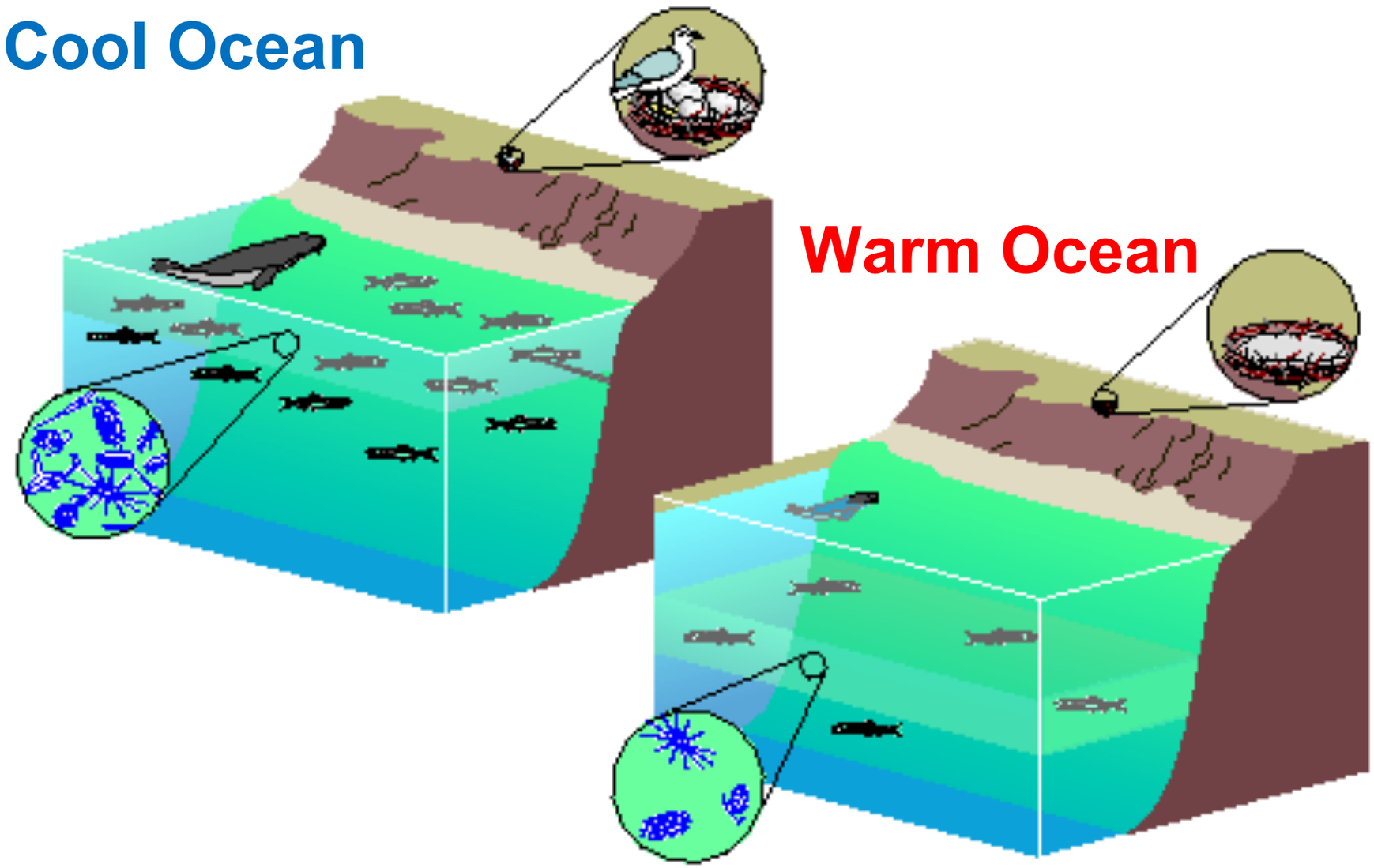
- Warmer continents than oceans
- Increased atmospheric pressure gradient (land – sea)
- Intensified alongshore winds during upwelling seasons
- AND potentially larger amplitude interannual to decadal variability (El Niño, PDO, NPGO, etc.)





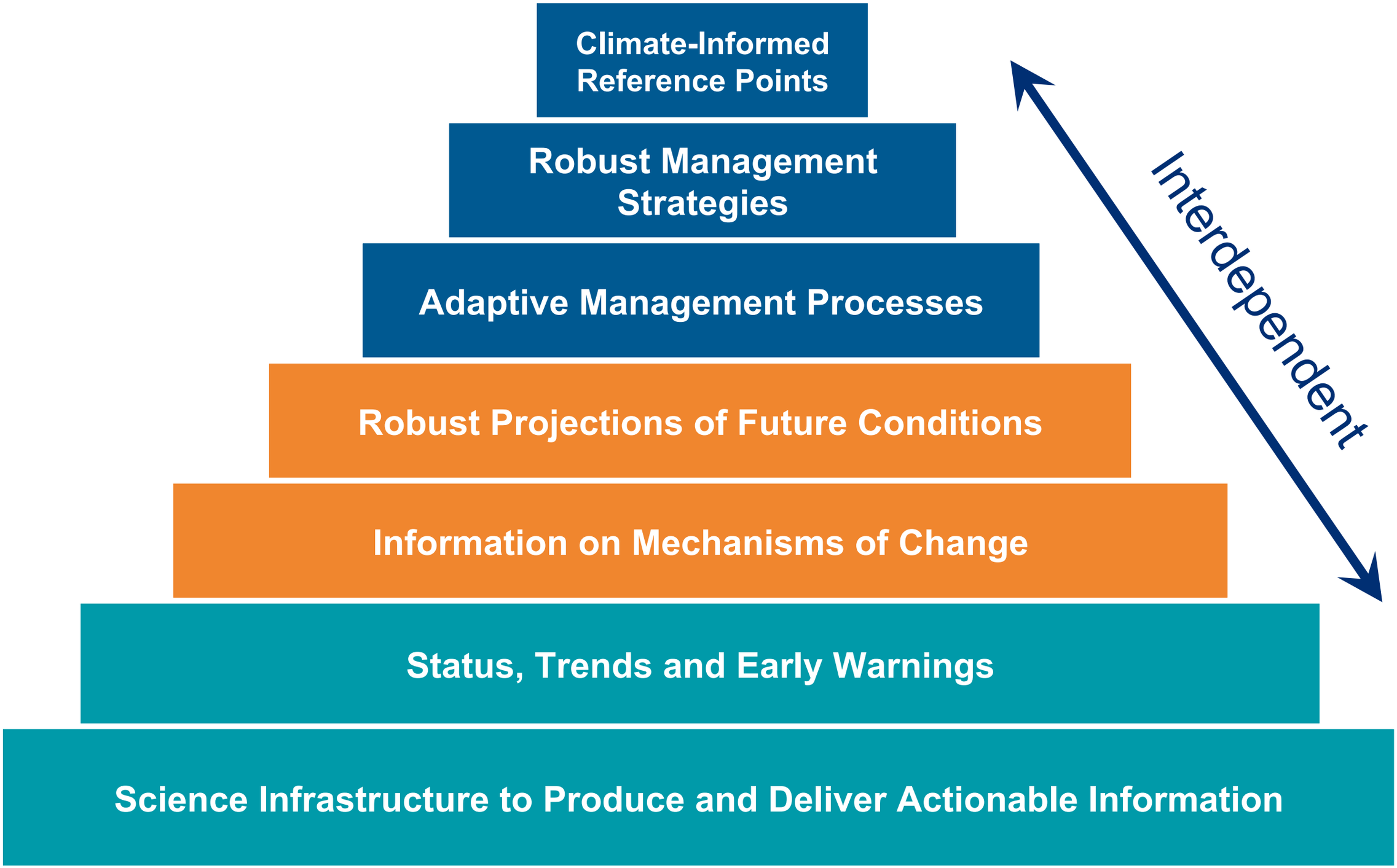
CALIFORNIA CURRENT FOOD WEB

Cool upper ocean: decreased stratification, increased nutrients, high phytoplankton production, and large lipid-rich “subarctic” copepods and krill-like zooplankton support higher trophic levels



Warm upper ocean: increased stratification, low nutrients, decreased primary and secondary production and stressed higher trophic levels

Draft Climate Science Objectives



Recommendations—Immediate Actions

1	progress	Conduct LMR climate vulnerability analyses in each region.
2	progress	Maintain and develop Ecosystem Status Reports to track change and provide early-warnings.
3	progress	Increase capacity to conduct climate-informed Management Strategy Evaluations

Recommendations—Short-term Actions (6-24 months)

1	Complete region-level action plans.
2	Strengthen climate-related science capacity nation-wide.
3	Increase resources for process-oriented research.
4	Establish climate-ready terms of reference for ESA, MSFCMA, MMPA stock assessments and Biological Opinions, etc.

Working Toward a Predictive Habitat Model for Albacore

Can we identify environmental influences on albacore distribution over long time scales and large spatial scales and develop a predictive model?

Case Study: Using the U.S./Canada surface fishery catch and effort data to begin to characterize habitat

Principal Investigators: **Yi Xu, Karen Nieto**, Steve Teo, Sam McClatchie, John Holmes

Roles and Responsibilities

MSE is at the interface between science and decision-making

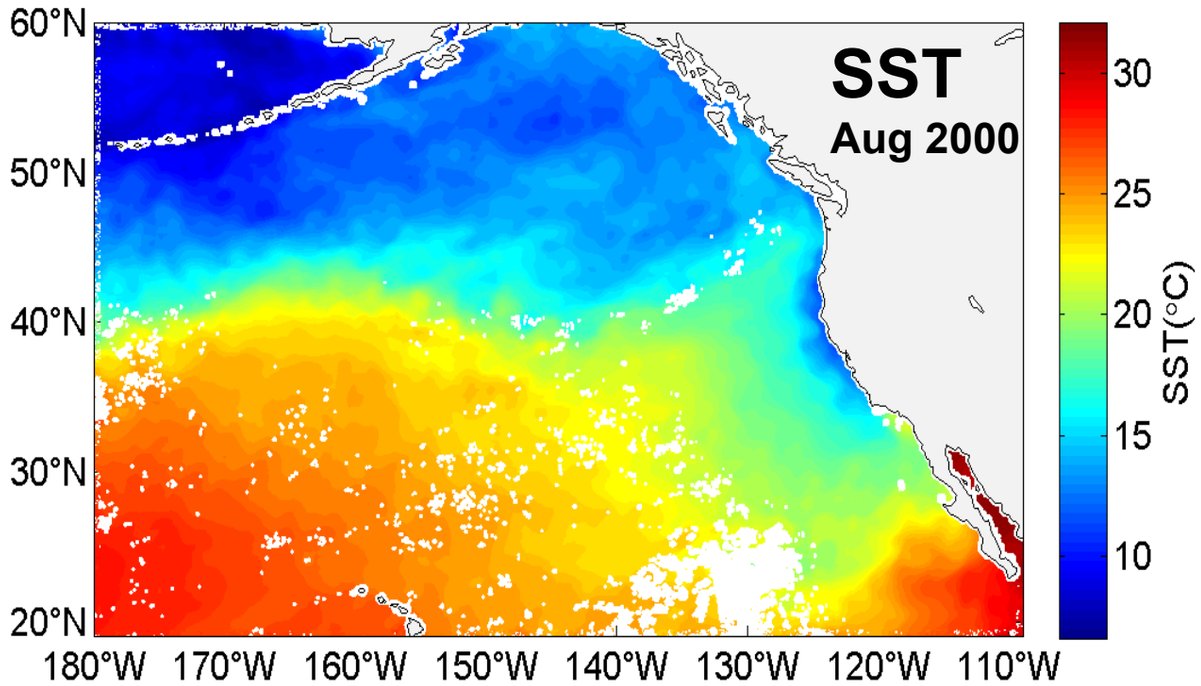
Scientists:

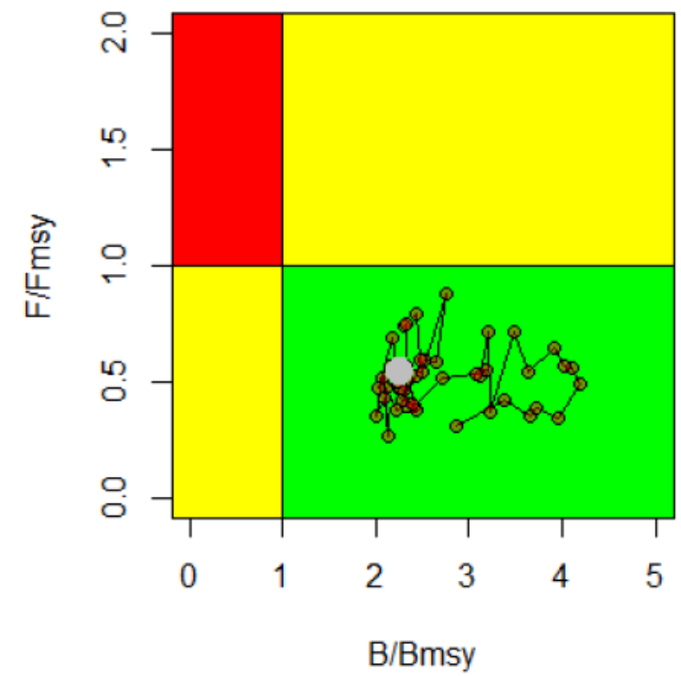
- Identify the hypotheses to represent in the operating model.
- Represent the objectives of the decision makers quantitatively.
- Identify factors which could be used in management strategies.

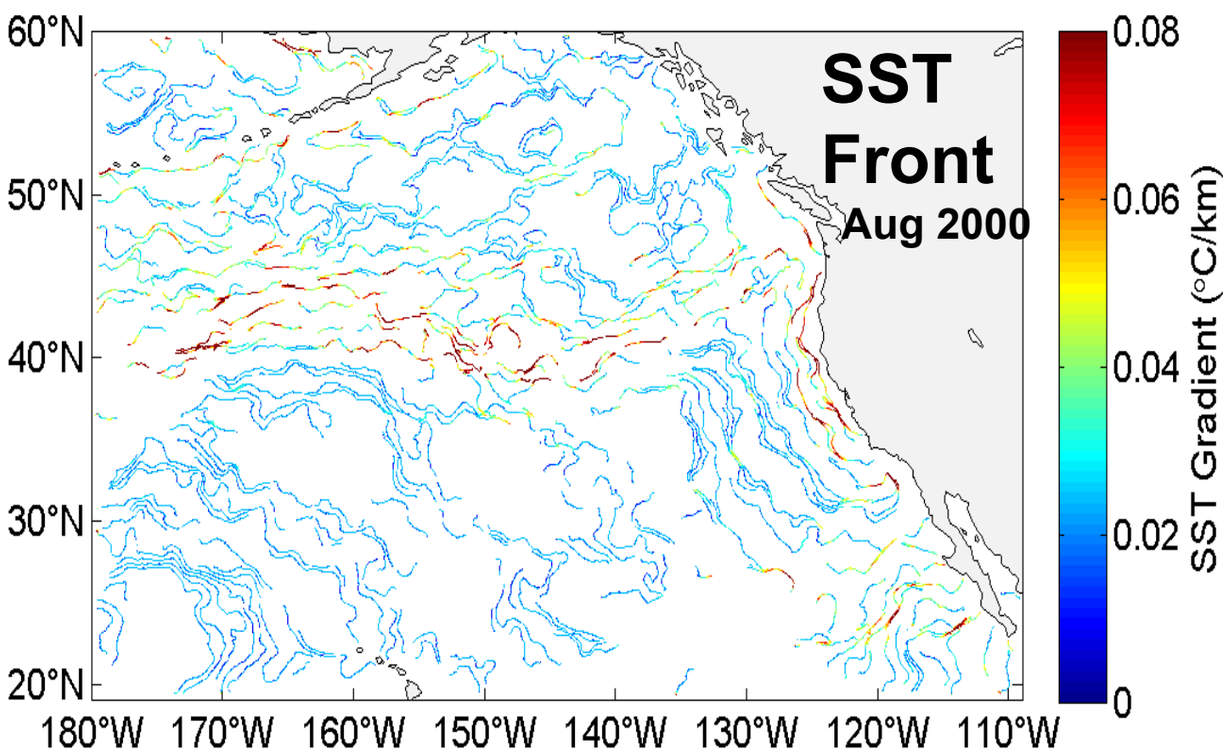
Stakeholders / decision makers / advocates:

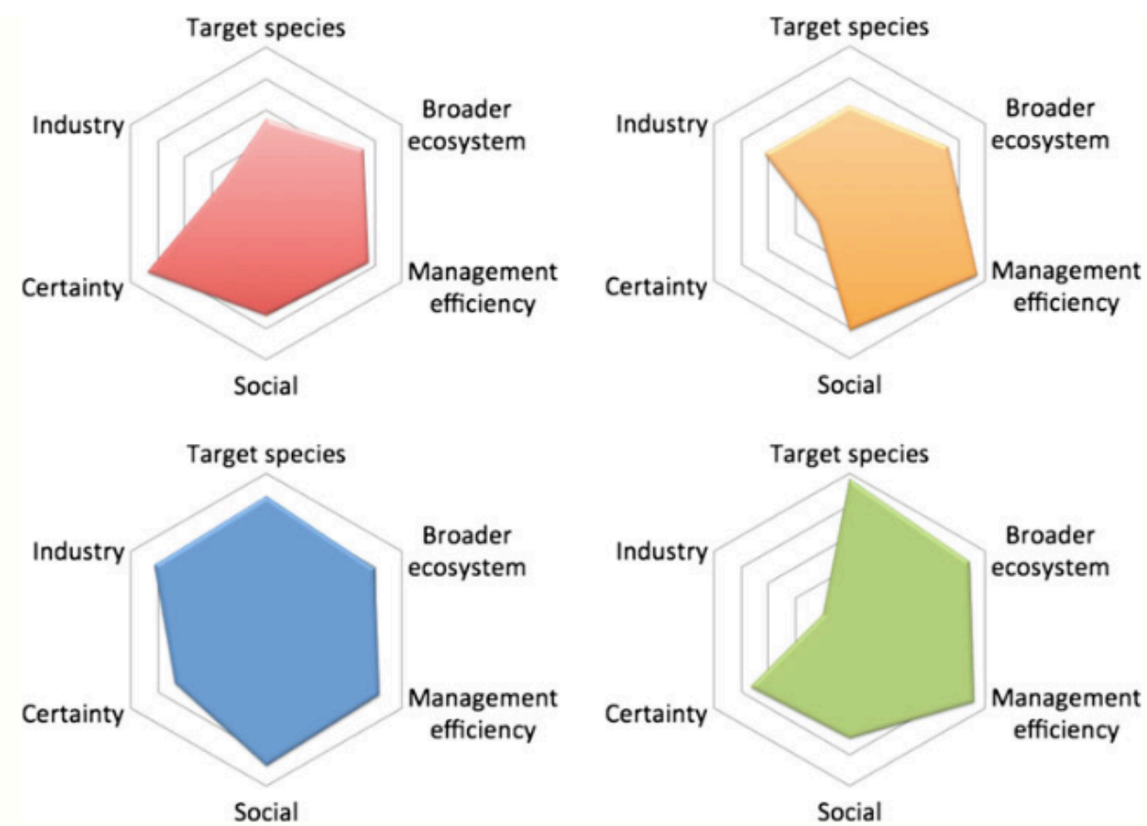
- Identify management objectives (note this may be a function of legislation / court decisions, etc.)
- Identify candidate management strategies
- Make decisions on the final management strategy (policy call)

Actions over the next three years…



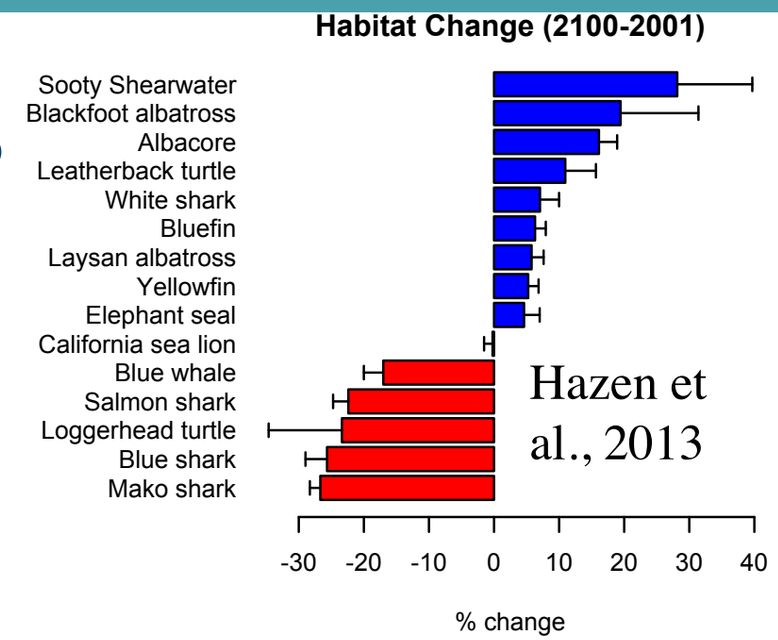






Changes in Marine Resources

Some species are predicted to gain and some predicted to lose habitat with future climate change



Warm events lead to "top-down" impacts on coastal food-webs from major changes in distribution of pelagic fishes and squid

CALIFORNIA CURRENT – KEY QUESTIONS

- What will happen to basin-scale circulation and regional-scale upwelling winds?
- How will increases in stratification interact with changes in winds to alter the upwelling of cooler, nutrient-rich, carbon-rich, and oxygen poor waters?
- What will happen to El Niño cycles in a warming climate?
  - Will they become more or less frequent, more or less intense?
- How will ocean acidification interact with physical changes in ocean properties to impact ecosystems?
- How will life history changes effect survival and distribution of species?

Implications for West Coast Communities

Fishery impacts will vary with sector

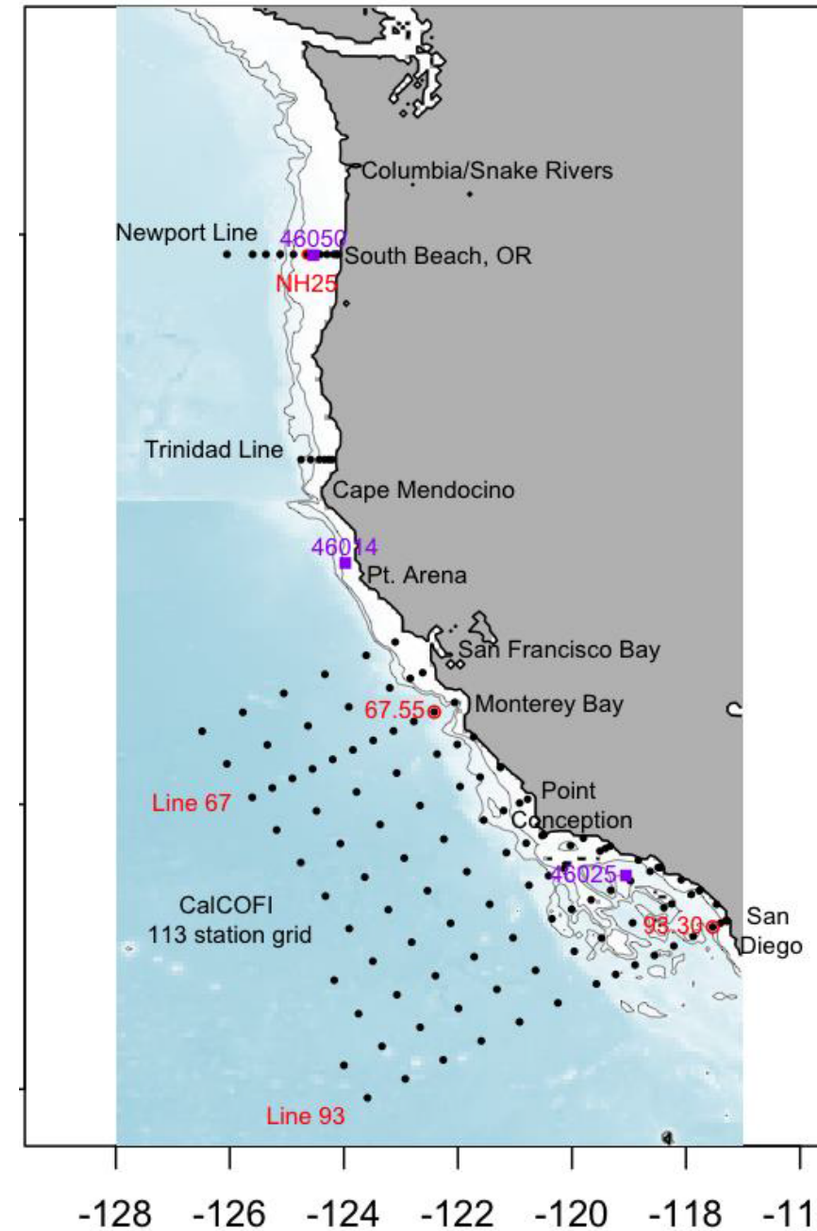
Interactions with climate change will be complicated

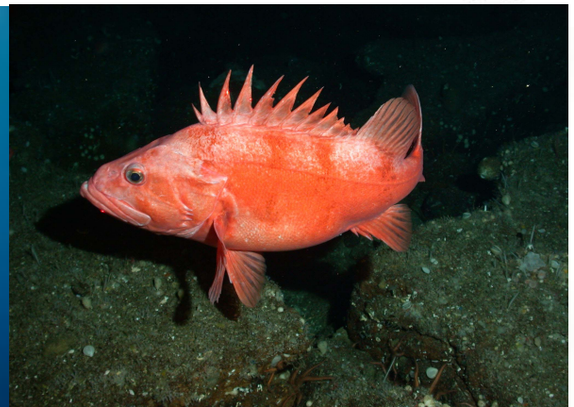
Research and Observations Suggest

- Range shifts in species, poleward and with depth
- OA and hypoxia effects on the base of the food web
- Warmer ocean/altered river hydrology – poor salmon survival
- Effects on long-lived groundfish difficult to predict

Importance of sustained observations

- CalCOFI, Newport and Trinidad Head lines





NOAA FISHERIES

Modeling the California Current and its Ecosystem:

End-2-End & Earth System Models (Physics-2-Fishers)

and some implementations in management

Cisco Werner
SWFSC/NOAA

Enrique Curchitser
Rutgers University

Curchitser Lab
F. Castruccio,
G. Hervieux

GFDL
C. Stock
J. Dunne

IEO-Spain/FAO
M. Bernal

LSU
K. Rose

NOAA-SWFSC
A. MacCall
S. McClatchie

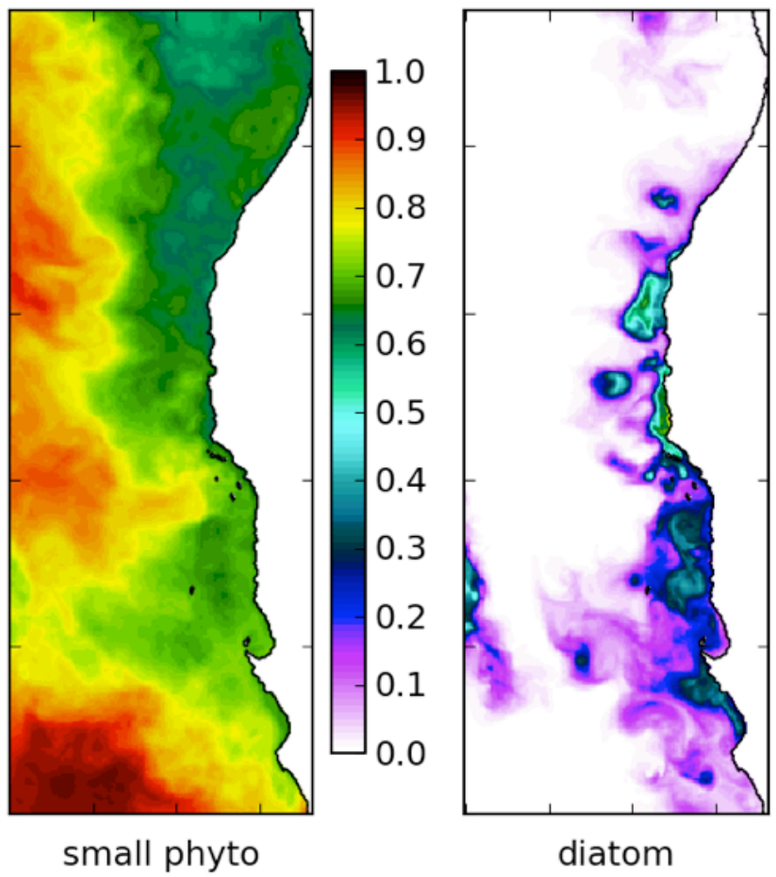
NOAA-AFSC
A. Haynie

SIO/UCSD
D. Checkley
T. Koslow

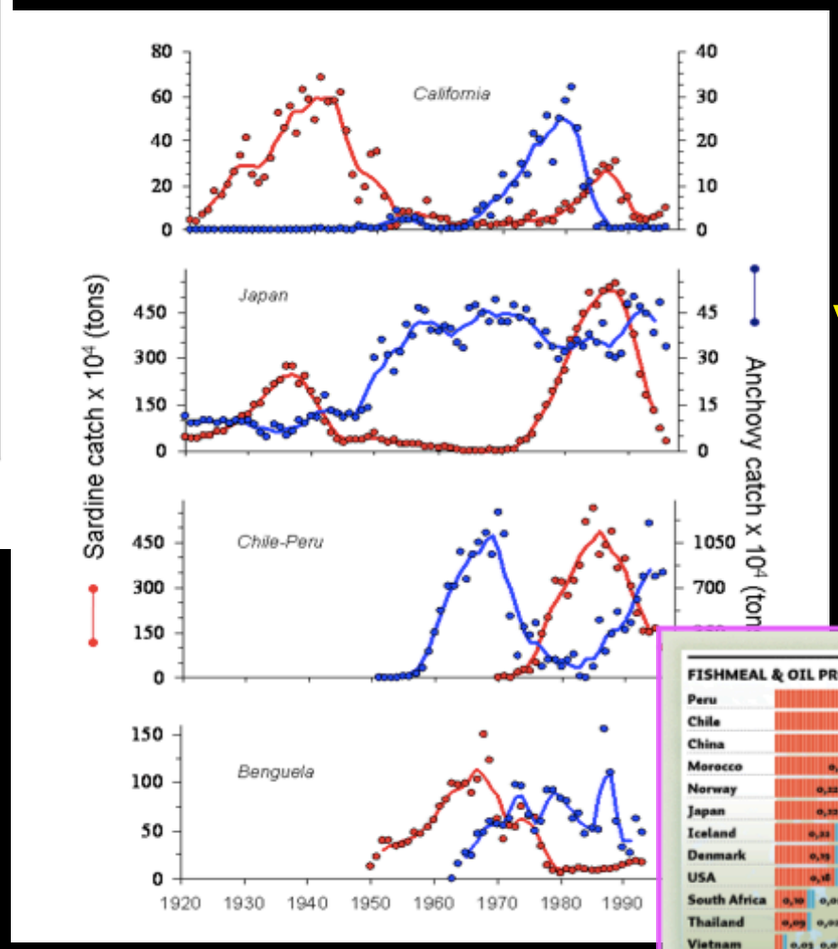
UAF
K. Hedstrom

UCSC
C. Edwards
J. Fiechter

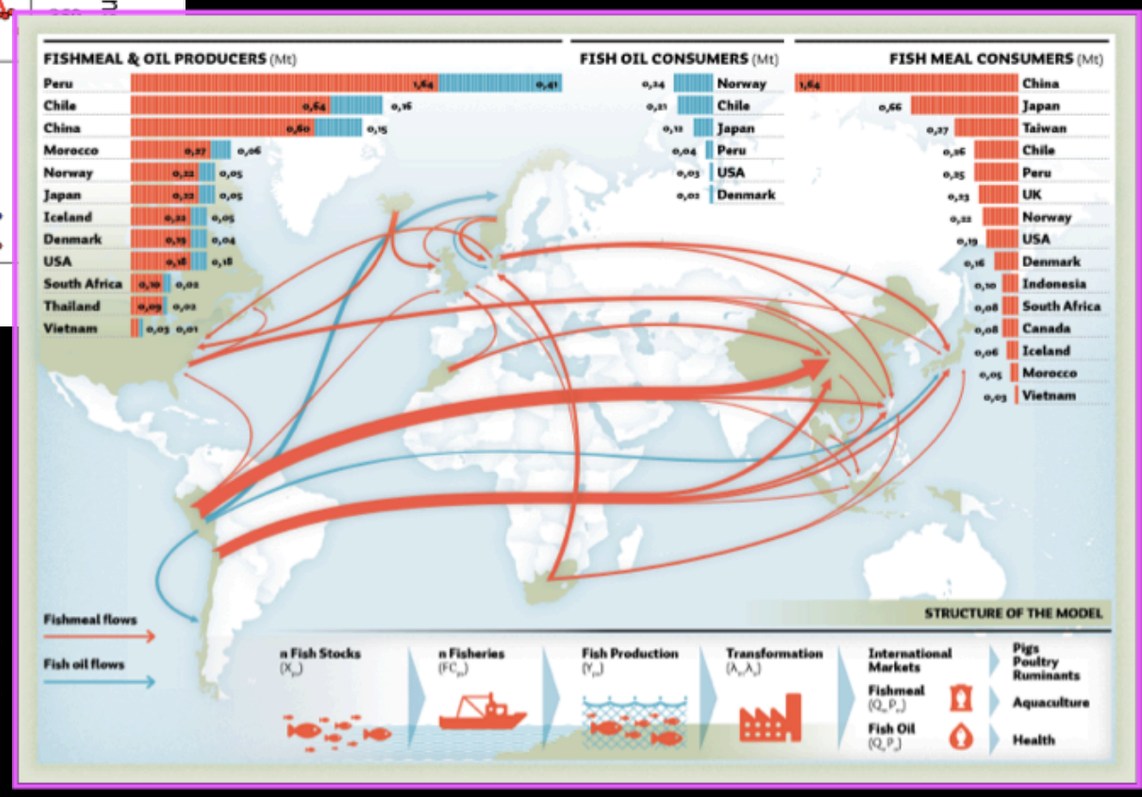
Eastern Boundary Upwelling Systems (EBUS) are characterized by...



Complex dynamics



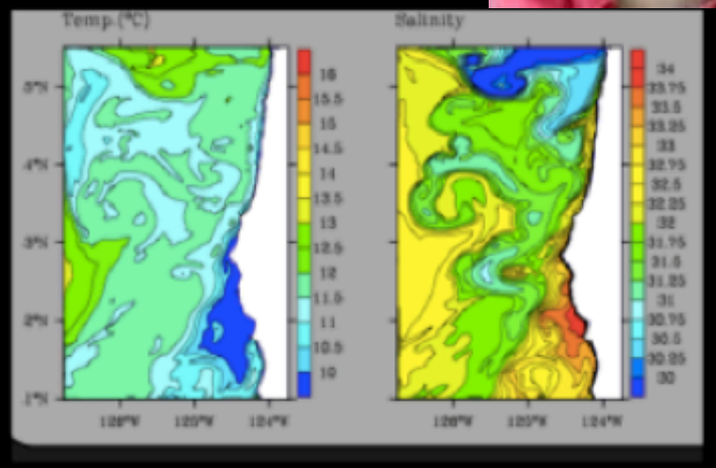
Decadal variability



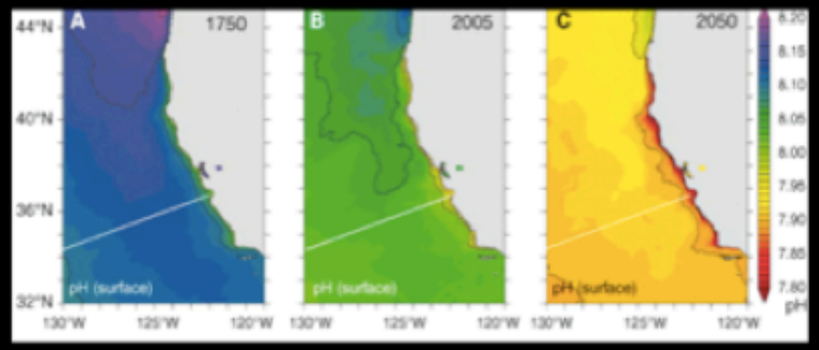
Global impact

Incremental and complementary modeling approaches

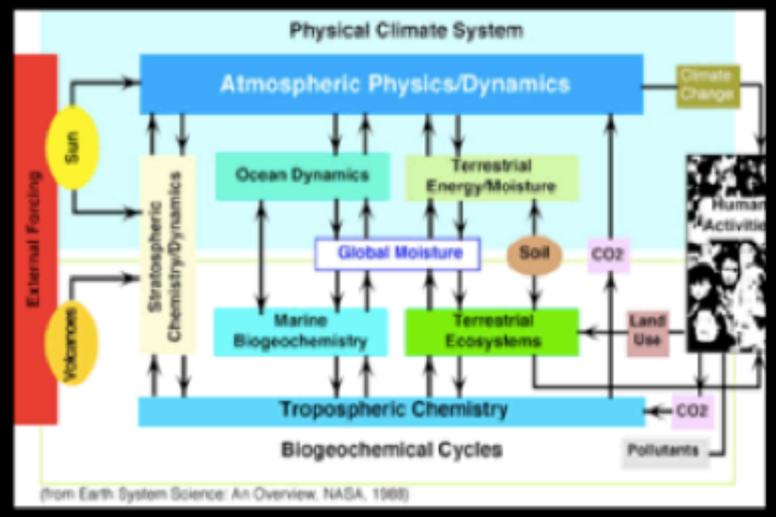
- **Hindcast/data assimilative** one-way nesting (example of "high frequency" physics and biogeochemistry – BGC – for 1980-2010)



- **One-way downscaled** basin-scale BGC (understanding how to achieve 1-way coupling-ongoing 1970-2050 integration before 2-way coupling)



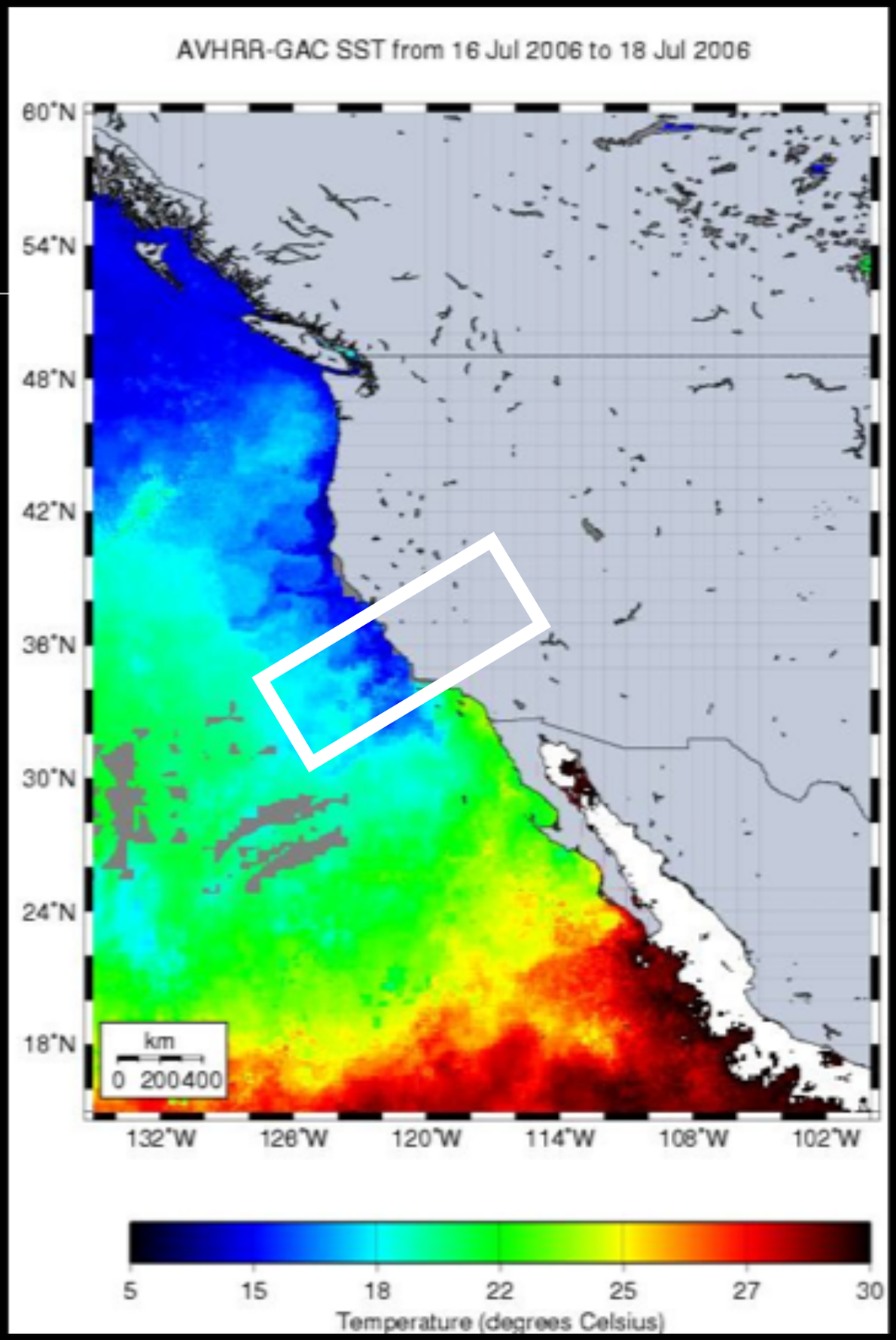
- **Two-way coupled** basin-scale physics (preliminary results in fully dynamically-coupled global & regional physics)



- Hindcast

End-to-End

- Future California Current Ecosystem (CCE) conditions (forced by an IPCC scenario) and some bioeconomic steps… Earth System Models



Lots of information…
three steps to tease out the drivers

- Step 1: establish the biological processes that control adult sardine and anchovy population dynamics
  - Anchovy: adult population fluctuations are associated with age-1 growth and prey availability.
  - Sardine: adult populations correlated with temperature and age-0 survival.
- Step 2: link changes in processes to variations in environmental conditions
  - Anchovy: years of high growth related to enhanced upwelling in the southern CCS (more productive lower tropic levels)
  - Sardine: years of high age-0 survival related to high temperatures
- Step 3: correlate environmental conditions experienced by the individuals in the model to regional and climate-scale variability in the CCS using ROMS and NEMURO output directly.

Lots of information…
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Some summarizing thoughts… (before moving on to management)

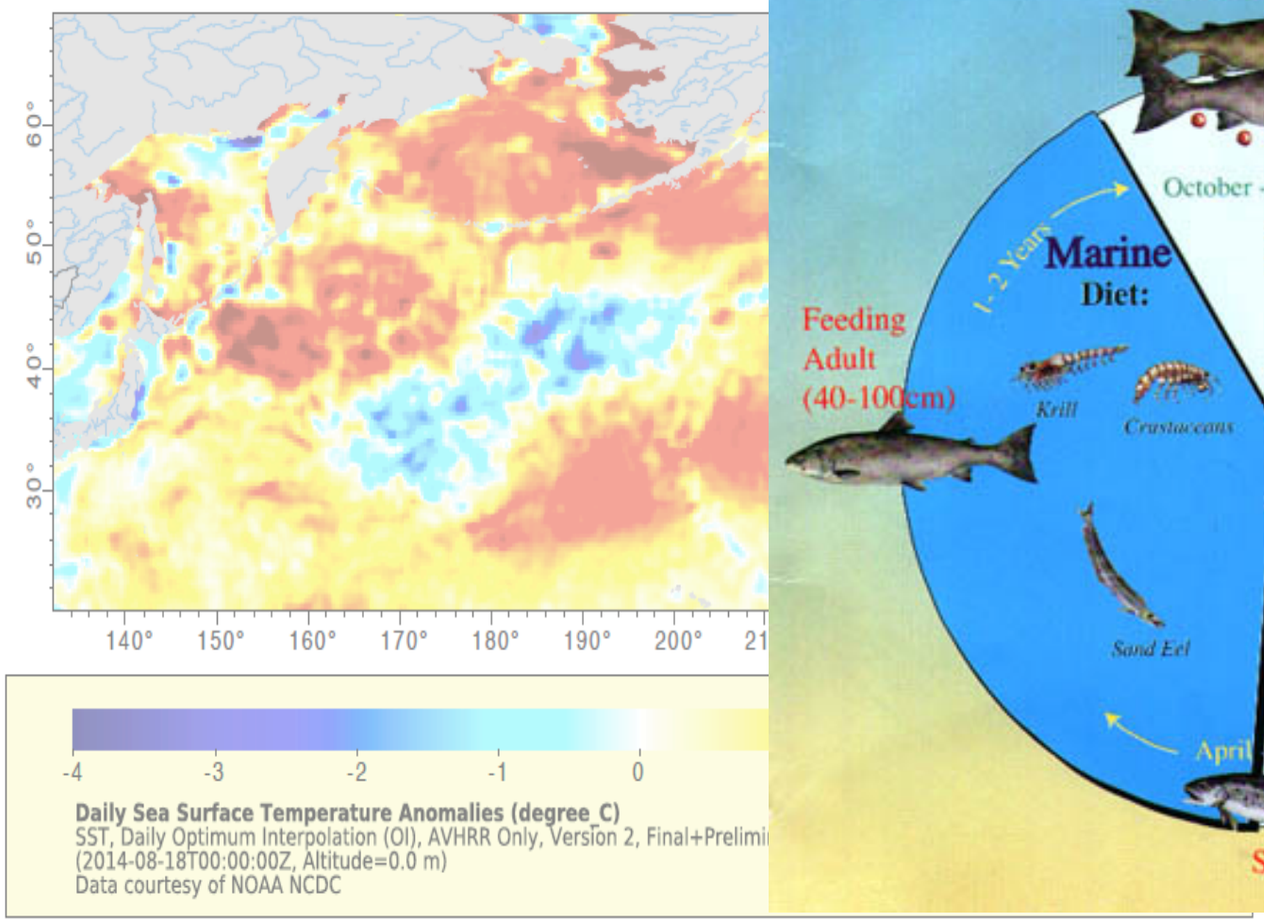
- We have shown progress in one- and two-way down/upscaling
- Links to the "human dimension" through economics can provide a quantitive way to link natural and social sciences
- Possible feedbacks or additive effects were explored

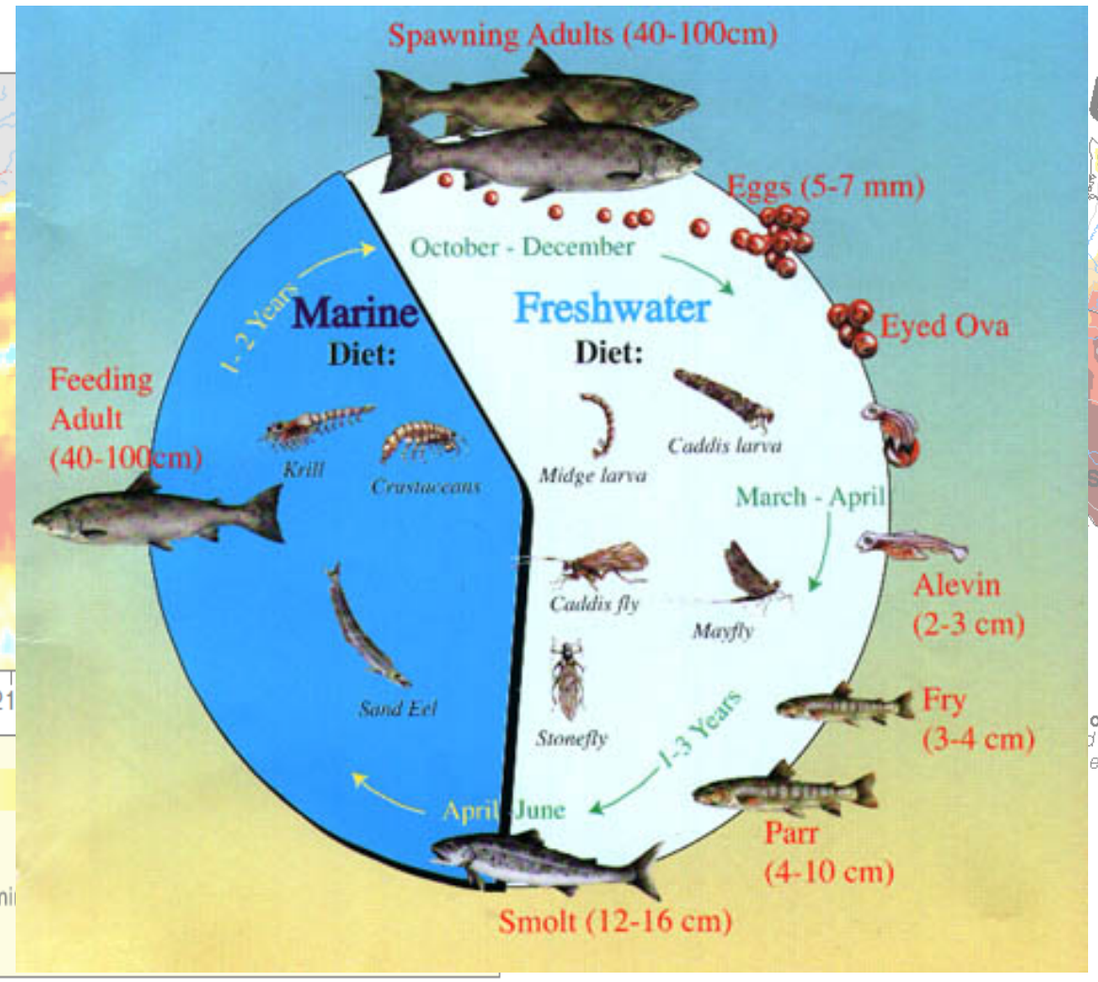
2015 State of the California Current Ecosystem

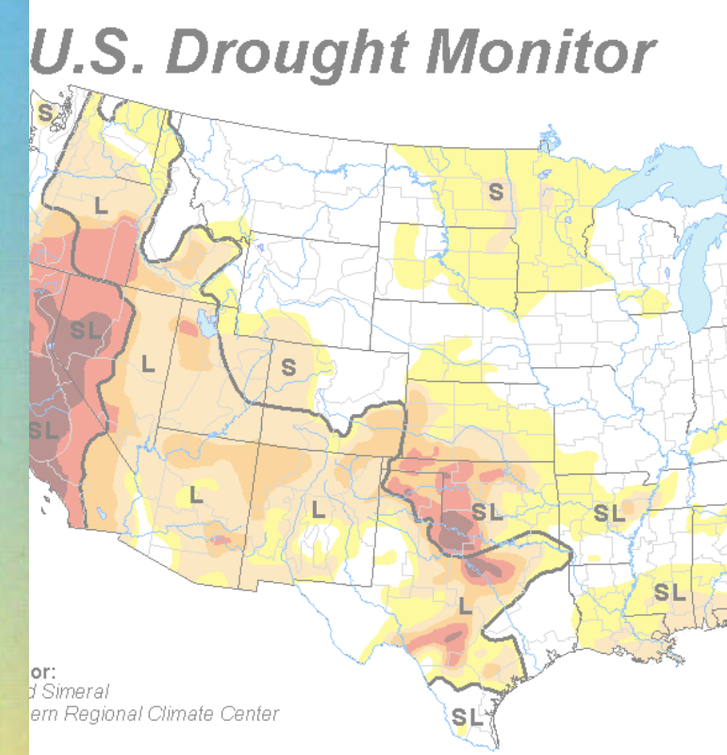
NOAA's California Current
Integrated Ecosystem Assessment

Chris Harvey (NWFSC)
Toby Garfield (SWFSC)

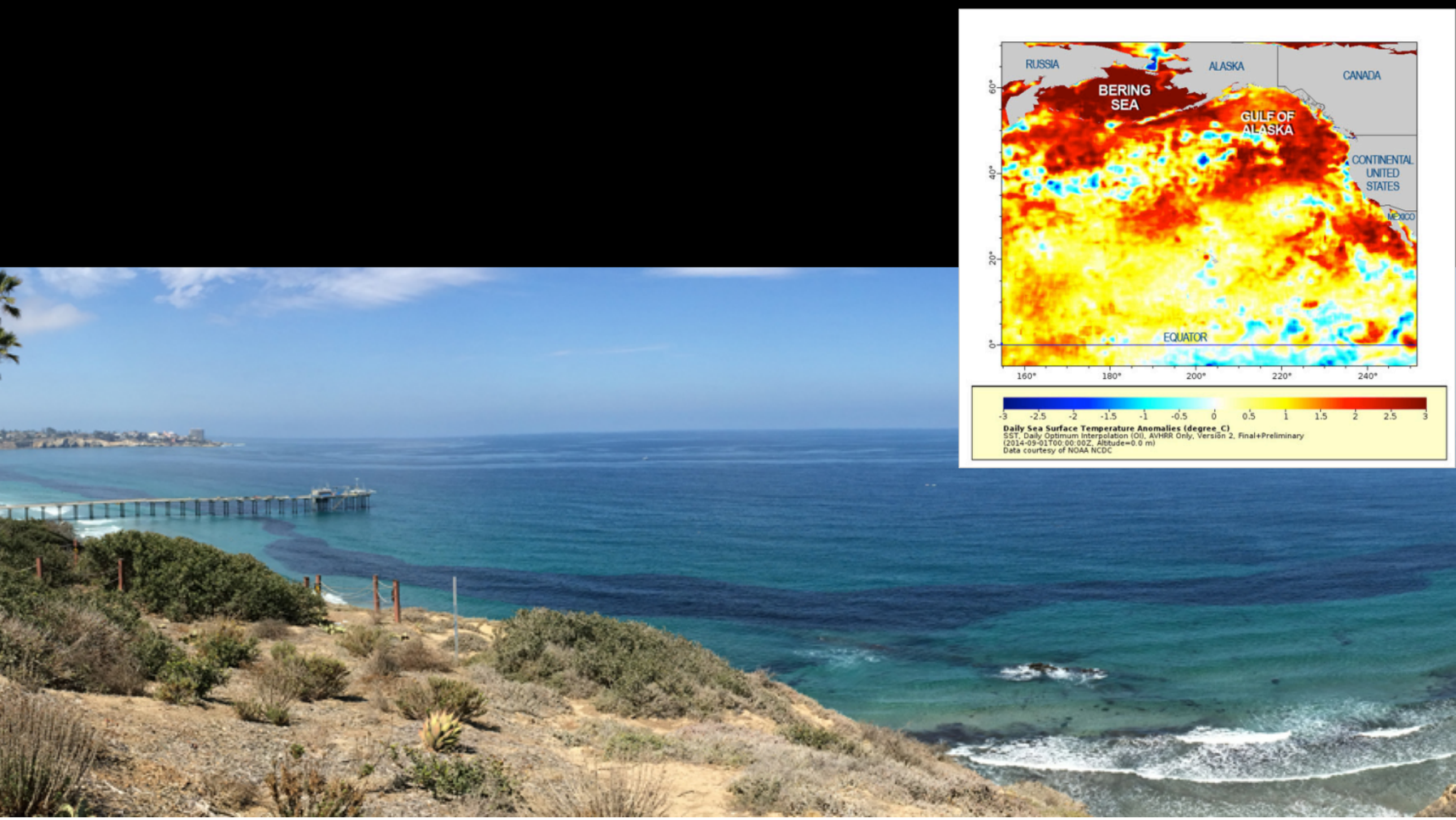
We can no longer look at the ecosystem components in isolation – they are *integrated*…







Hence an integrated Ecosystem Assessment Report
(Environmental Intelligence at its best)



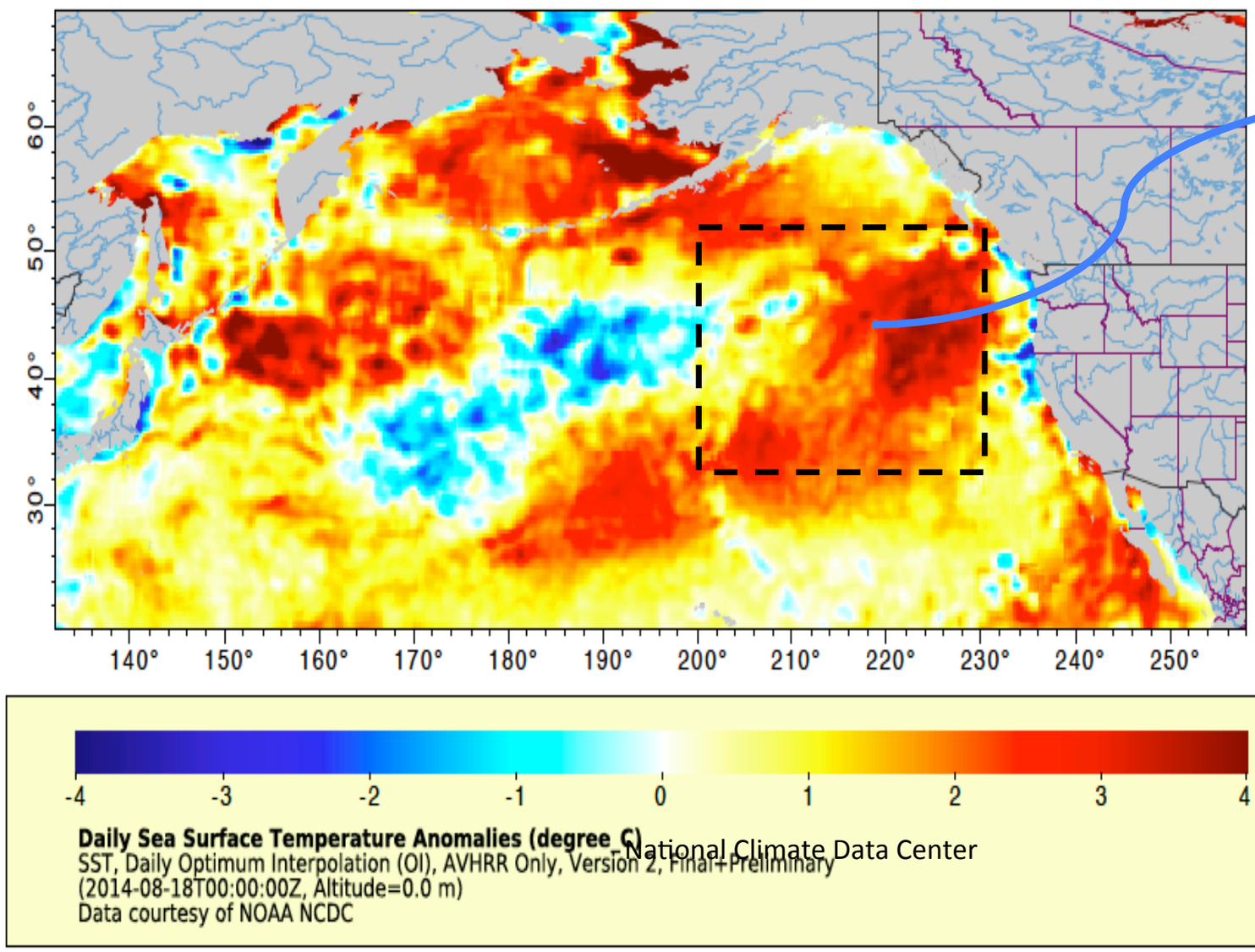
Unprecedented physical conditions

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

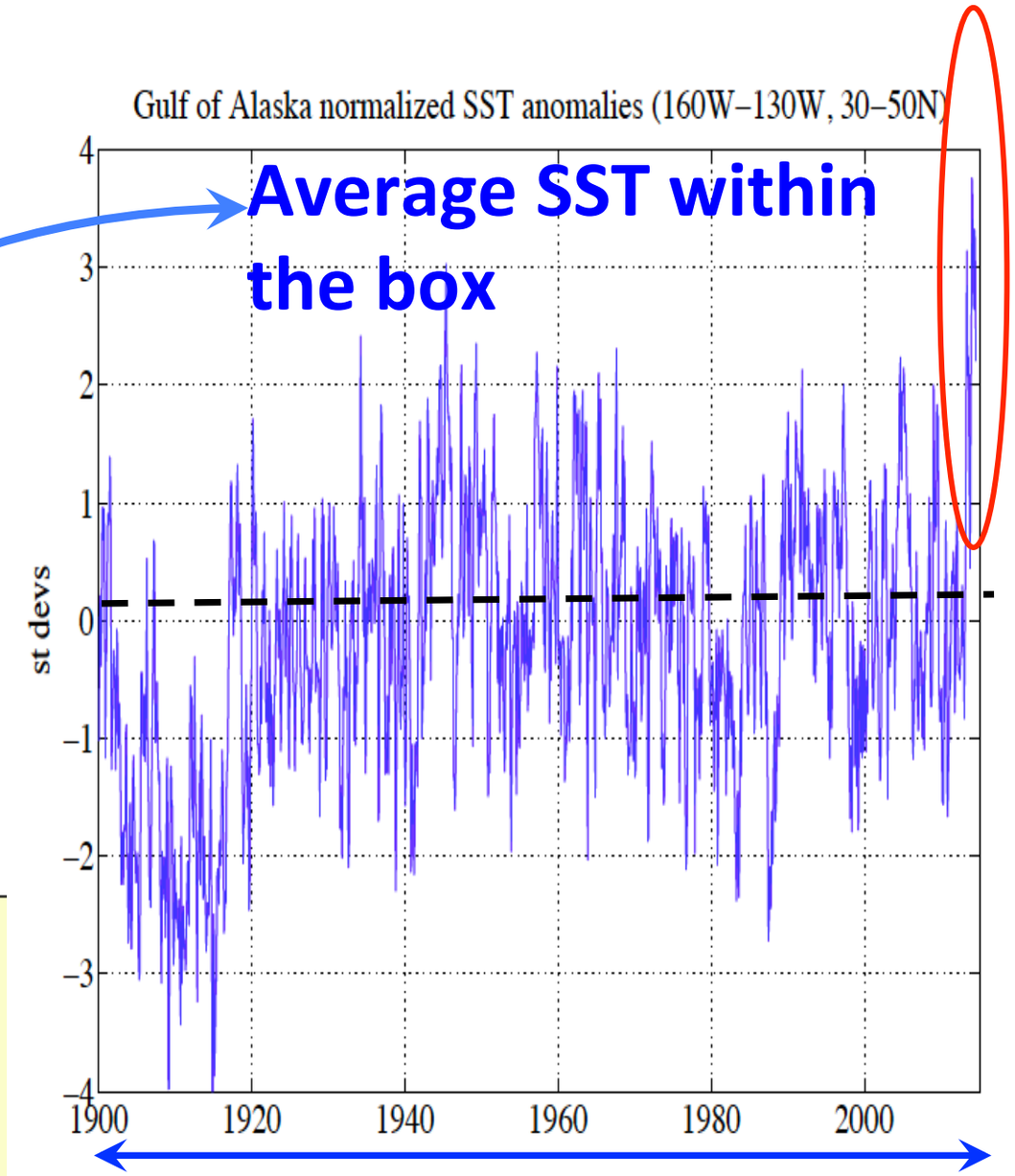
IEA
INTEGRATED ECOSYSTEM ASSESSMENT

The 100+ year time series of Sea Surface Temperature in the eastern Pacific shows this is the warmest on record

"There's something happening here, what it is ain't exactly clear…" (Buffalo Springfield)



National Climate Data Center



Average SST within the box

114 Years

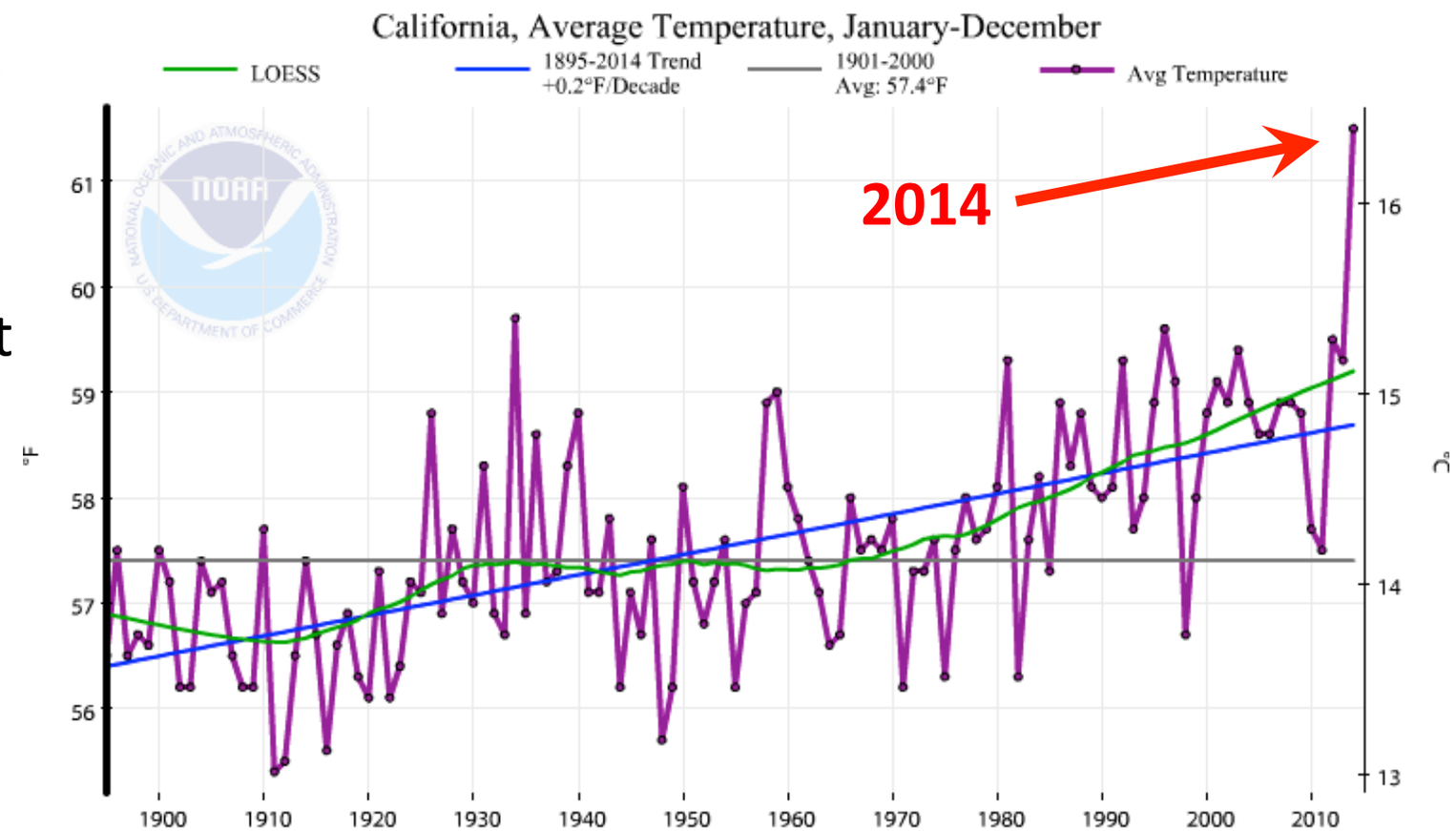
Daily SST anomaly (18 Aug 2014) relative to the 30-year (1982-2010) climatology

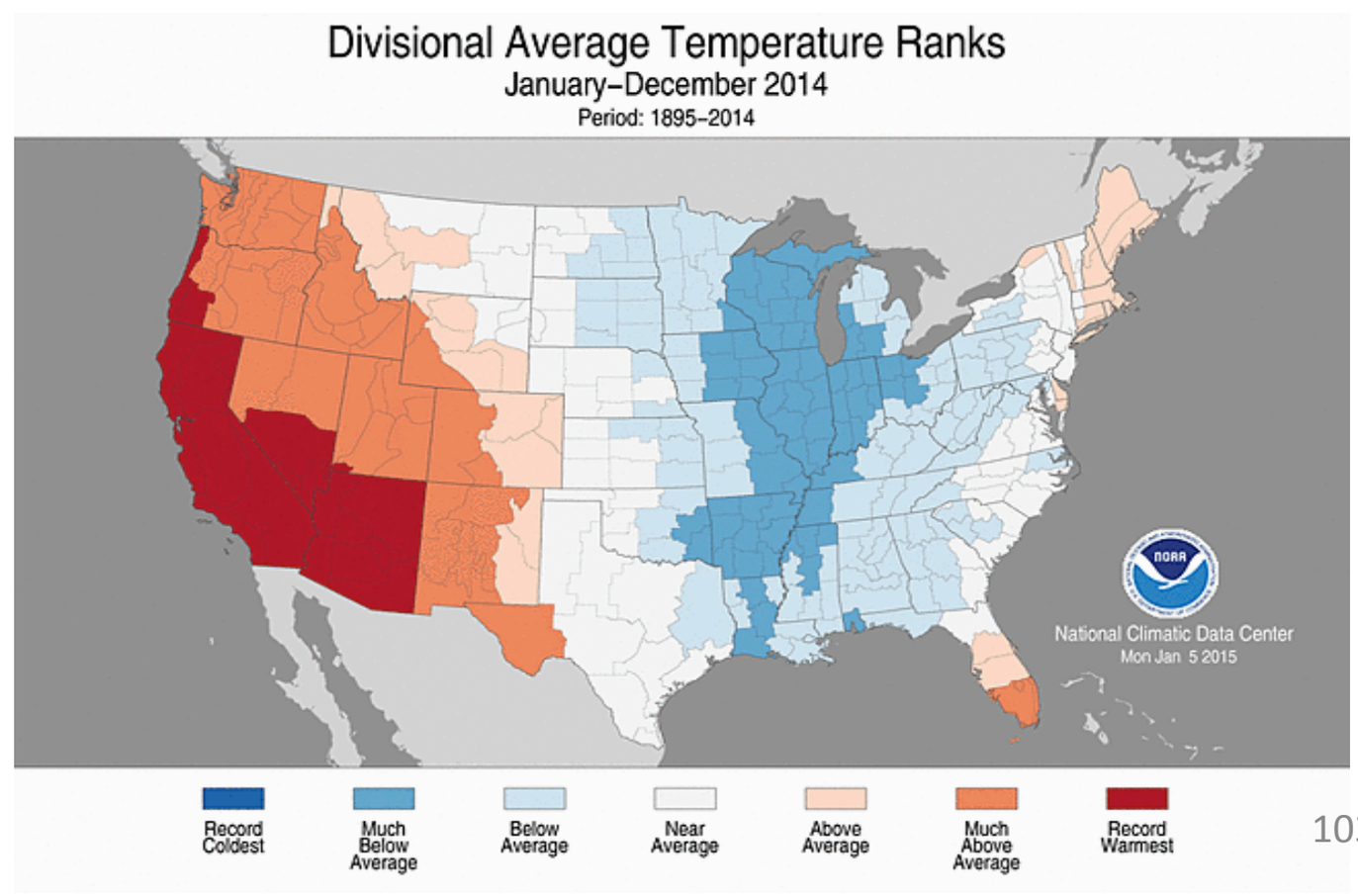
It wasn't just the ocean that was warm.

In California, 2014 weather was not only dry, but it was also extraordinarily hot

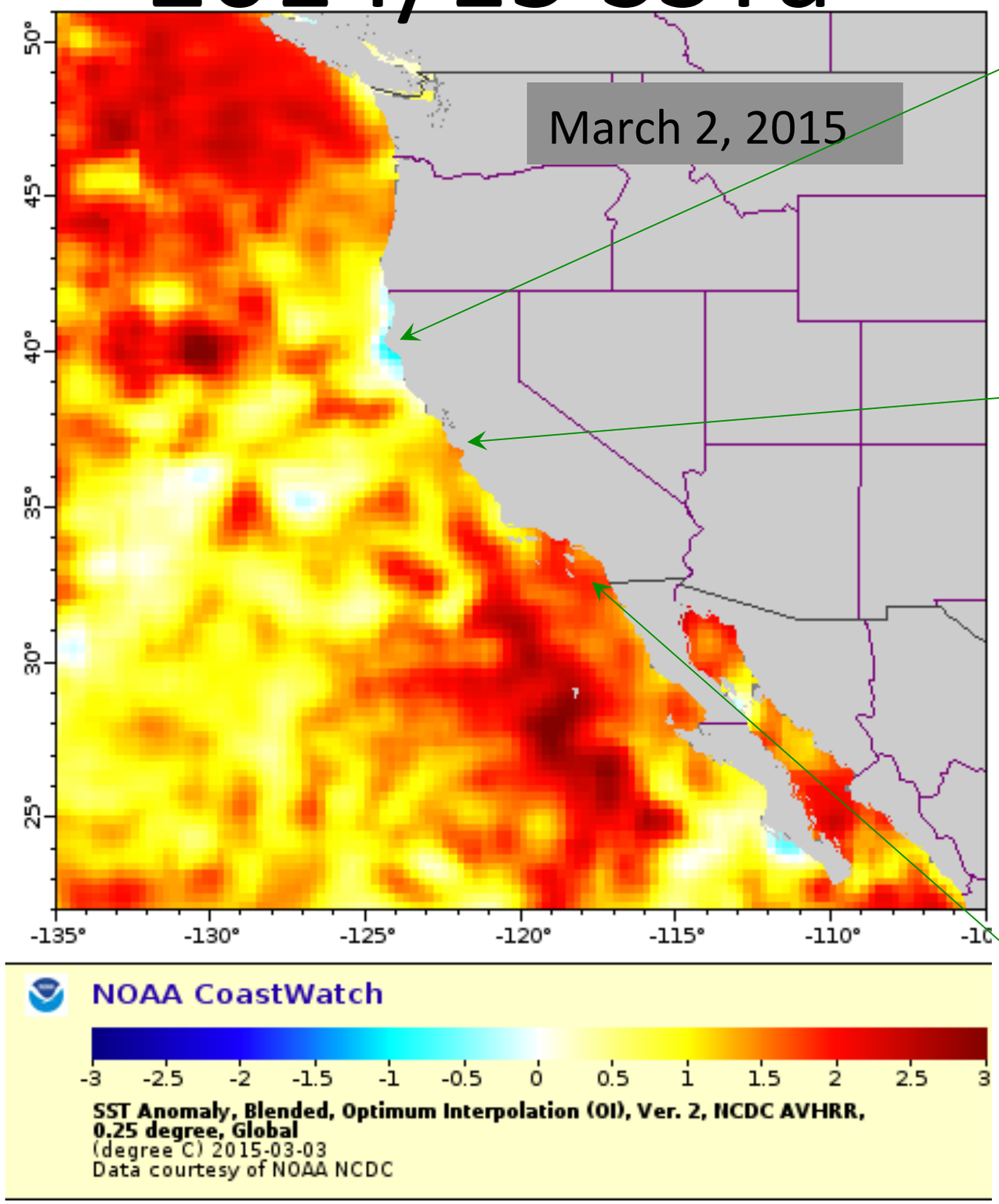
- Surface air temperature record was almost off the charts, ~ 1 °C warmer than the previous record

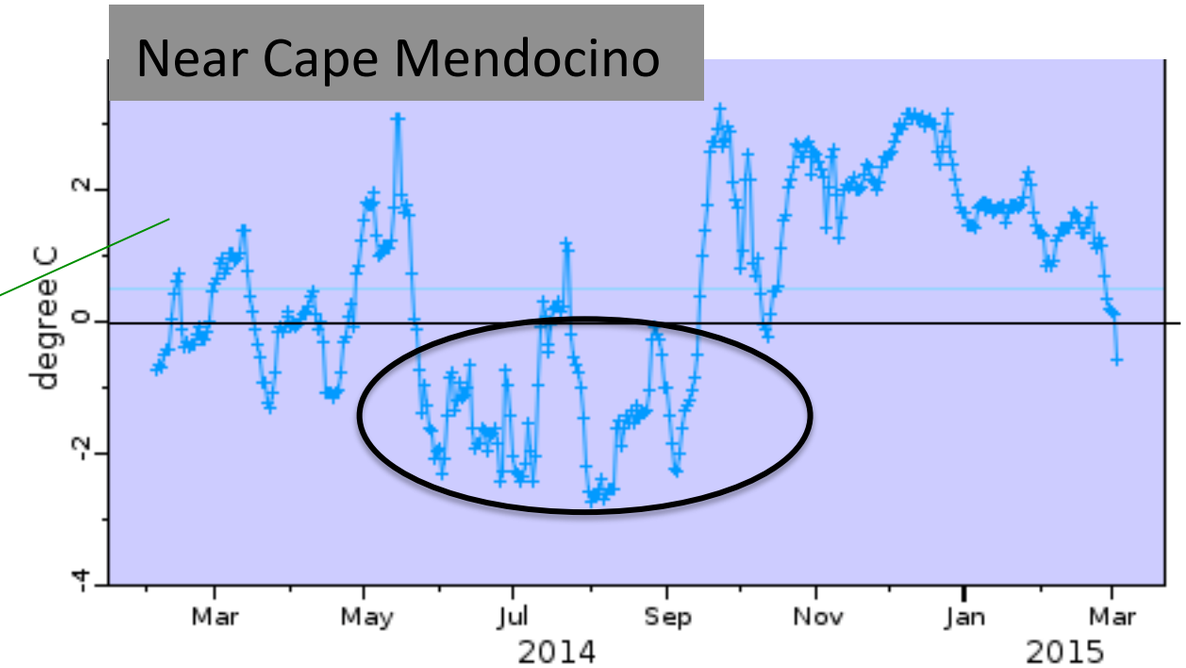
- Extraordinary warmth was confined to the southwest, centered in California

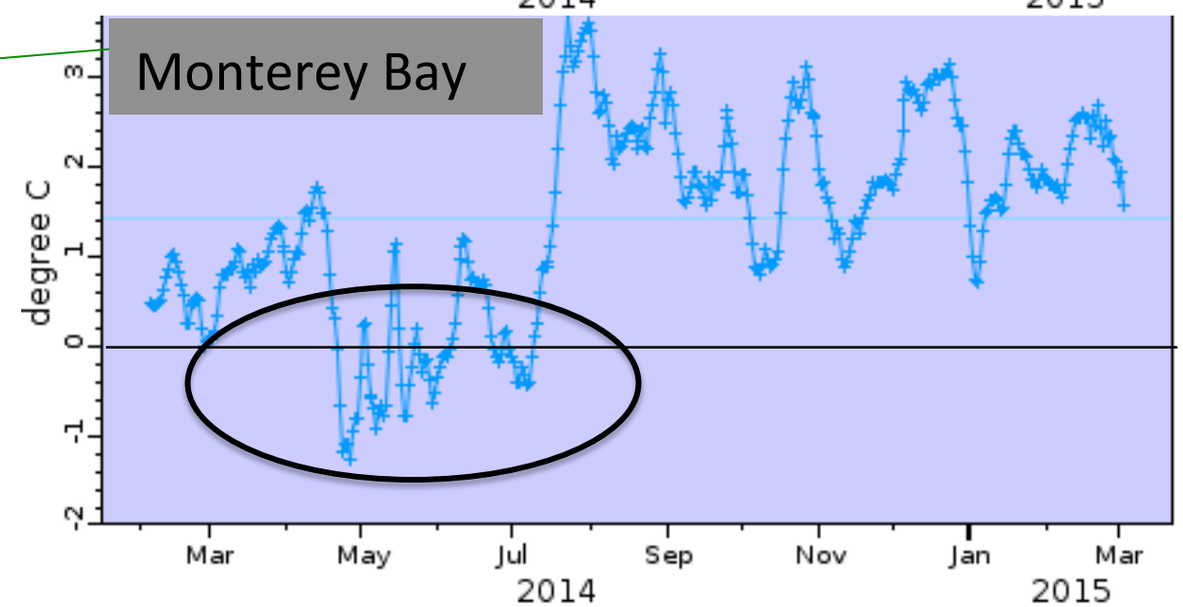


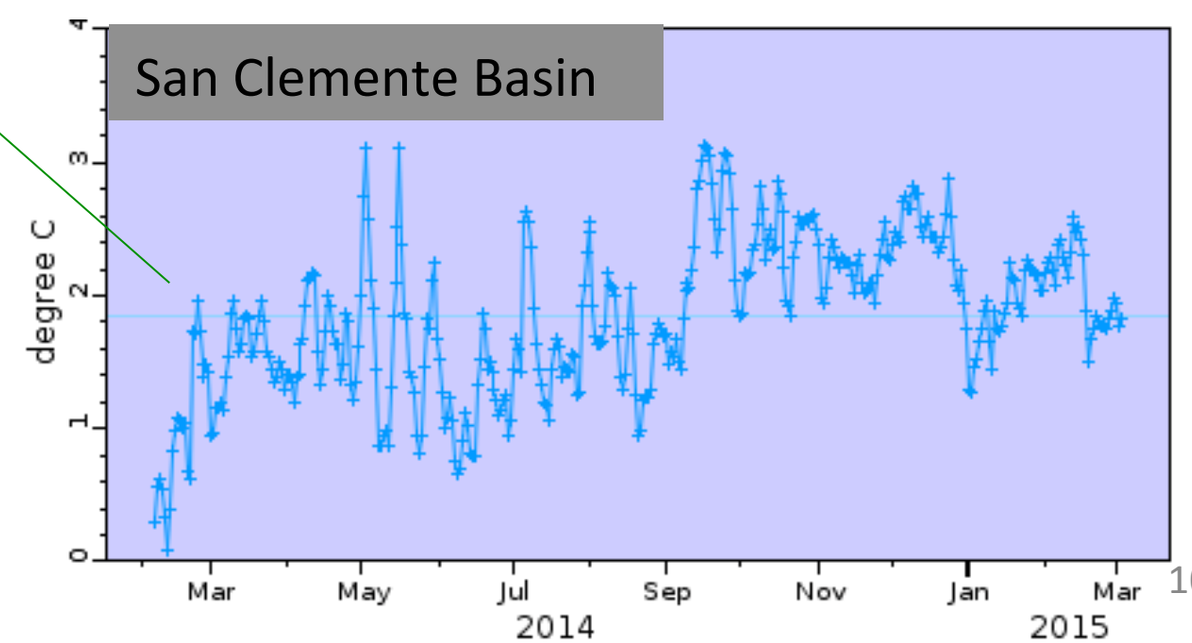


2014/15 SSTa

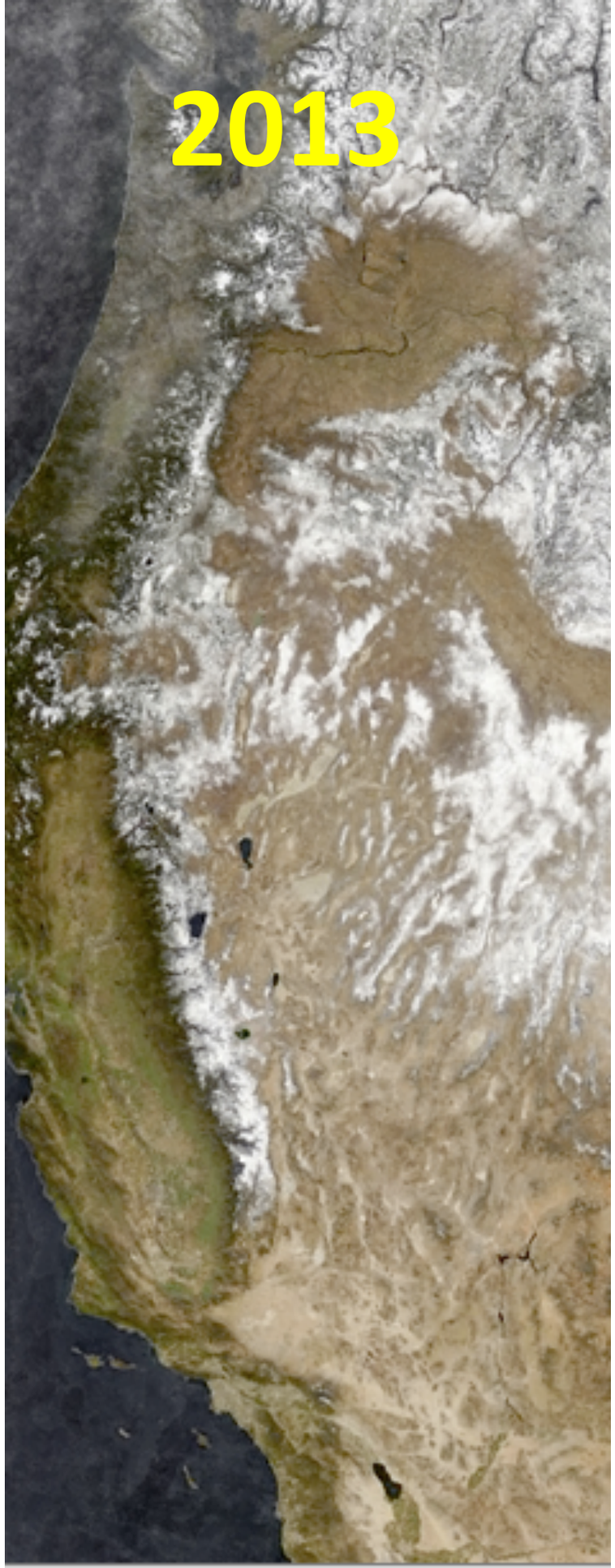

March 2, 2015
50°
45°
40°
35°
30°
25°
-135°
-130°
-125°
-120°
-115°
-110°
NOAA CoastWatch
-3
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3
SST Anomaly, Blended, Optimum Interpolation (OI), Ver. 2, NCDC AVHRR, 0.25 degree, Global
(degree C) 2015-03-03
Data courtesy of NOAA NCDC

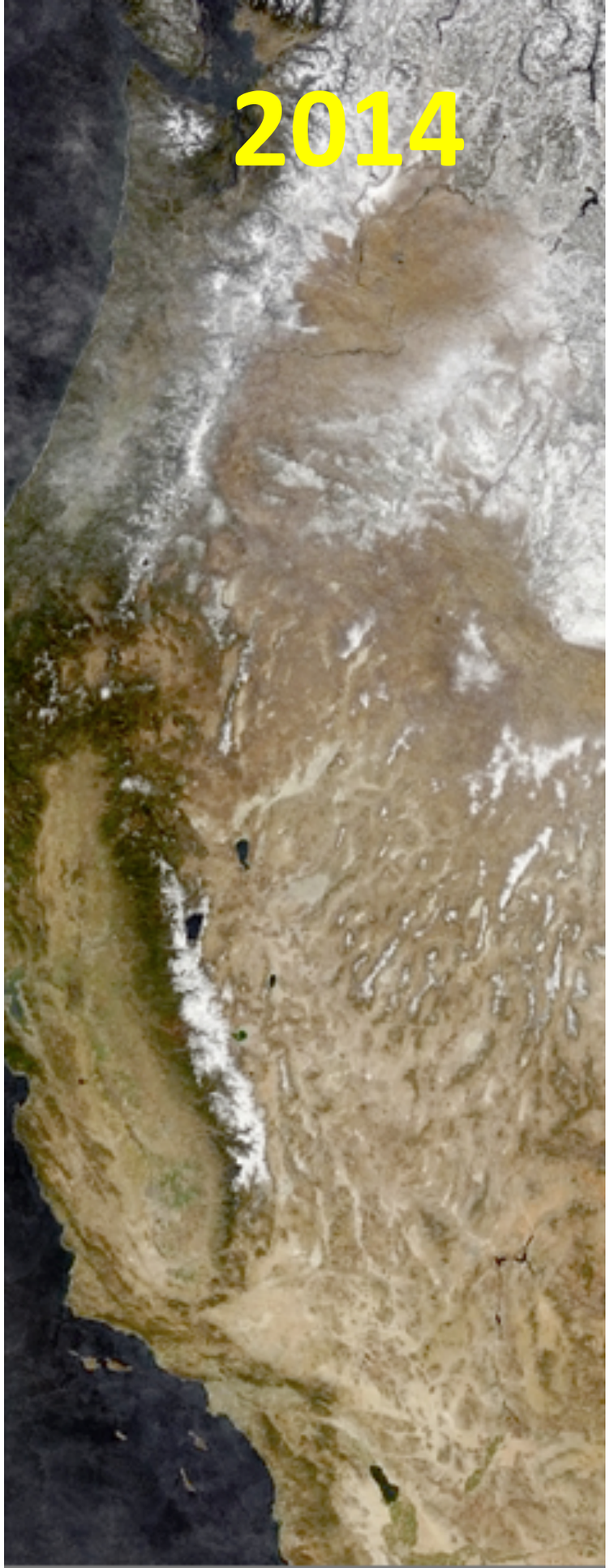

Near Cape Mendocino
degree C
2
0
-2
-4
Mar
May
Jul
Sep
Nov
Jan
Mar
2014
2015

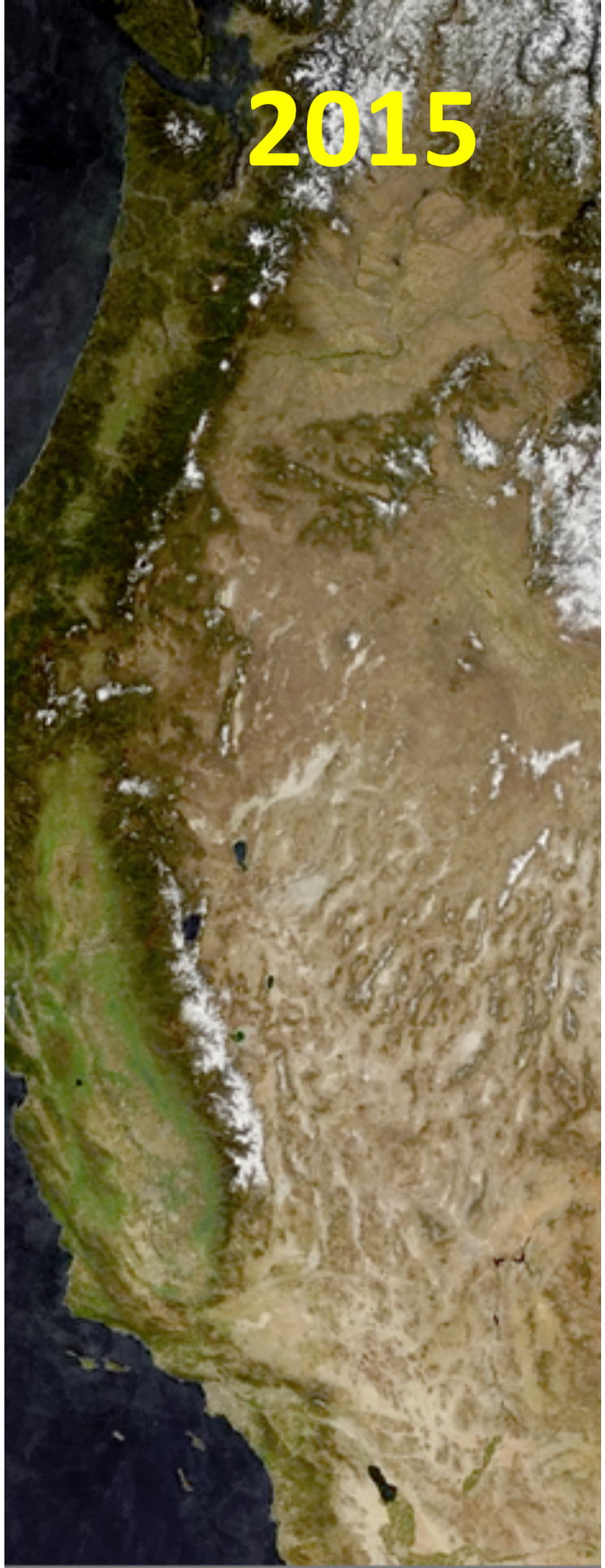

Monterey Bay
degree C
3
2
1
0
-1
-2
Mar
May
Jul
Sep
Nov
Jan
Mar
2014
2015


San Clemente Basin
degree C
4
3
2
1
0
Mar
May
Jul
Sep
Nov
Jan
Mar
2014
2015

http://www.nytimes.com/interactive/2015/03/05/us/one-giant-picture-of-all-the-snow-across-the-us.html?smid=tw-share&_r=0

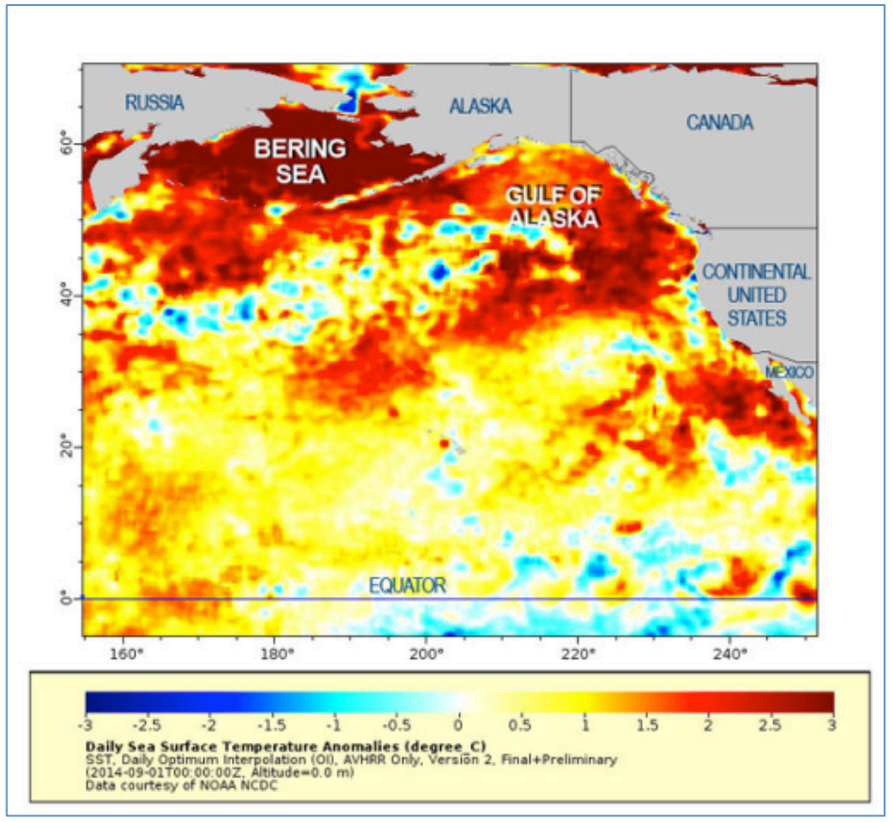




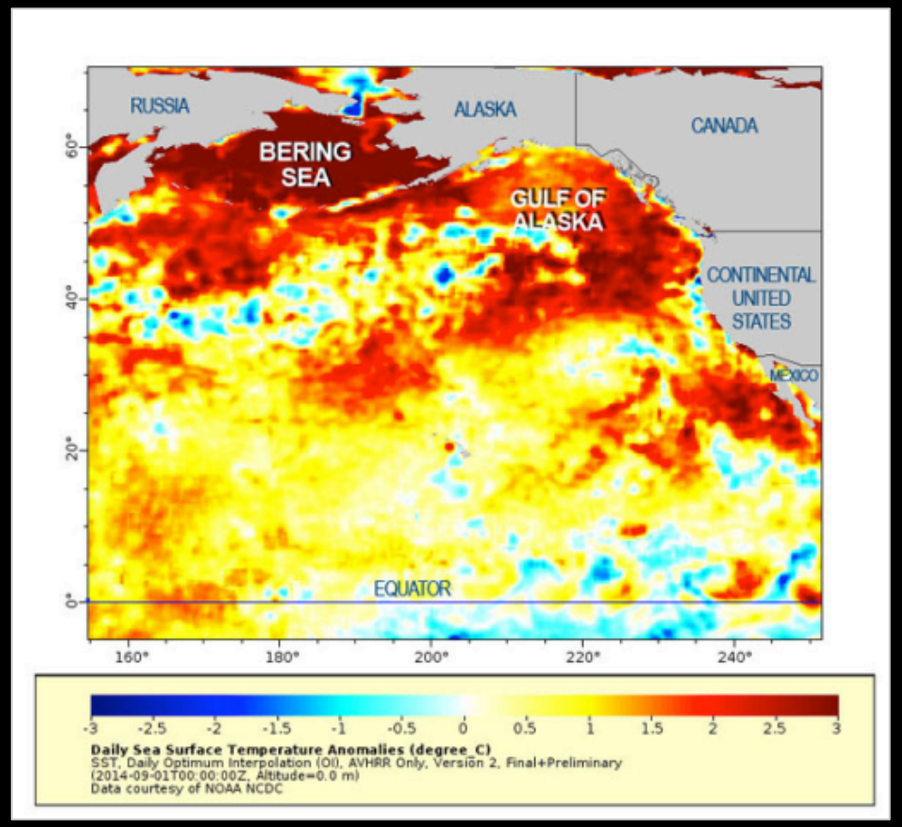


We're in a strange and possibly transitional period

- NE Pacific dominated by "warm blob"
- El Niño has arrived
- Basin scale productivity indices are flipping to "poor"
  - Uncharted territory for climate conditions
- Several leading indicators show that the system is responding to these changes
  - Copepods shifting to less energy-rich "southern" species
  - Cassin's auklets & California sea lion pups distress
  - Water storage in snow pack at record lows in all major river basins



Sea surface temperature anomalies, Sept. 1, 2014 (NOAA National Climate Data Center)

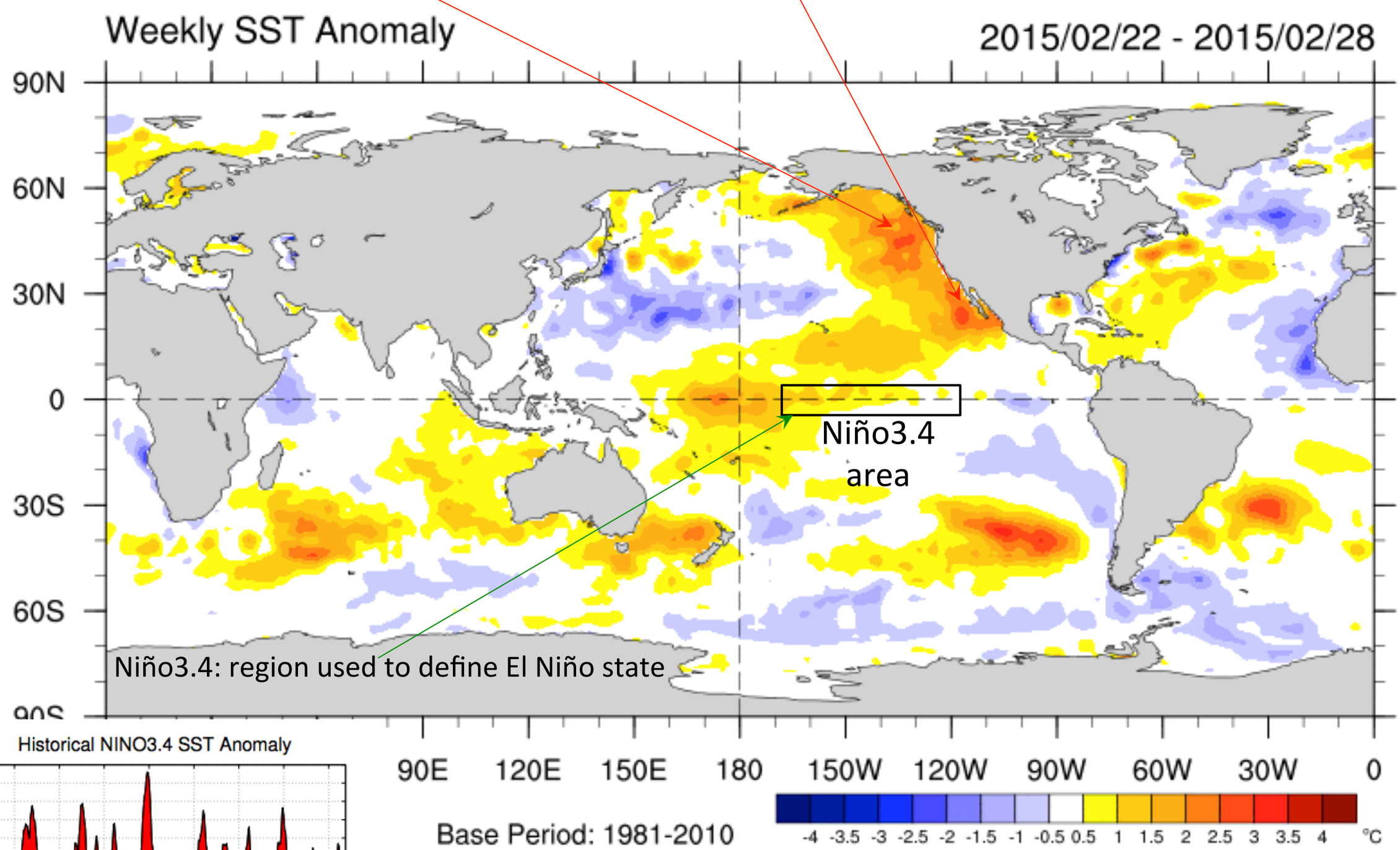


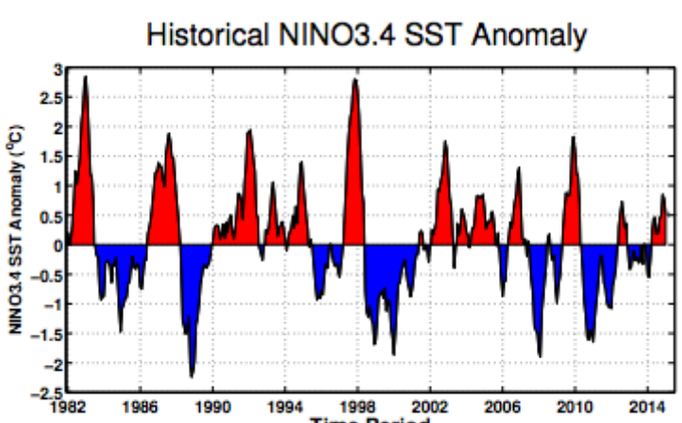
Sea surface temperature anomalies, Sept. 1, 2014 (NOAA National Climate Data Center)

1. Unprecedented physical conditions: the "warm blob"

Eastern Pacific sea surface temperatures (SST) were (and are) anomalously warm in 2014-2015

The Gulf of Alaska and the ocean off Baja California were >3°C warmer than average





Conditions along the equator were within normal ranges, warm in the west and cooler in the east.

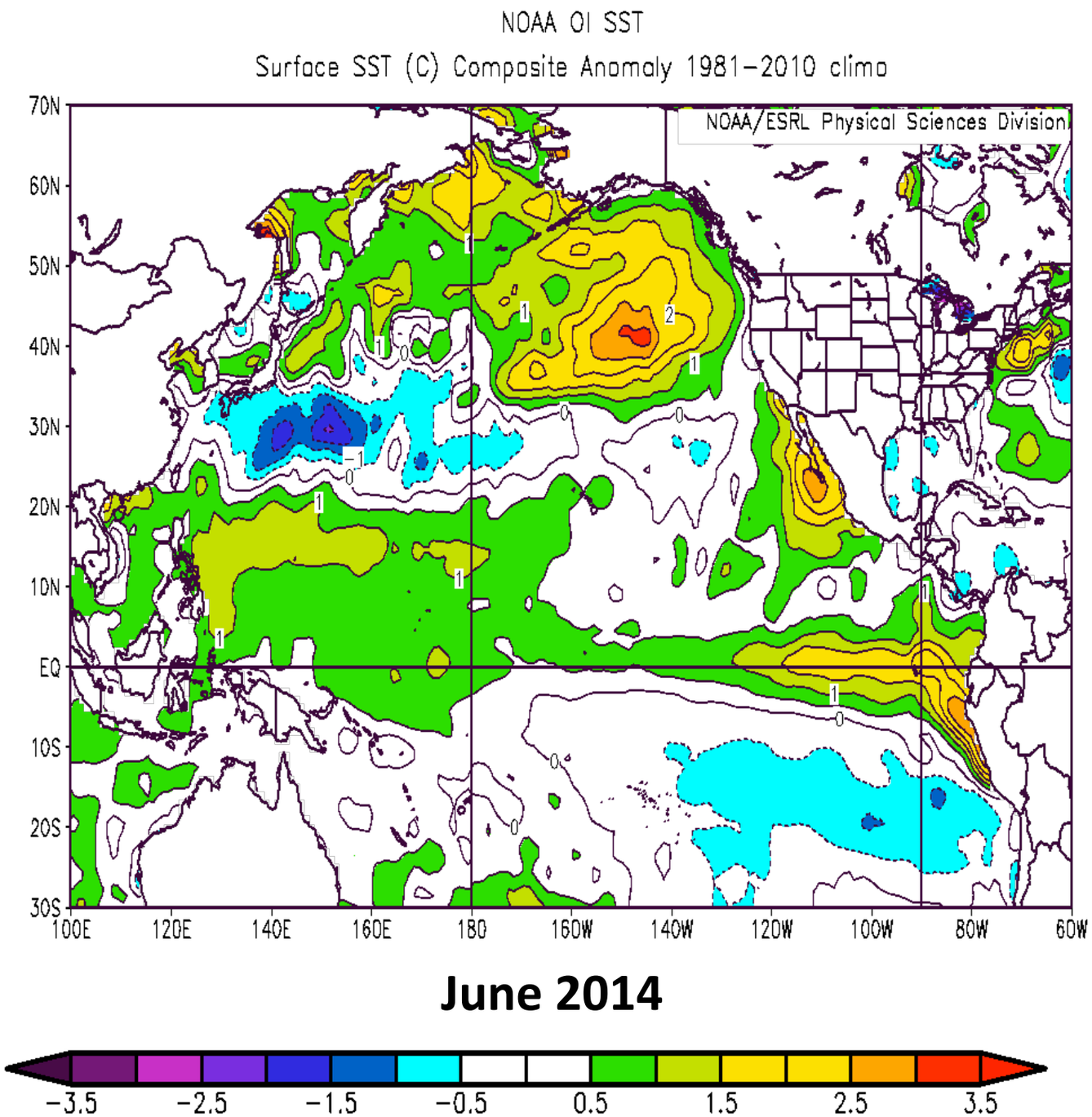
But – Northeast Pacific warmed *before* the Eastern Tropical Pacific warmed

- Gulf of Alaska has been extremely warm for the **past year and a half** (weak winter conditions)

- Baja and So. California near-shore have been warm **since June 2014** (local winds – not

False Killer Whales, 24 Feb 2015; Photo: M. Robbins

Sea Surface Temperature Anomaly (relative to 1981-2010)

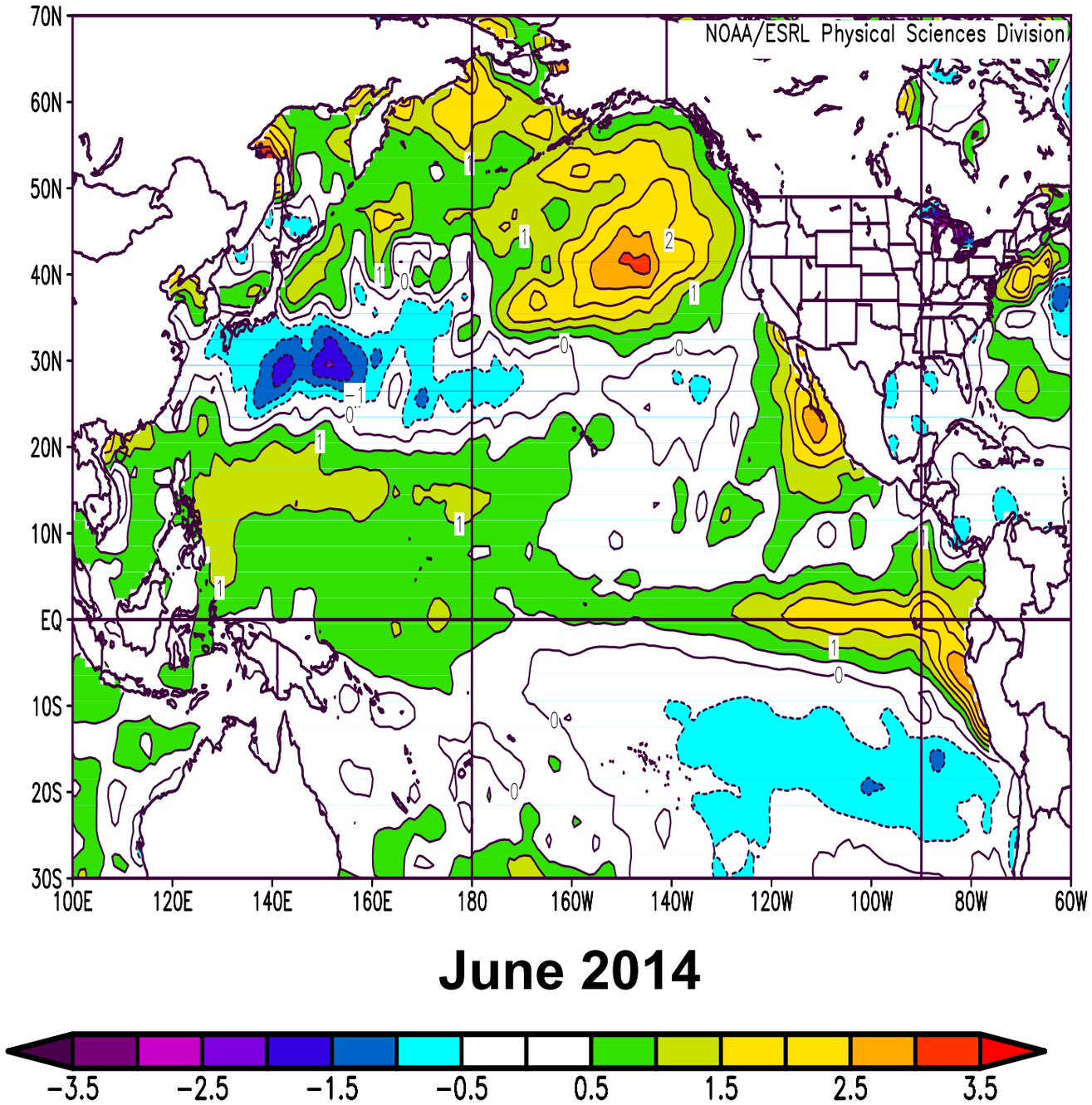


June 2014

But – Northeast Pacific warmed <u>before</u> the Eastern Tropical Pacific warmed

- Gulf of Alaska has been extremely warm for the **past year and a half** (weak winter)
- Baja and So. California near-shore have been warm **since June 2014** (local winds – not remotely-forced ENSO conditions)

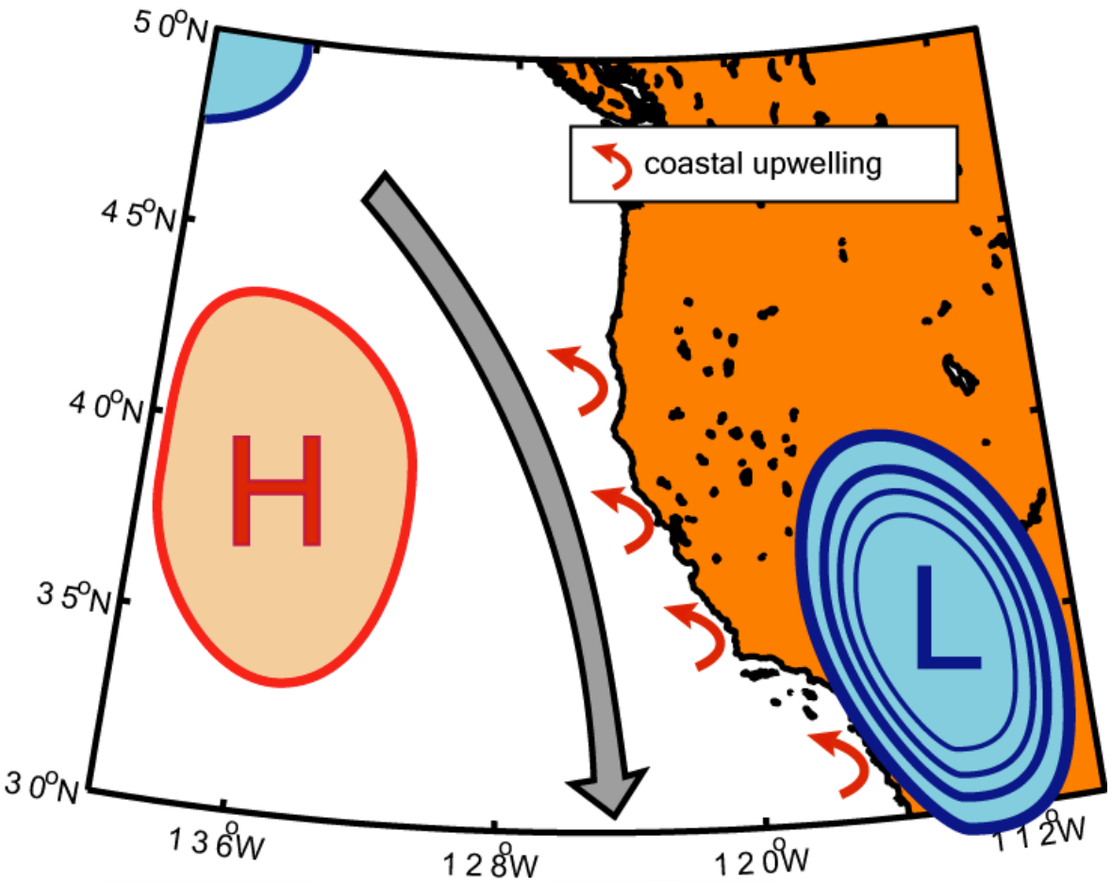
Sea Surface Temperature Anomaly (relative to 1981-2010)

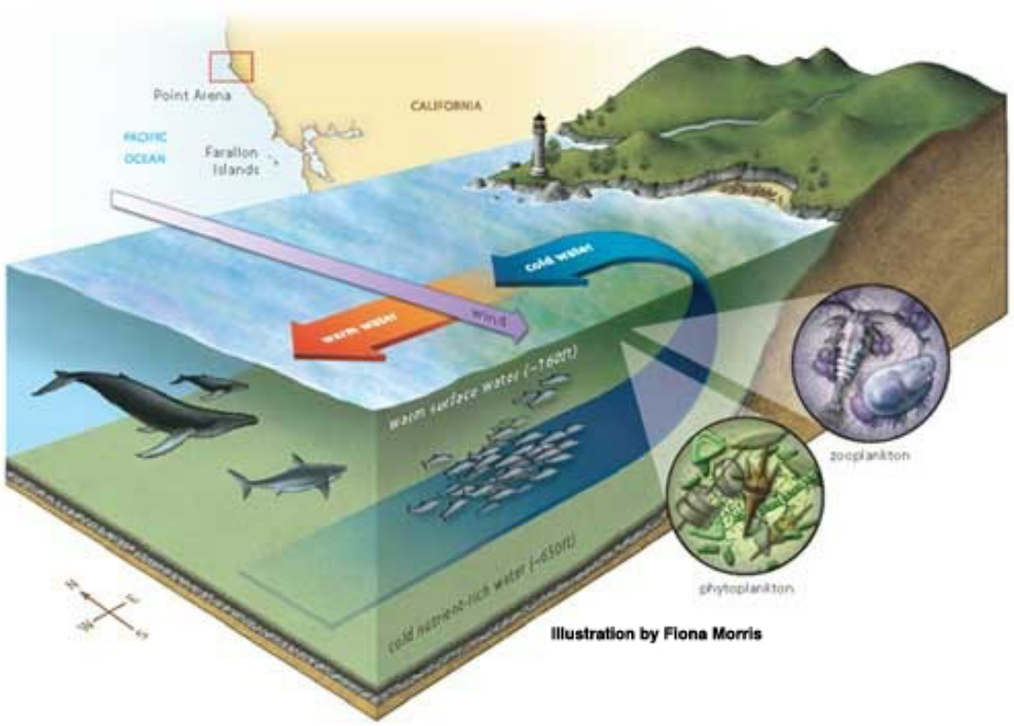


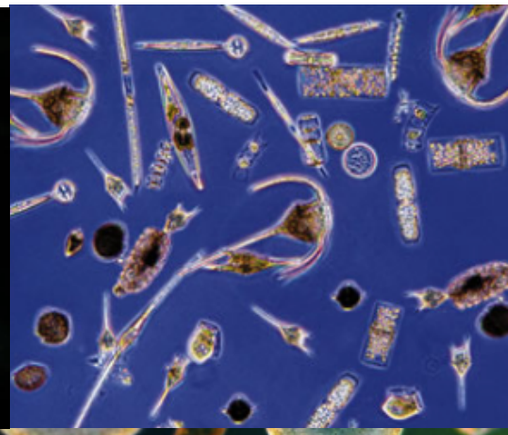
June 2014

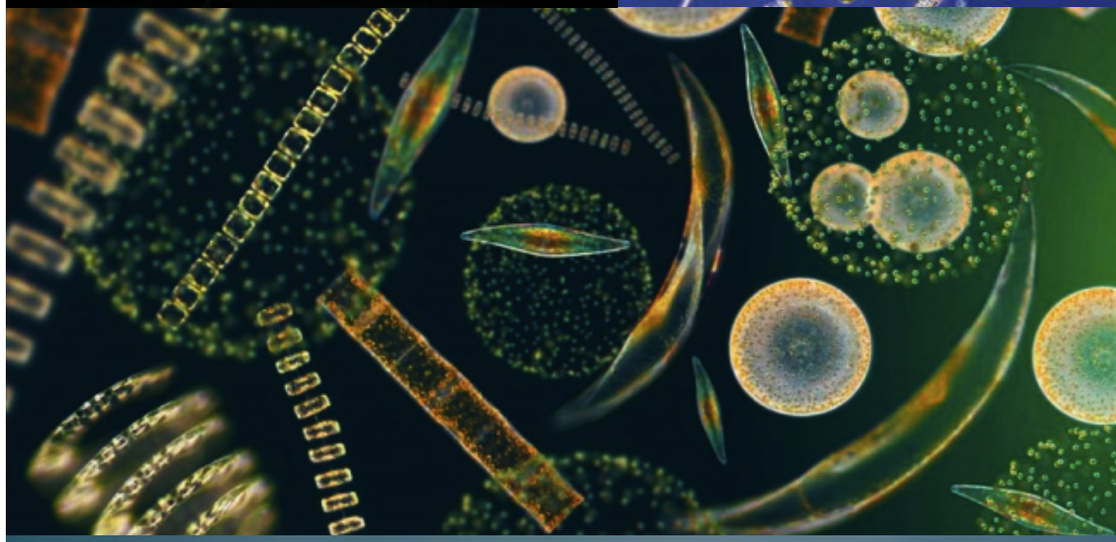
False Killer Whales, 24 Feb 2015; Photo: M. Robbins

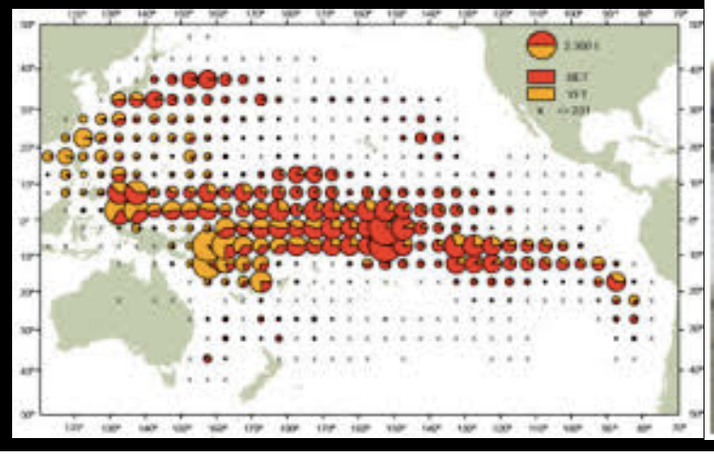
The source waters and upwelling strength determine the primary productivity



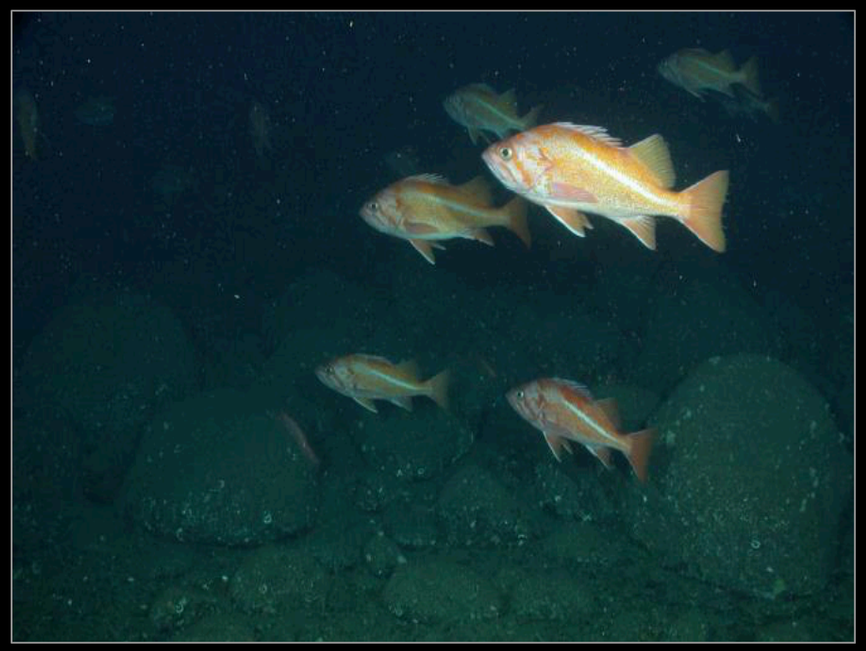






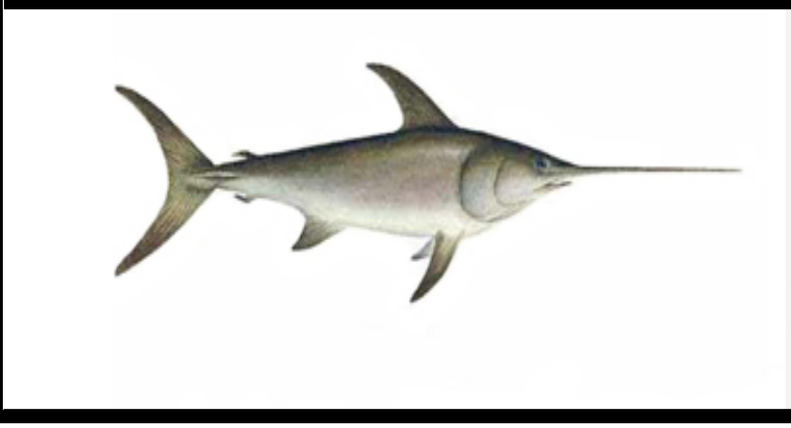


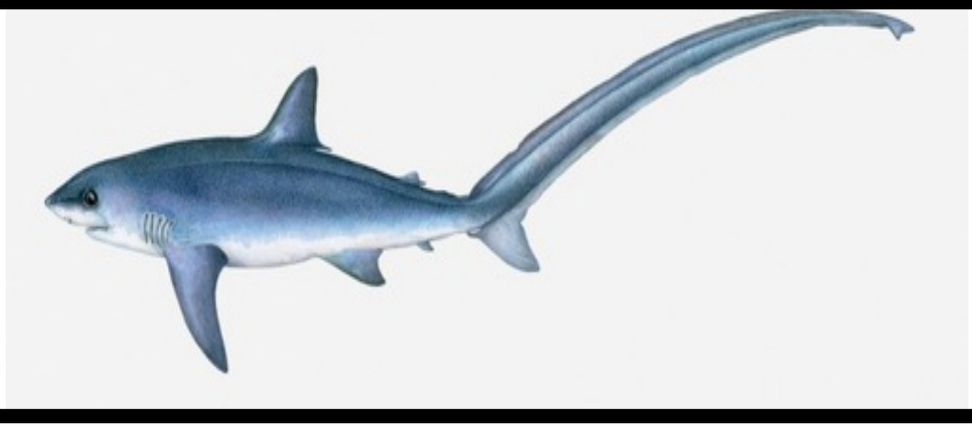
Ecological responses

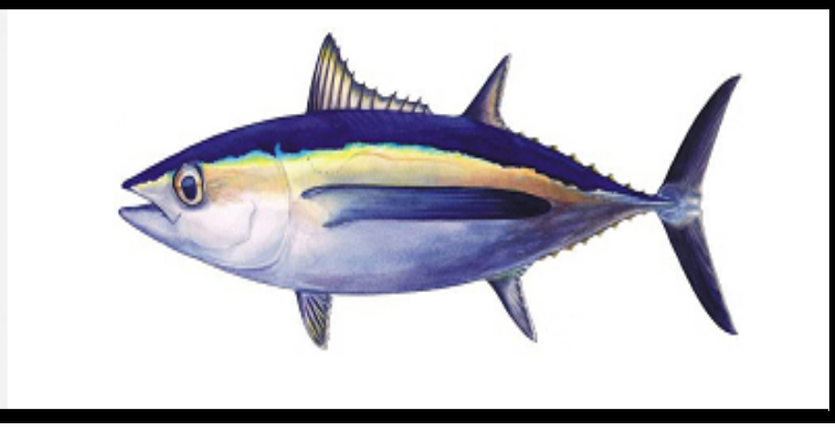


Canary rockfish in the Olympic Coast National Marine Sanctuary off the Washington coast (NOAA)

Rosy rockfish, corals, sponges and anemones on Cordell Bank. (Rick Starr, NOAA)





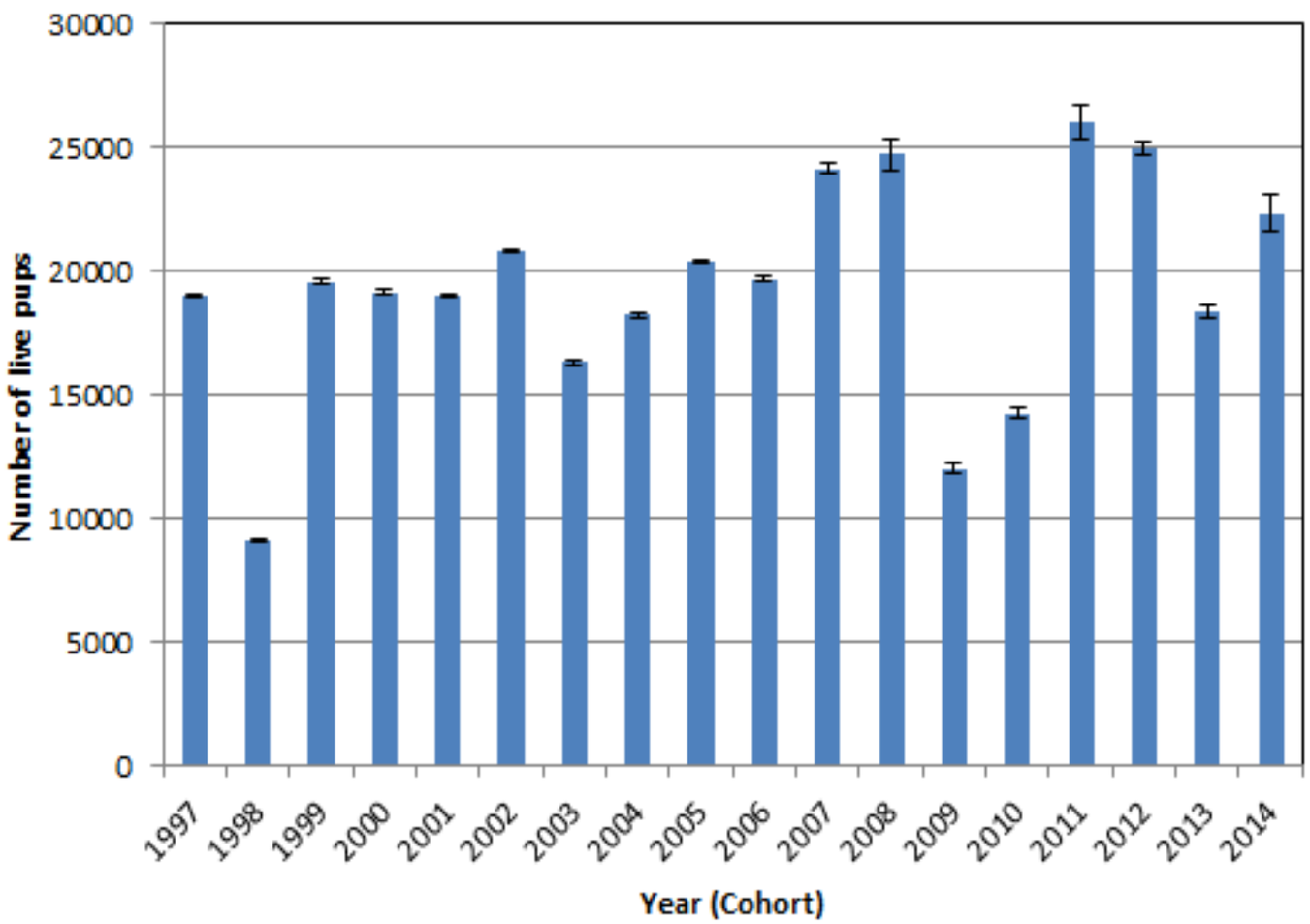


Steps toward management

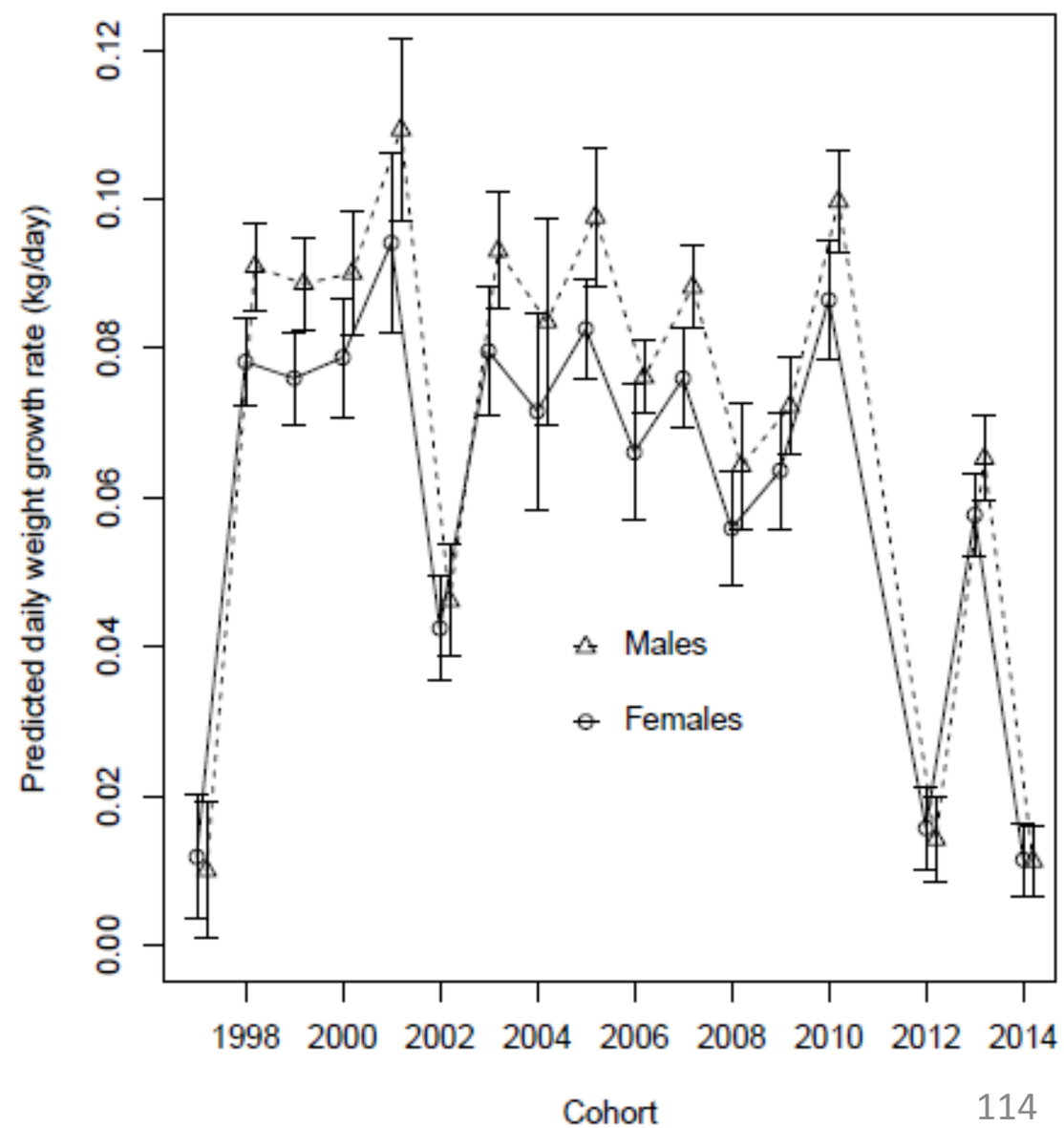
California sea lion pup strandings

- Pup count for 2014 cohort was fairly normal
- But, pup growth is very poor and mortality likely will be ~70%
- Many mothers have to go further to find food and thus are gone longer and having longer periods between nursing

Pup count at San Miguel Island

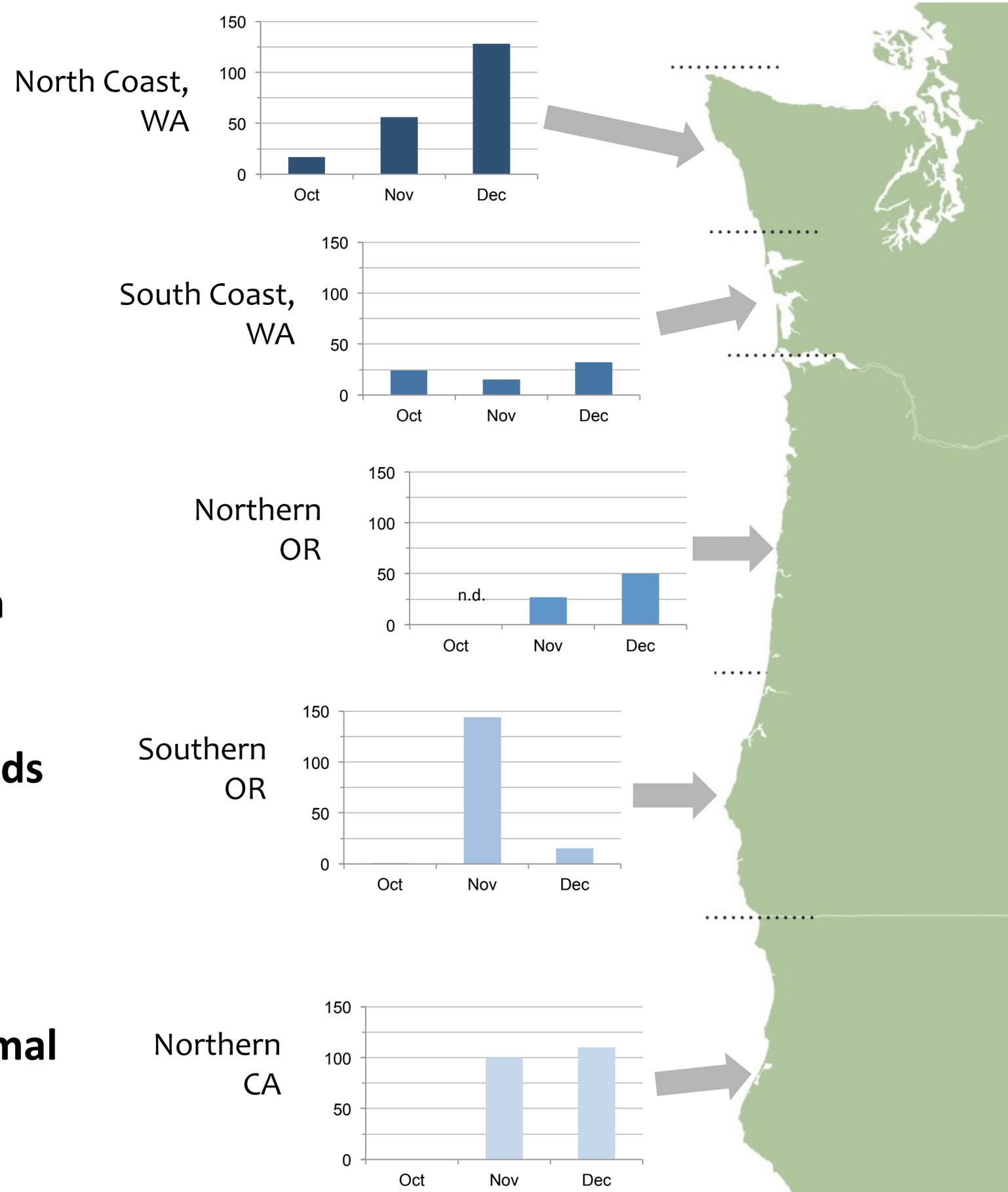


Pup growth at San Miguel Island



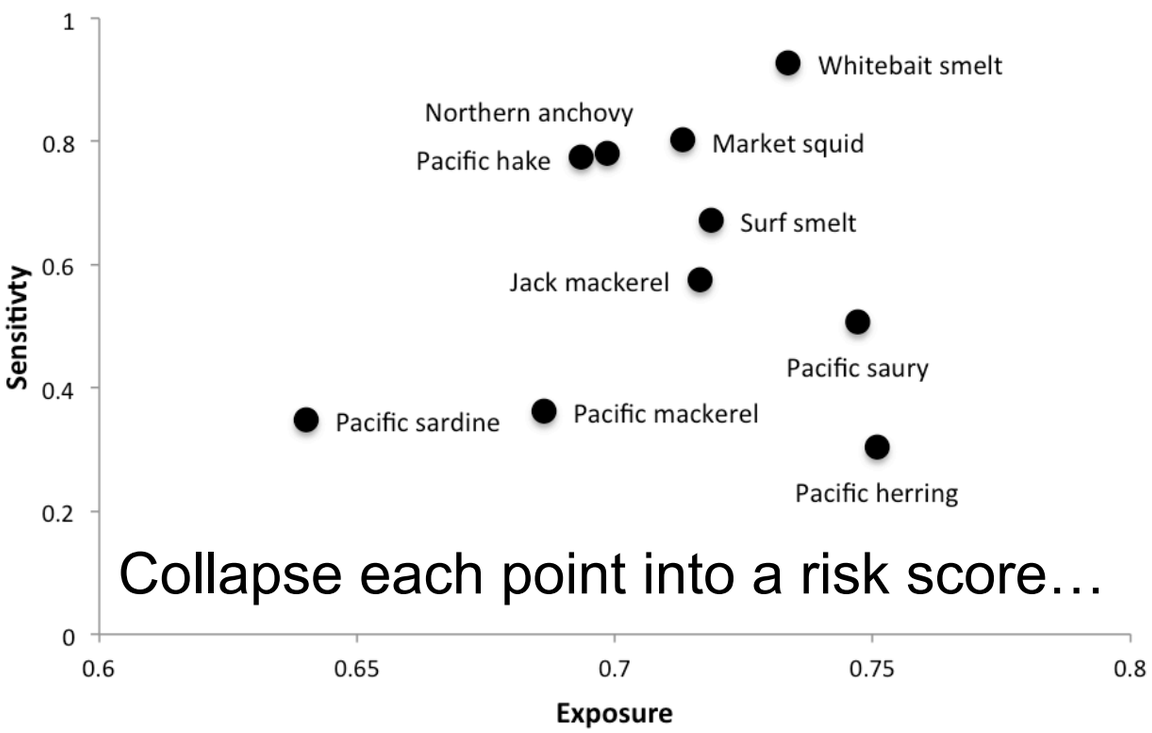
Cassin's Auklet die-off, 2014-2015

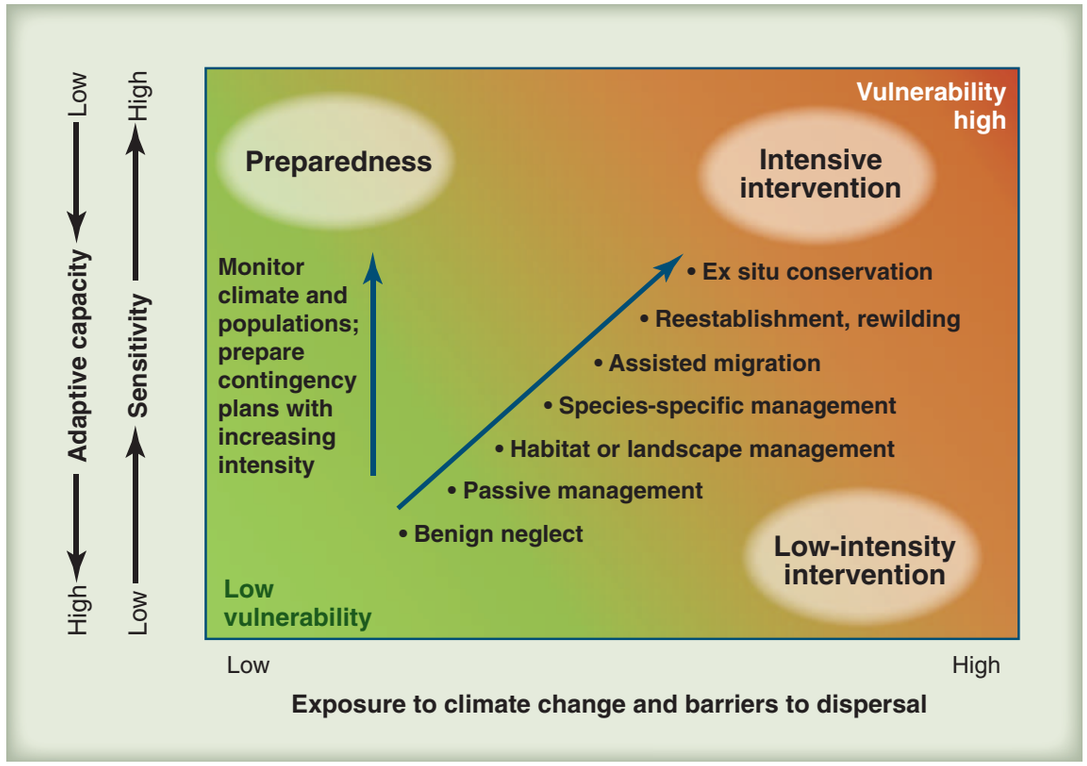
- **The Cassin's auklet is a common seabird that feeds on krill**
- **Data at right: counts of dead birds relative to long-term average**
  - **(i.e., 1 = "normal")**
- **Since last fall, mortality rates of auklets are up to 144 times normal**
- **Cause is still undetermined**



Vulnerability of forage fish to climate change

Premise: increased exposure to expected climatic change, and reduced climatic breadth in the present day → increased vulnerability



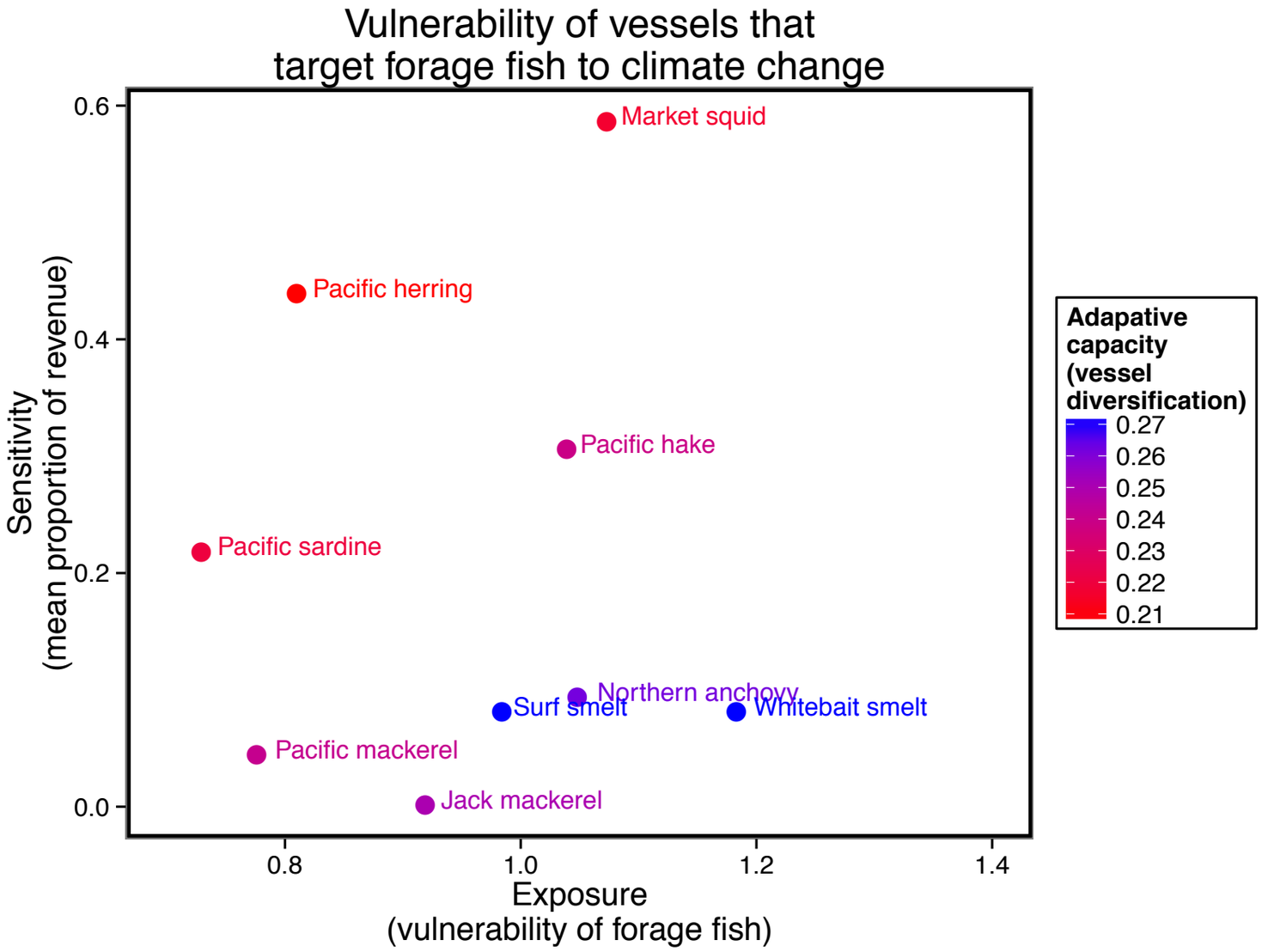


Samhouri et al. in review

Vulnerability of *people* to climate change

Is a vulnerable fish a vulnerable fishery?

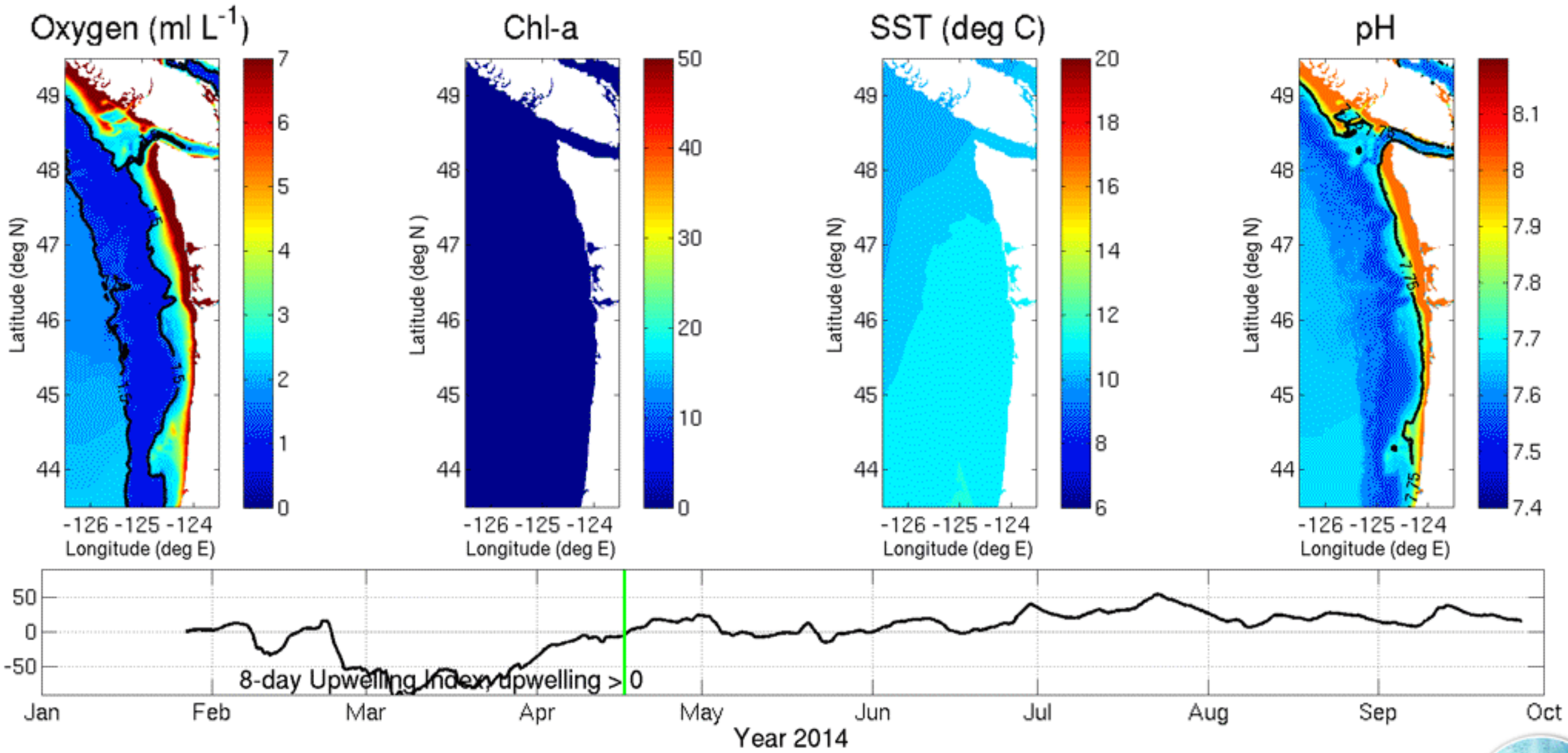
Premise: increased vulnerability of marine resources to expected climatic change, and reduced resilience in human communities → increased vulnerability



Samhouri et al. in review

2014 J-SCOPE Forecast

http://www.nanoos.org/products/j-scope/



Isaac Kaplan, Sam Siedlecki, Al Hermann, Nick Bond, Greg Williams, Bill Peterson, Phil Levin, Jan Newton

Roles and Responsibilities

MSE is at the interface between science and decision-making

Scientists:

- Identify the hypotheses to represent in the operating model.
- Represent the objectives of the decision makers quantitatively.
- Identify factors which could be used in management strategies.

Stakeholders / decision makers / advocates:

- Identify management objectives (note this may be a function of legislation / court decisions, etc.)
- Identify candidate management strategies
- Make decisions on the final management strategy (policy call)

Advantages	Disadvantages
• Having a management strategy makes decision making easier. • Forces explicit consideration of objectives. • Explicit focus on uncertainty and robustness – not optimal performance.	• Development can be lengthy. • Bad MSEs can lead to bad outcomes. • Stakeholders may not wish to state their objectives. • In the US, some strategies are constrained by law.

Recommendations and responses (3/3)

Recommendation

Panelists recommended fostering international collaboration (ISC, PICES, ICES) on climate variability effects on pelagic fish/fisheries and associated ecosystems to identify thresholds for defining the risk to marine resources.

Action Item

The Center will continue its participation in international bodies such as ISC and PICES with respect to research into the effects of climate variability and change on pelagic and other fisheries resources and their ecosystems.

PICES-ISC Collaboration

ISC's Mission: enhance scientific research and cooperation for conservation and rational utilization of the species of tuna and tuna-like fisheries which inhabit the N. Pacific

PICES' Mission: promote and coordinate marine research in the northern N. Pacific and adjacent seas.

ISC-PICES Geographic Overlap

1. Many pelagic species have environmental thresholds and preferences that limit the spatial distribution of a species (oxygen, salinity and temperature).
2. Because these factors generally exhibit persistent space-time patterns, the general distribution of pelagic fishes is known.
3. Knowledge of these relationships allows for the incorporation of climate change into stock assessments, which forms the basis for fisheries management.

Thank you!

An Integrated Ecosystem Assessment (IEA) ties the environment, fisheries and socio-economics together

The IEA brings Environmental Intelligence into Ecosystem Based Management.

- The California Current (CCIEA) is the most advanced of the seven regional IEA programs

- The California Current extends from Canada to central Mexico and includes the entire west coast of the continental US.

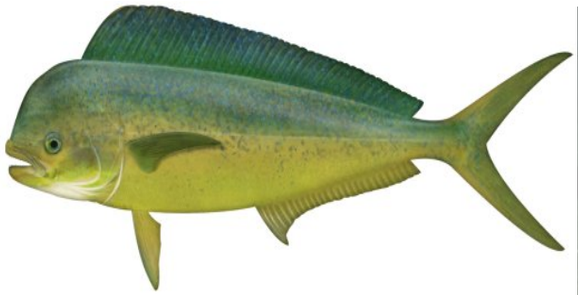
- We are experiencing the warmest conditions ever observed in the NE Pacific

- NOAA Fisheries Science Centers are assembling the integrated assessments

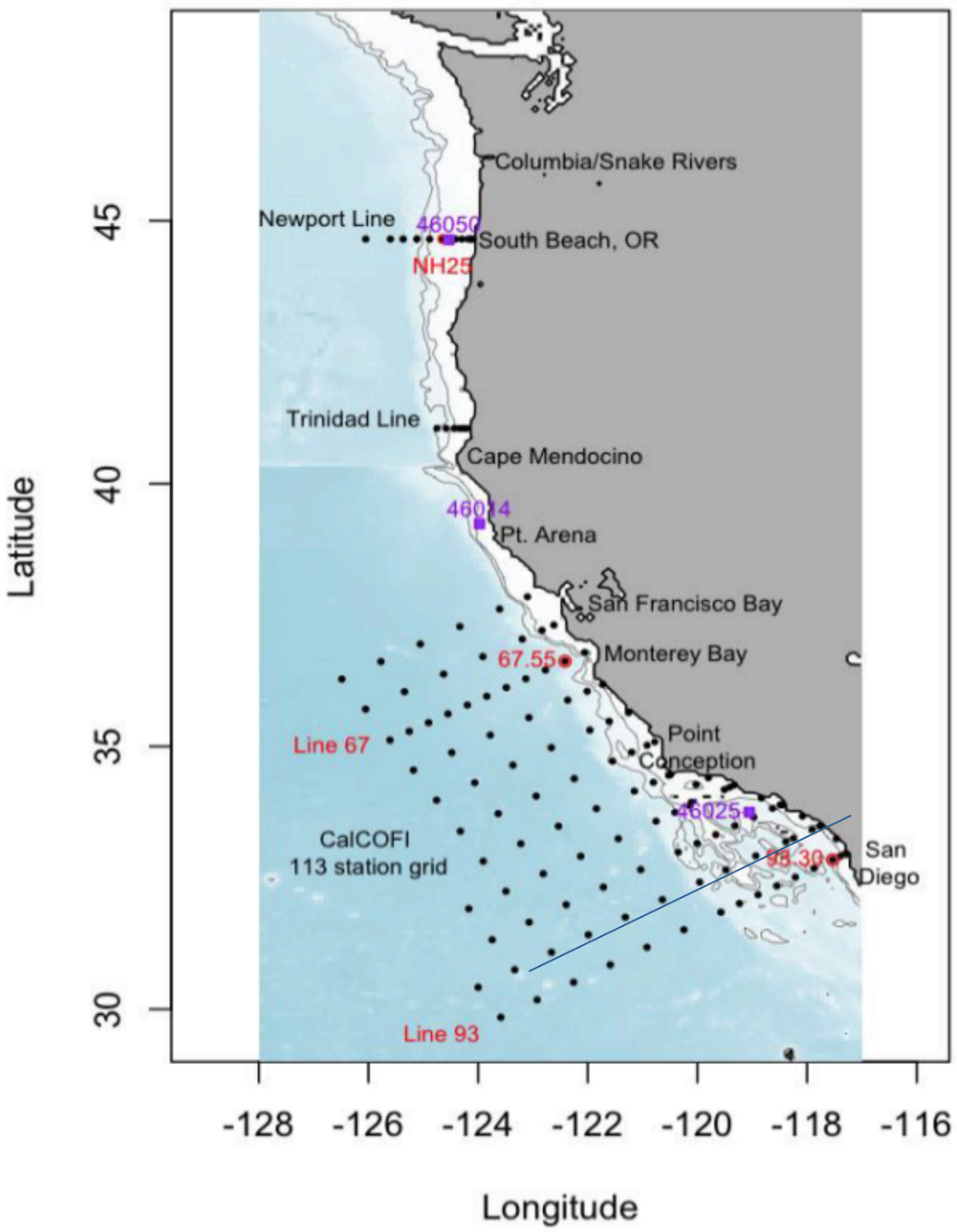
- The Pacific Fishery Management Council's Fishery Ecosystem Plan includes an annual presentation from the NOAA CCIEA team with an update on both the ecosystem and ecological conditions.

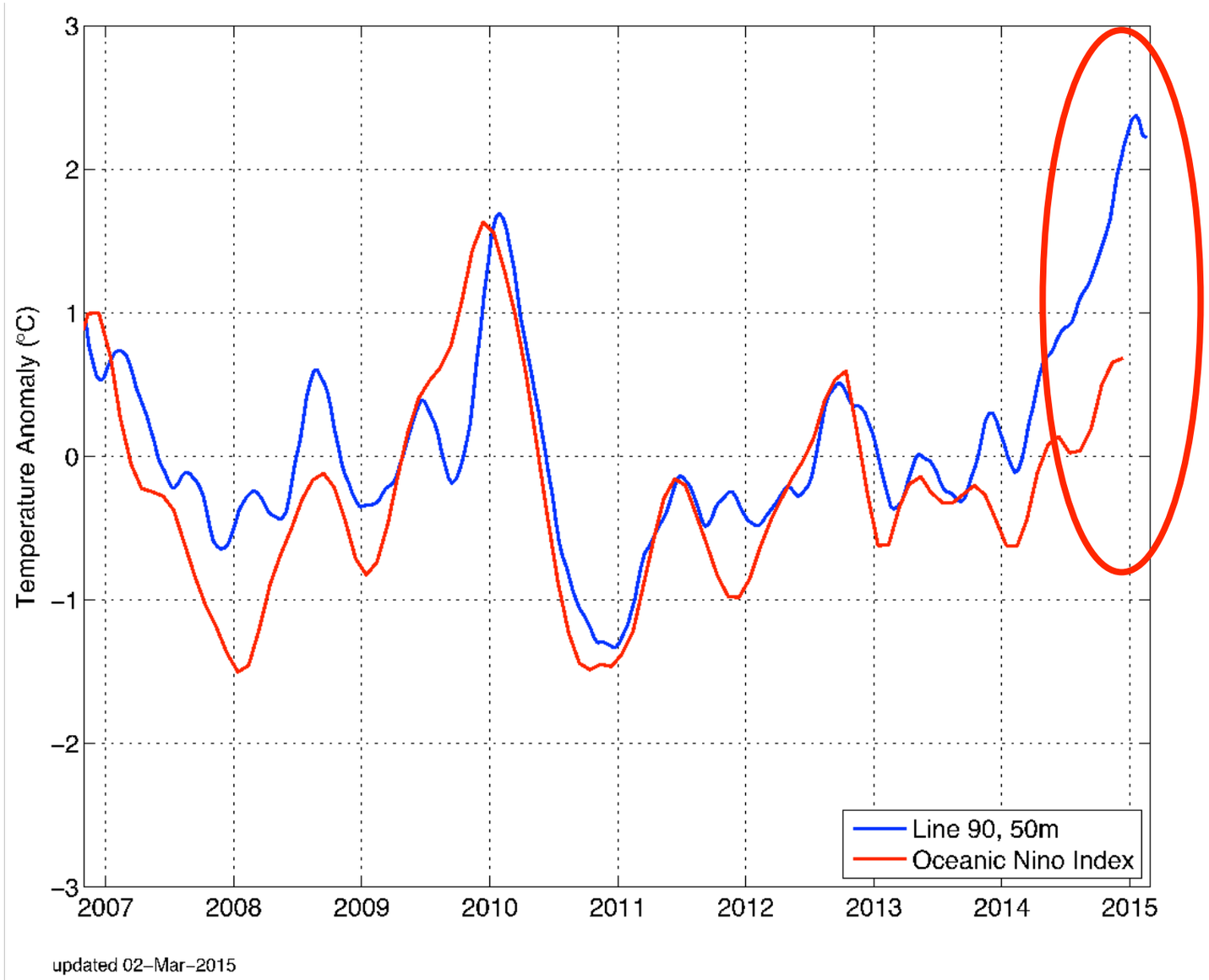
Effects of El Niño/Warm Conditions in the CC

- Warmer, more subtropical, ocean conditions; reduced primary and secondary production
- Improved growth and recruitment for some species, such as sardines; reduced recruitment for rockfish, squid, anchovies, etc.
- Anchovy, market squid and CA sea lion populations in So. California decline; whiting and sardines migrate further north, into Canadian waters
- Tropical fish like mahimahi, swordfish, and marlin, and subtropical fish like Albacore and Pacific bonito, move north/onshore



Southern California Bight SST usually closely reflects the Niño3.4 index. 2014 is very different as the Bight is warmer.





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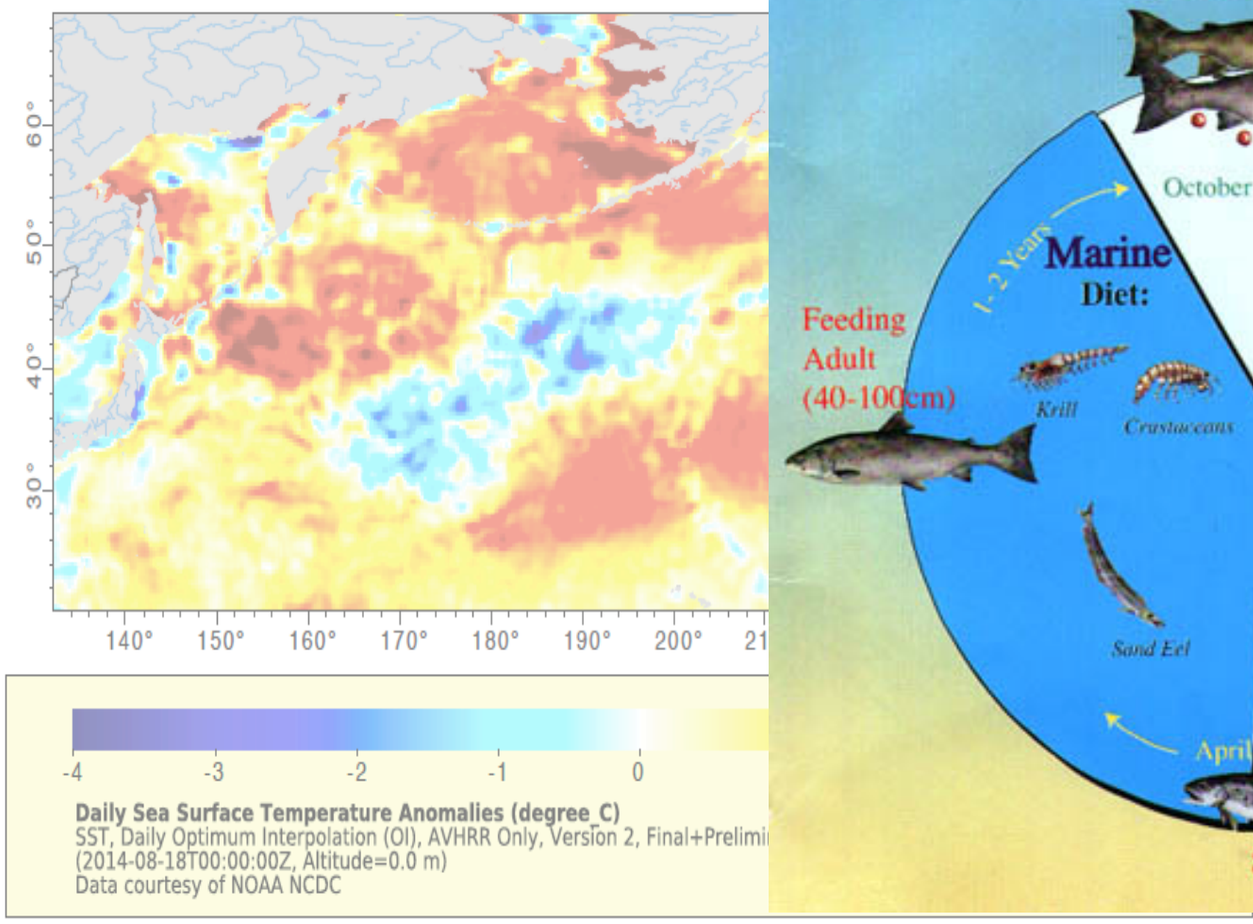
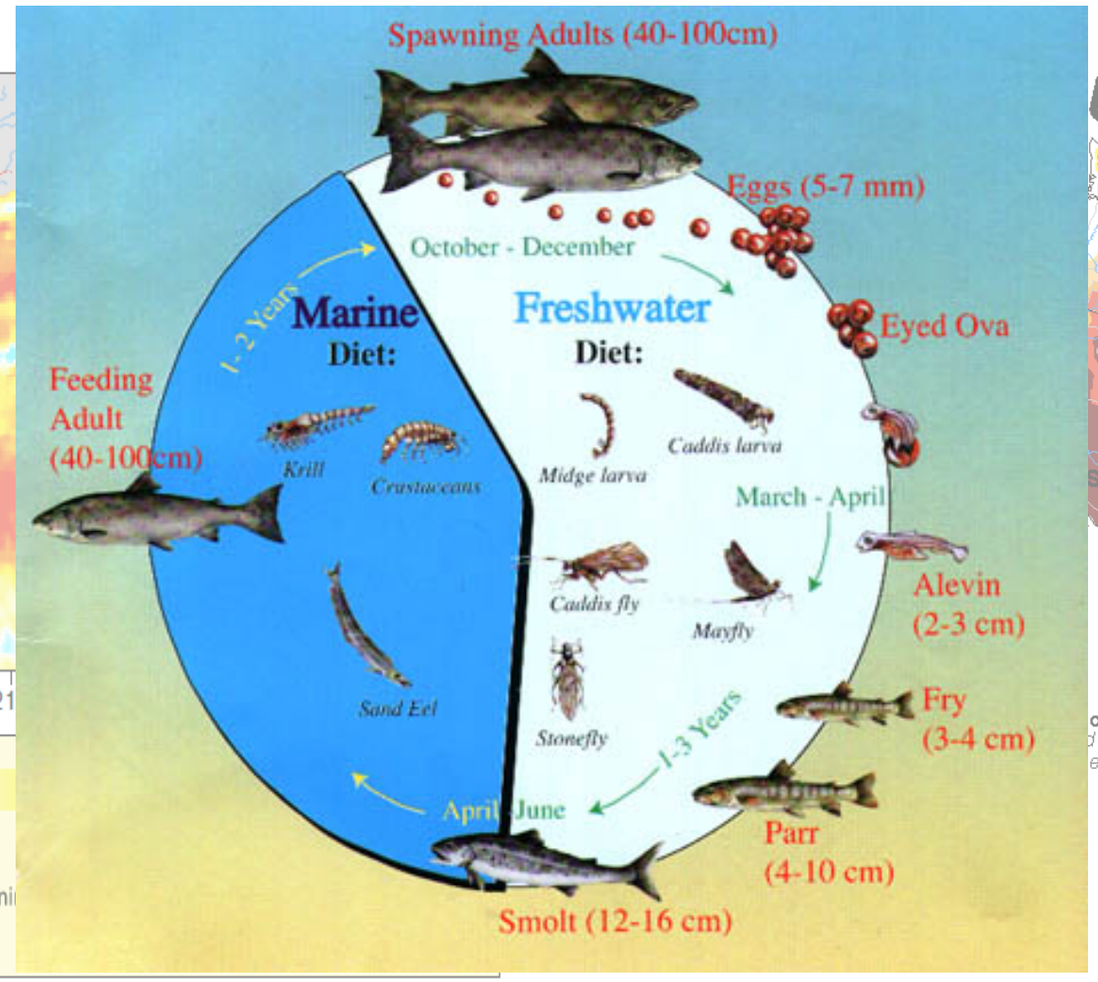
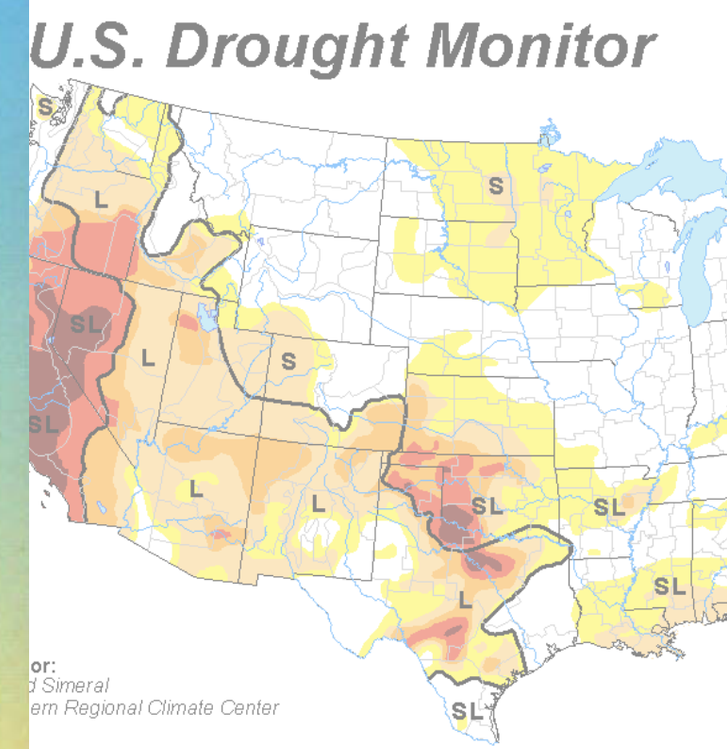
Human activities

Commercial albacore fishing off Oregon. (Helena Aryafar, NOAA)

Why bother?
We can no longer look at the ecosystem components in isolation – they are *integrated*…



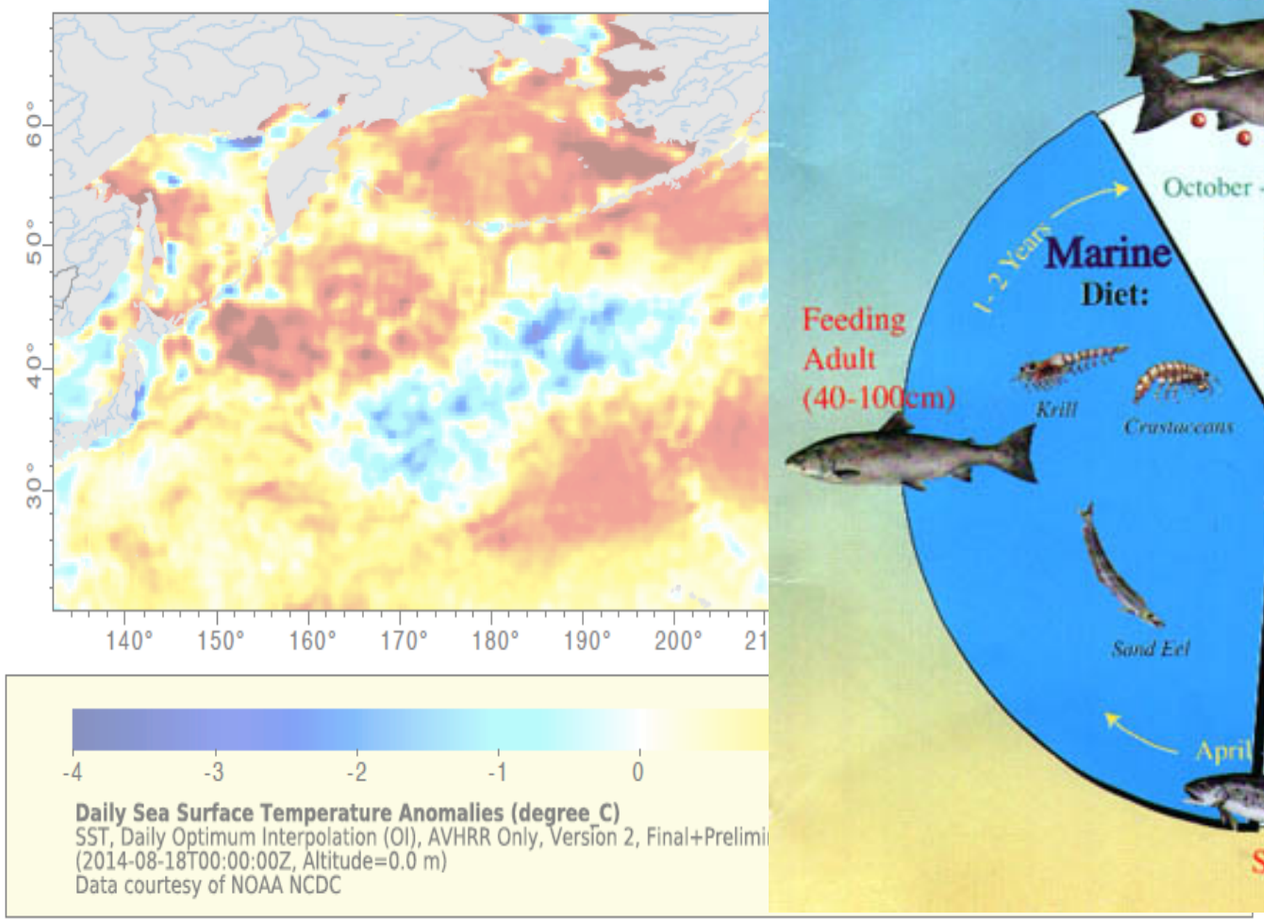


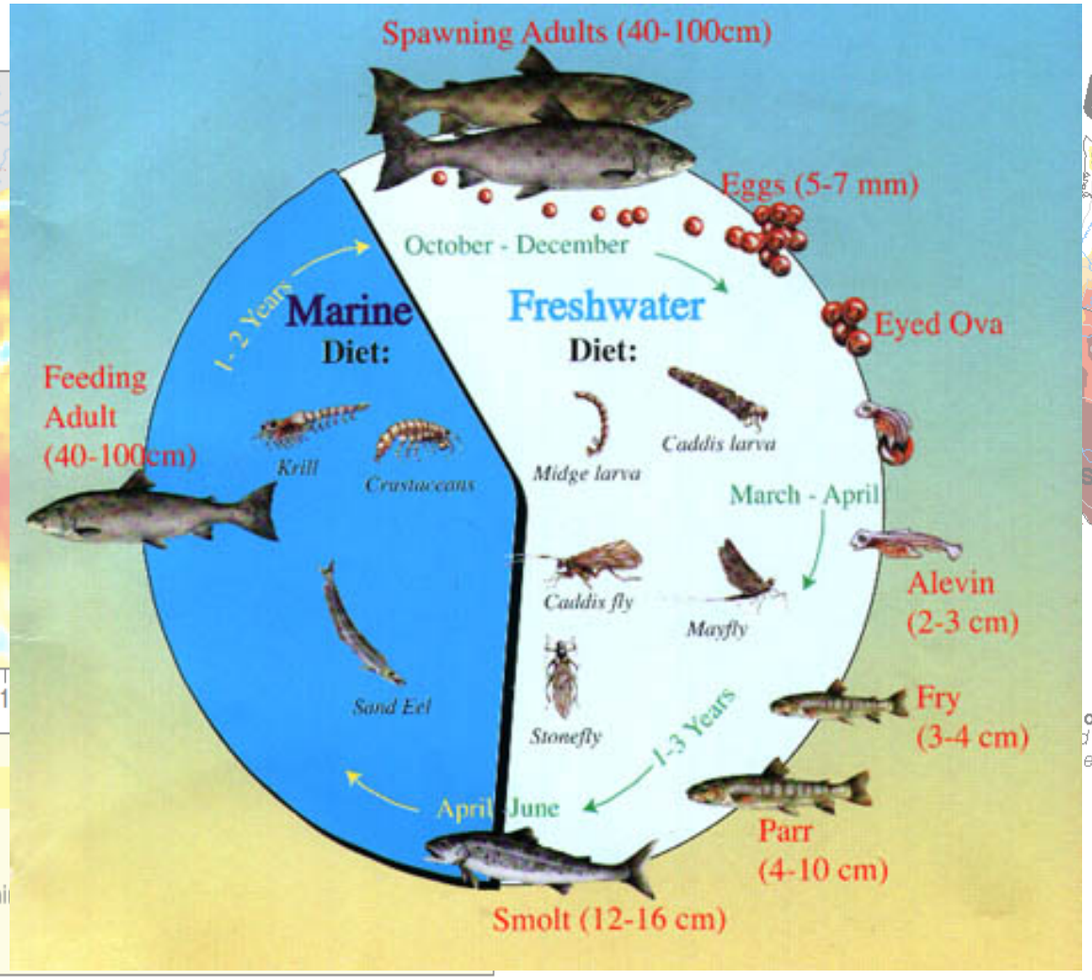


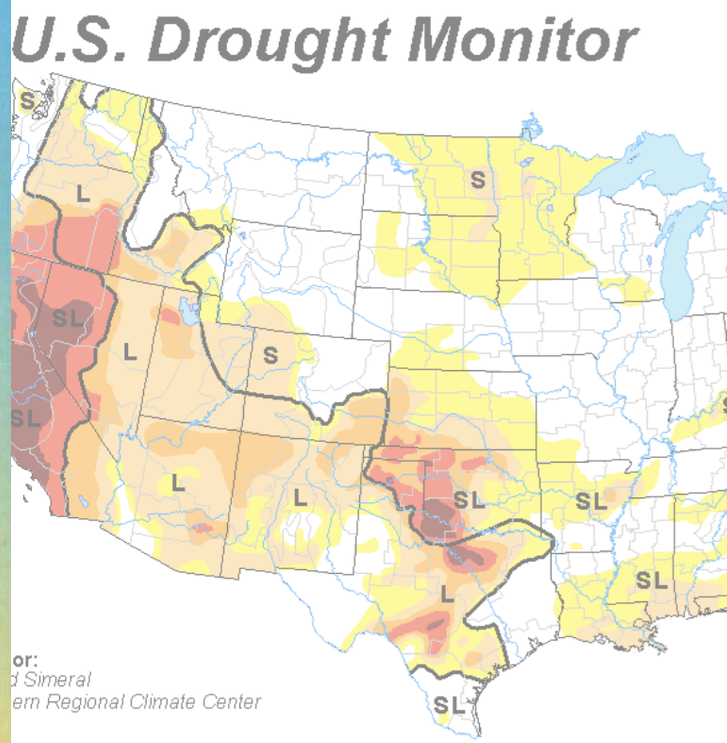
Hence an integrated Ecosystem Assessment Report to the Pacific Fishery Management Council

That's environmental Intelligence at its best.

We can’t look at the ecosystem components in isolation – they are *integrated*…



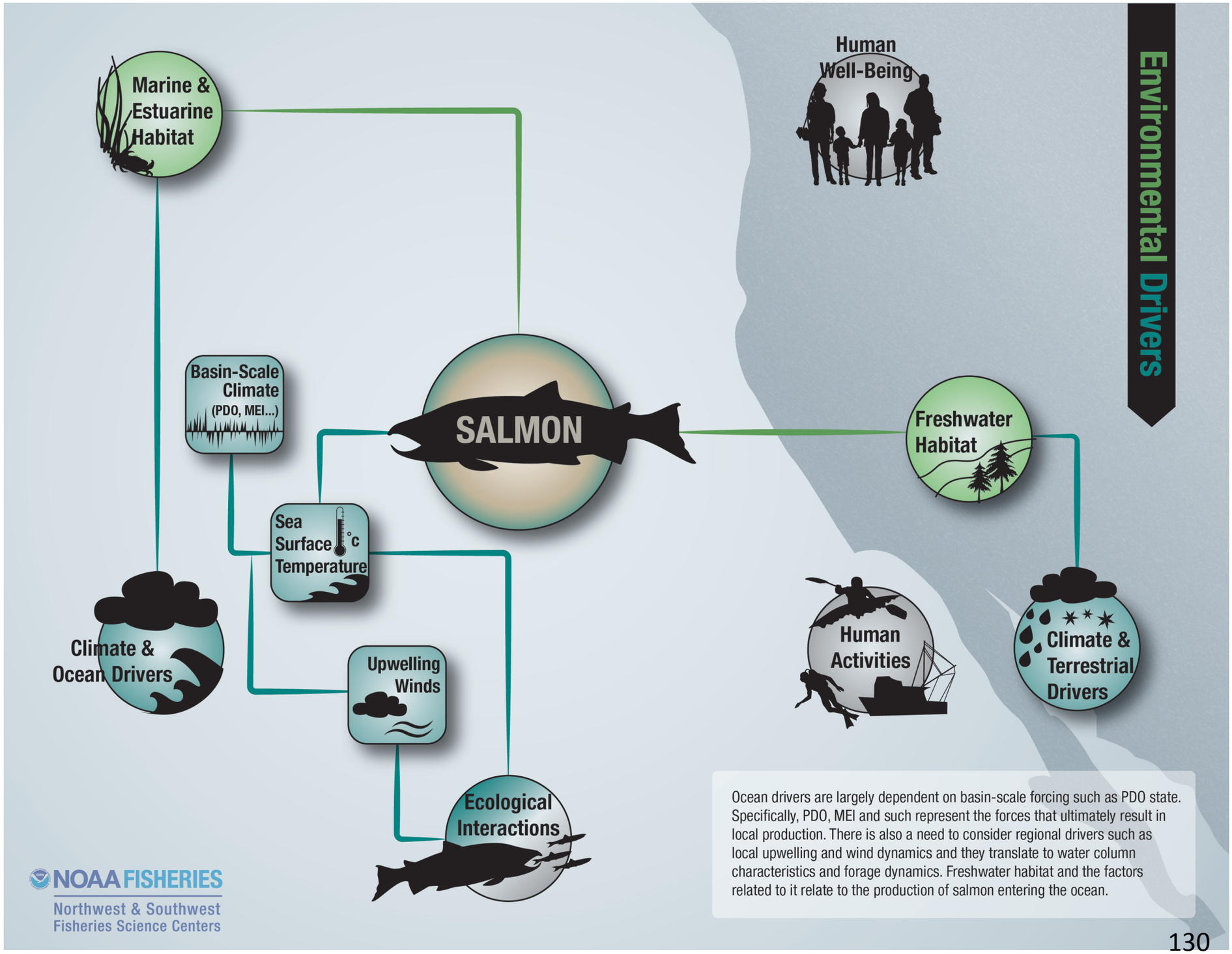




How do these anomalies affect us?

(case study: salmon)

Environmental Drivers

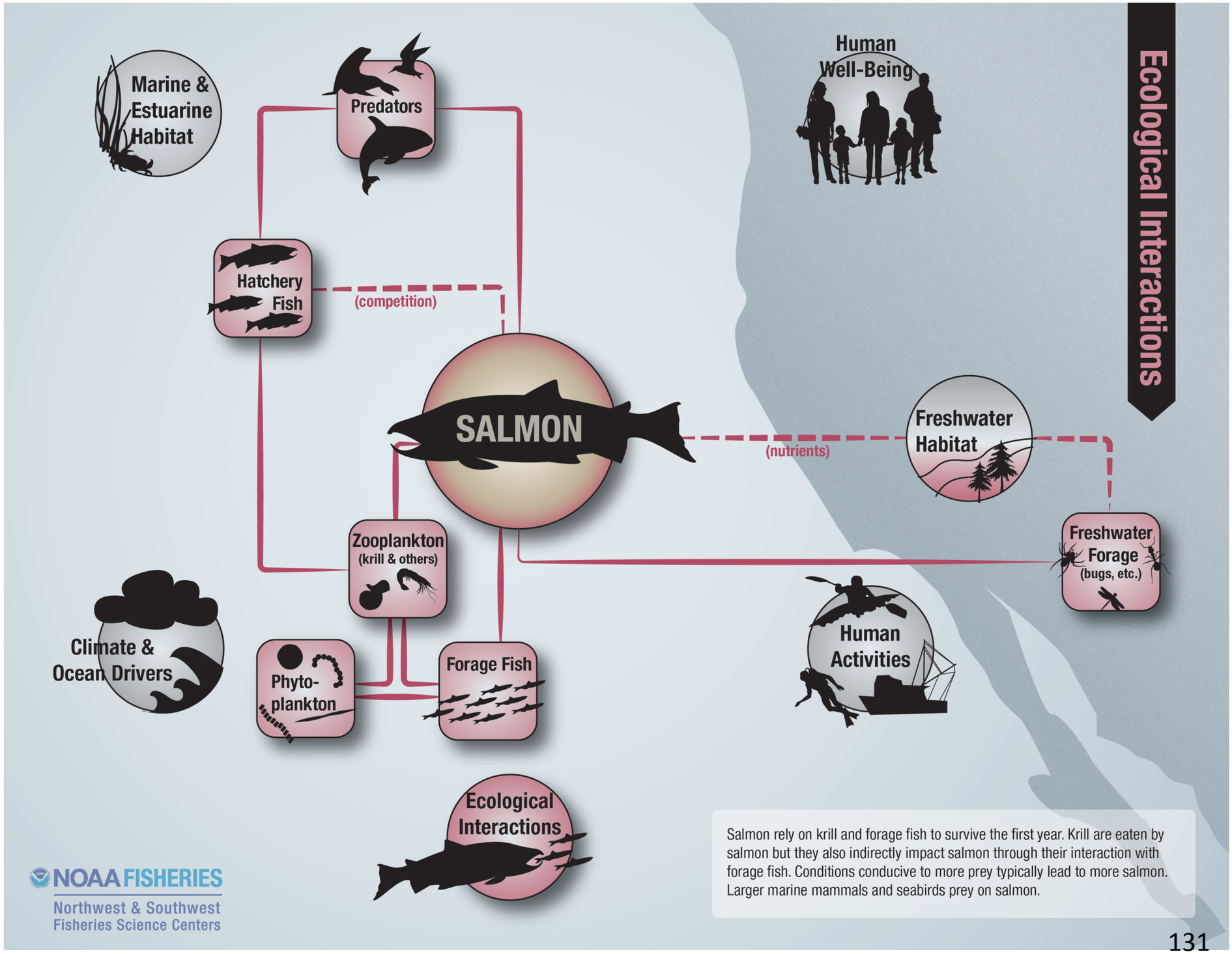


Ocean drivers are largely dependent on basin-scale forcing such as PDO state. Specifically, PDO, MEI and such represent the forces that ultimately result in local production. There is also a need to consider regional drivers such as local upwelling and wind dynamics and they translate to water column characteristics and forage dynamics. Freshwater habitat and the factors related to it relate to the production of salmon entering the ocean.

How do these anomalies affect us?

(case study: salmon)

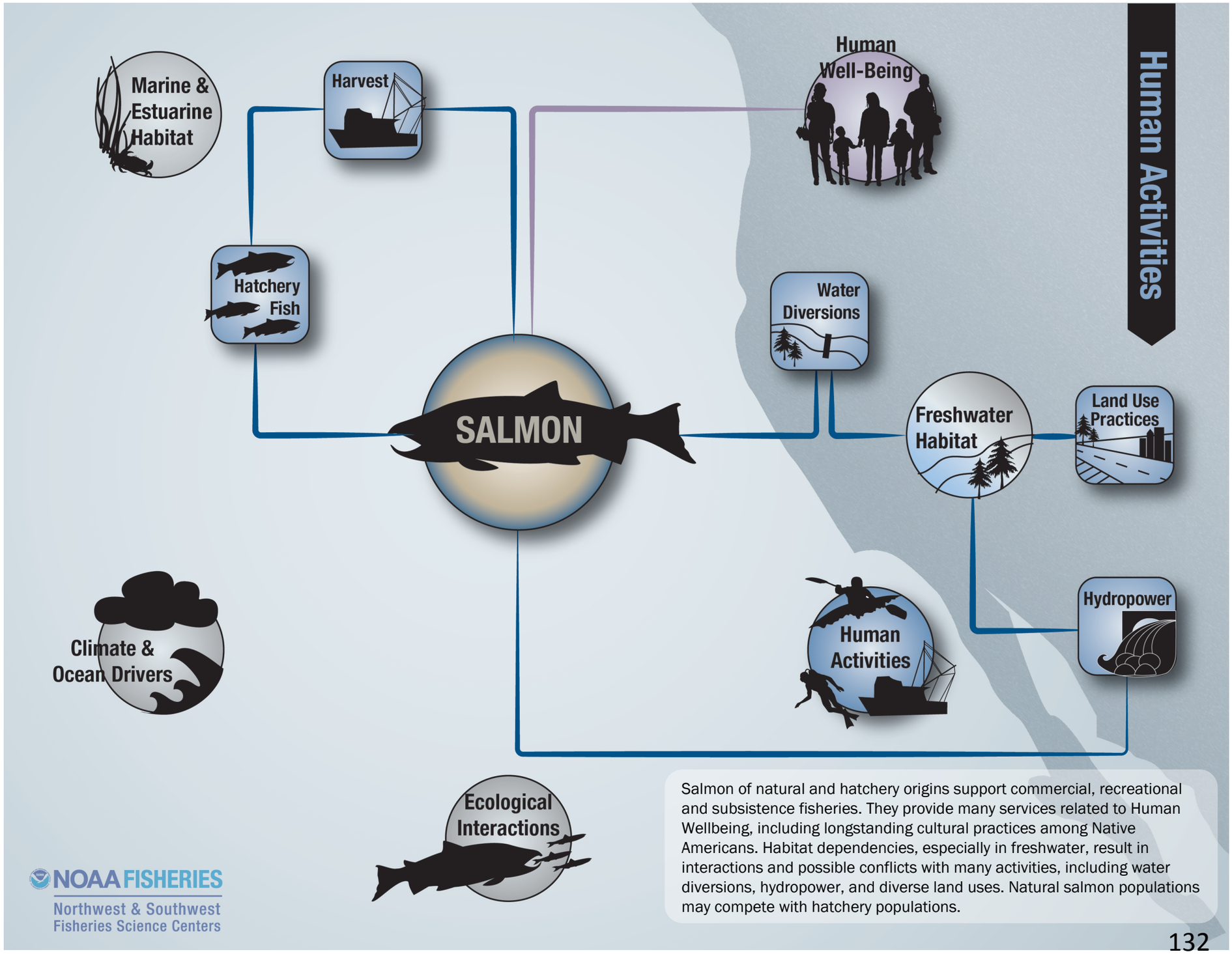
Ecological Interactions



How do these anomalies affect us?

(case study: salmon)

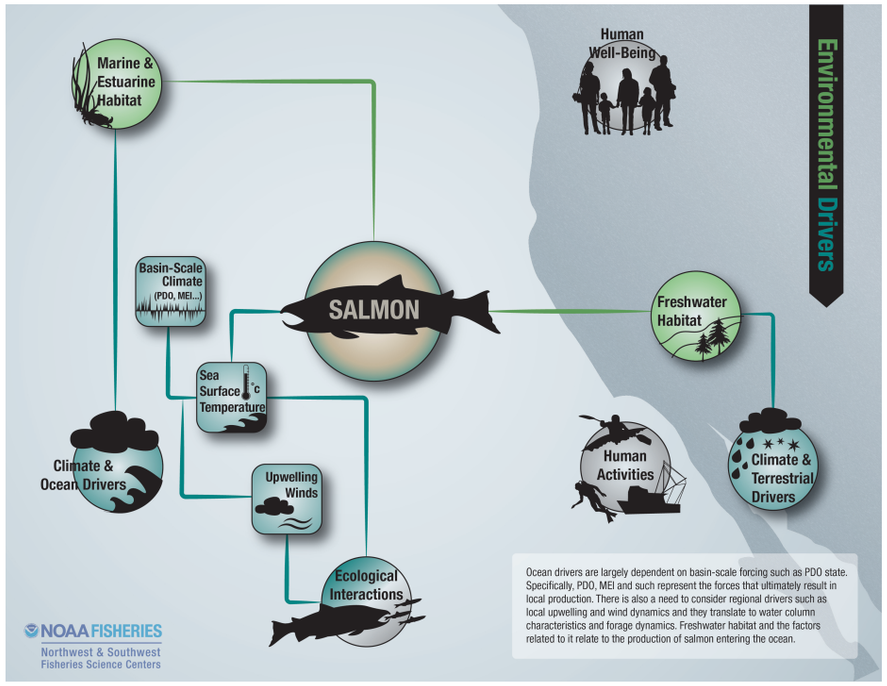
Human Activities



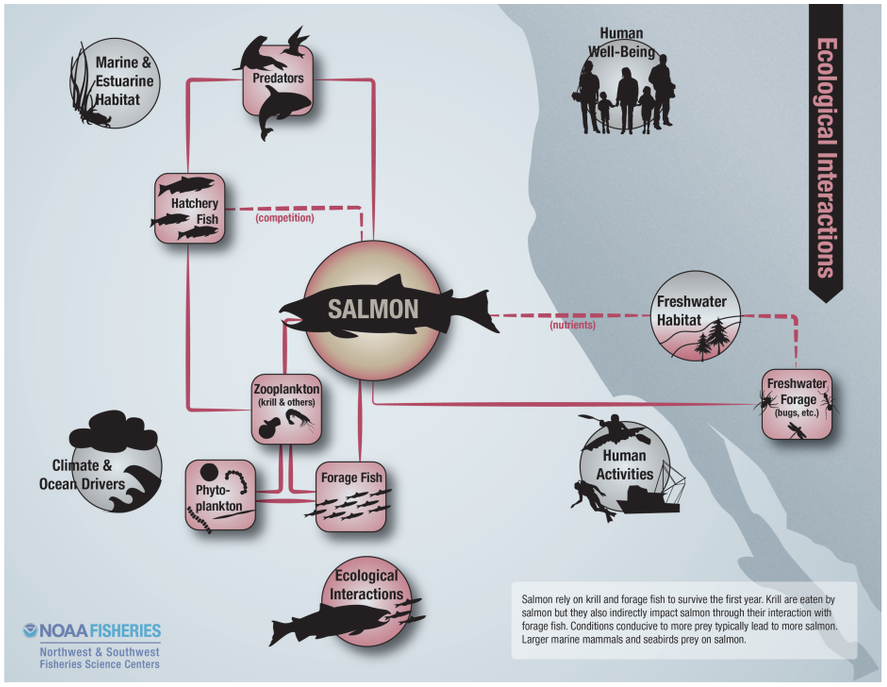
How do these anomalies affect us?

(case study: salmon)

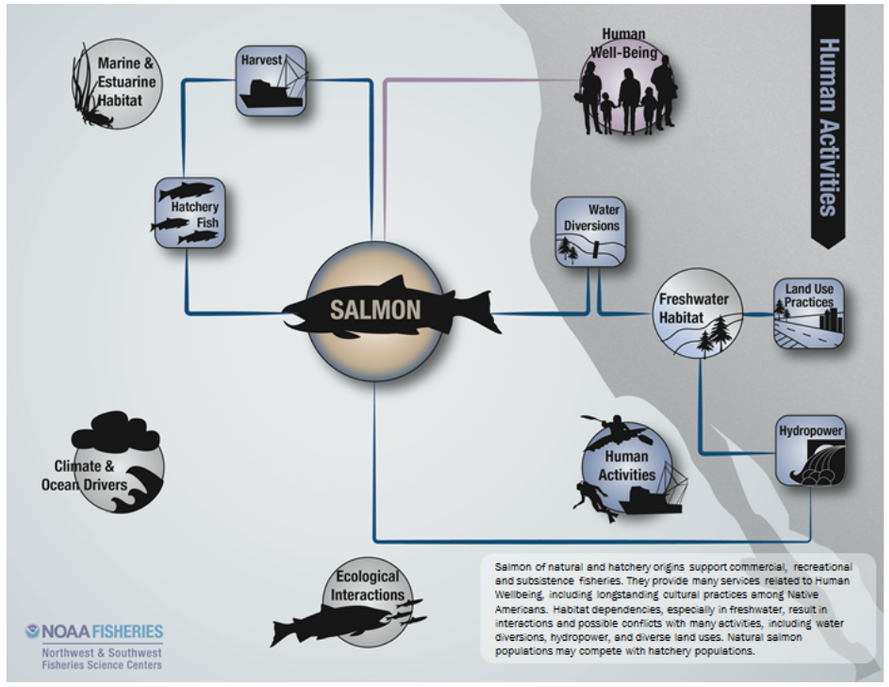
Environmental Drivers



Ecological Interactions



Human Activities



Emaciated California sea lion pup, San Nicolas Island, early 2015. (photo: Sharon Melin, NOAA)

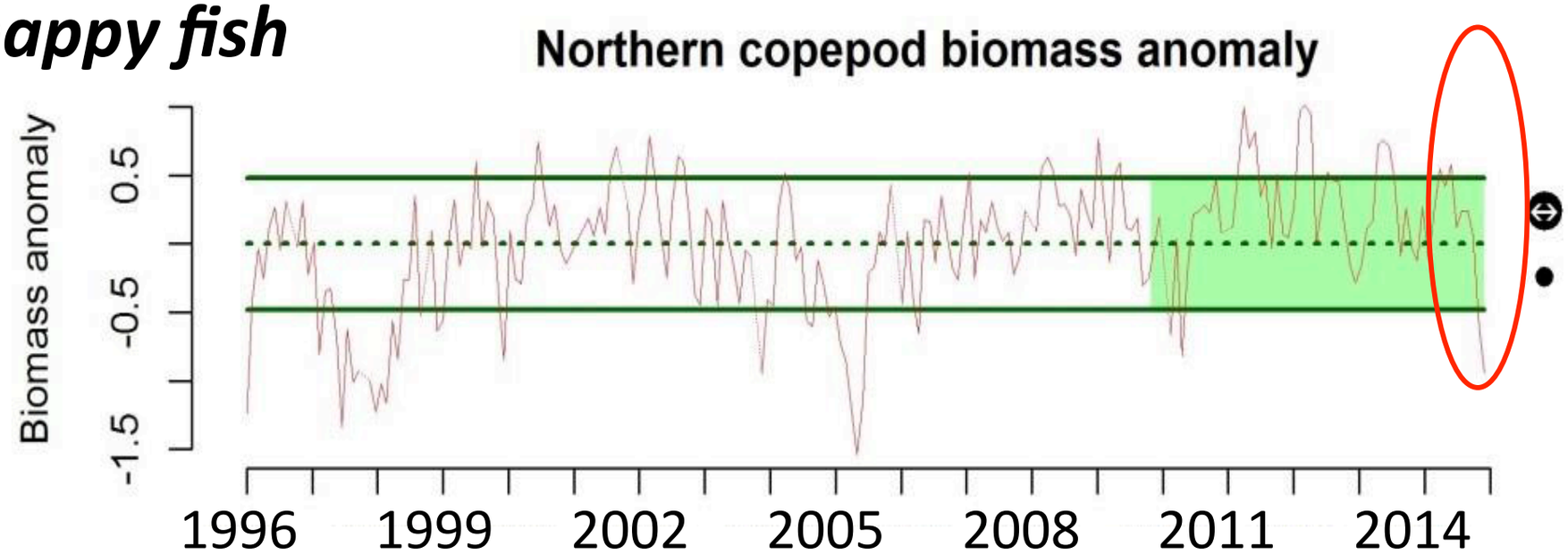
2. Ecological responses to "warm blob"

There are northern and southern copepod assemblages:

≈

northern copepod = happy fish

- **"Northern" copepods are rich in lipids that support fish production**
- **Northern copepods associated with cooler waters in the California Current**
- **In recent years off Newport, OR: northern copepods have been abundant**
- **But, a major shift occurred in late 2014**



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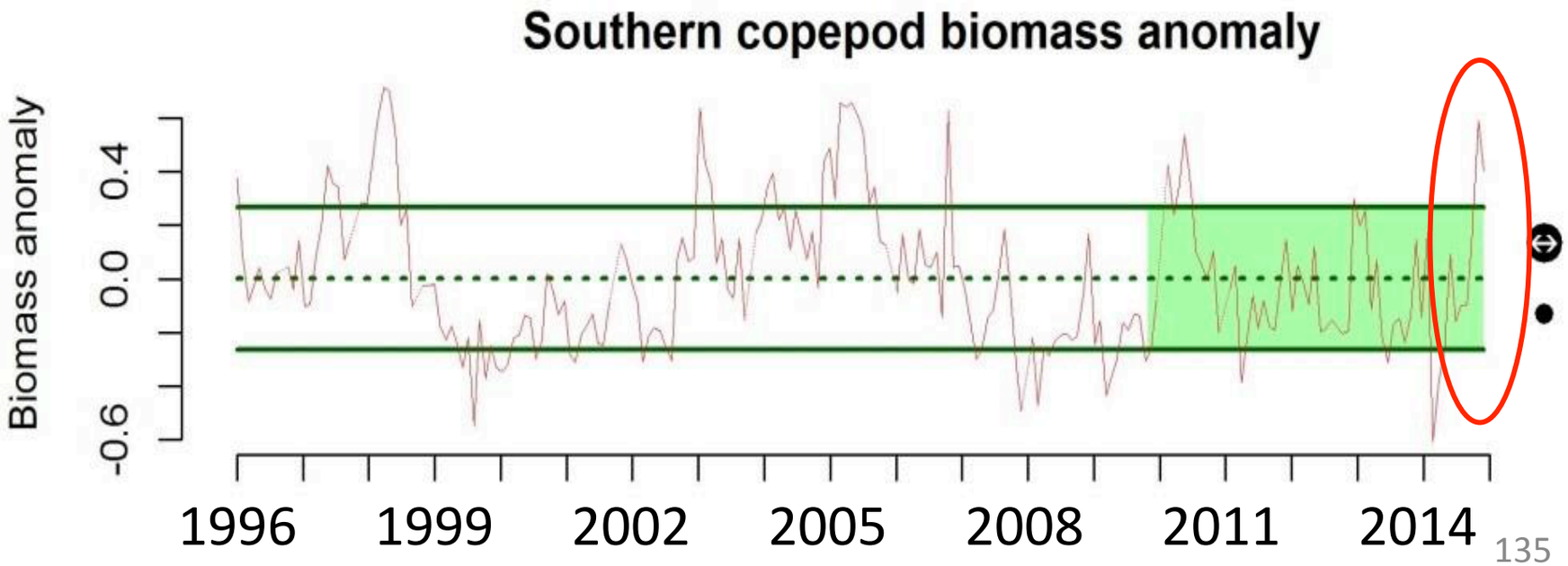
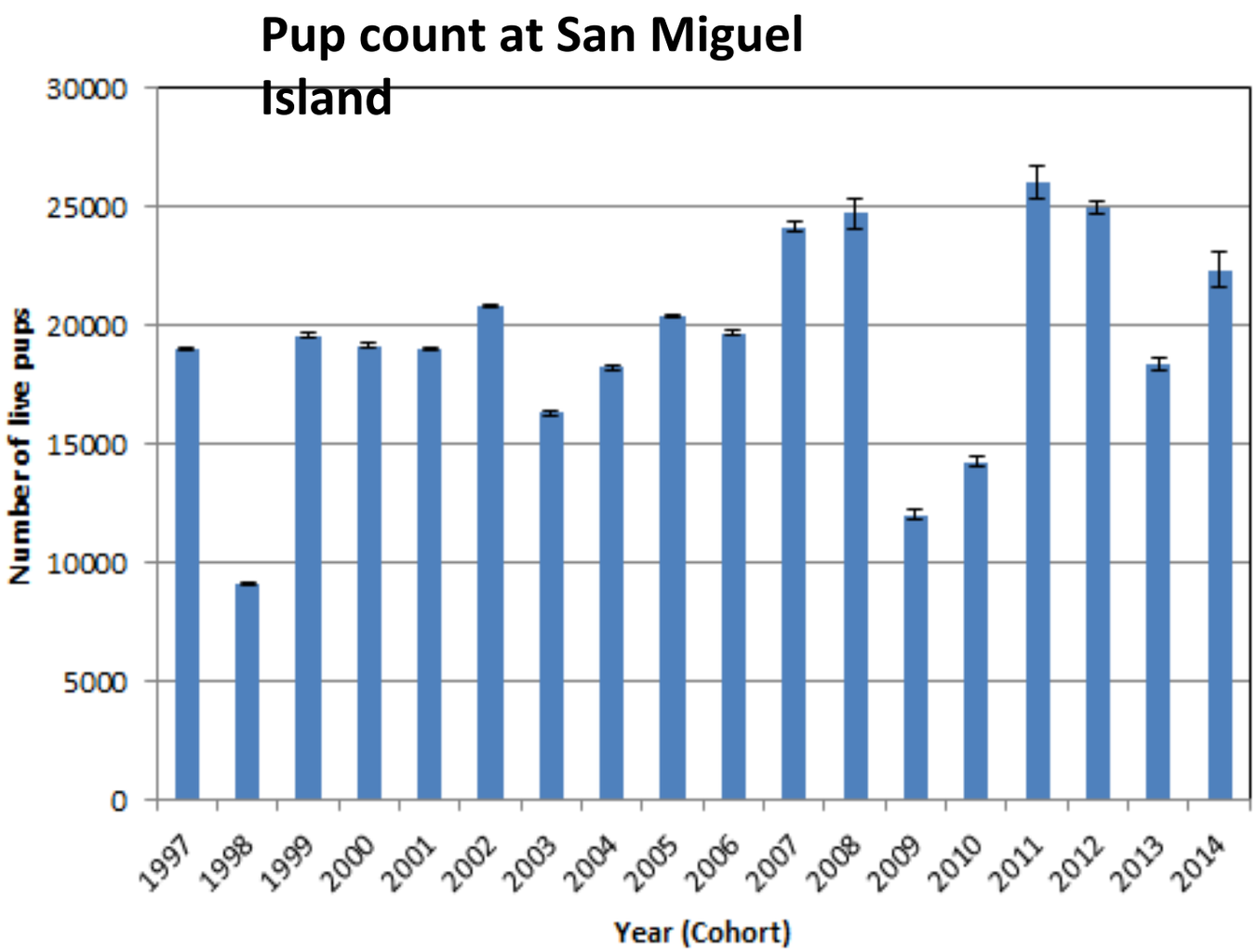
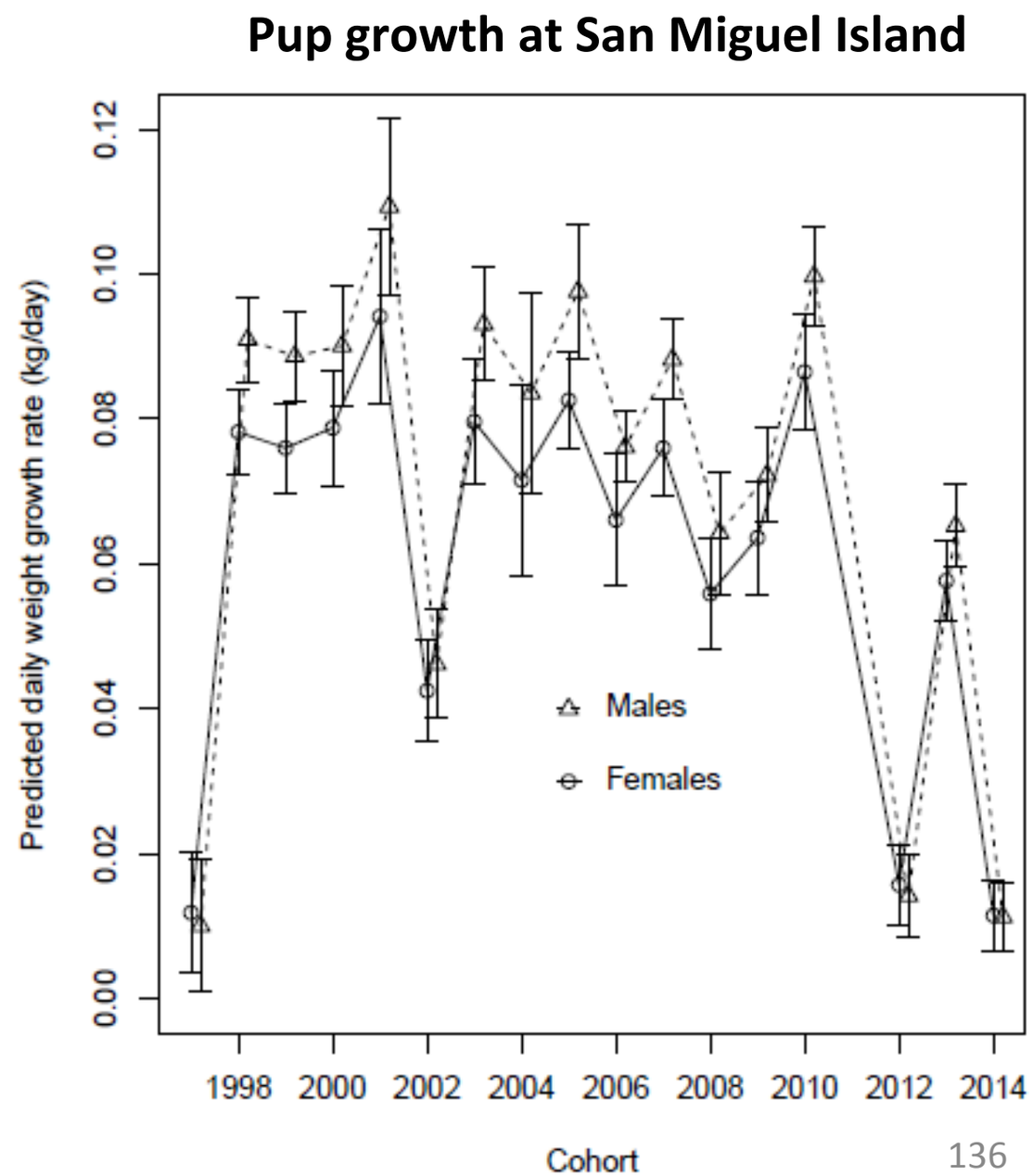


California sea lion pup strandings

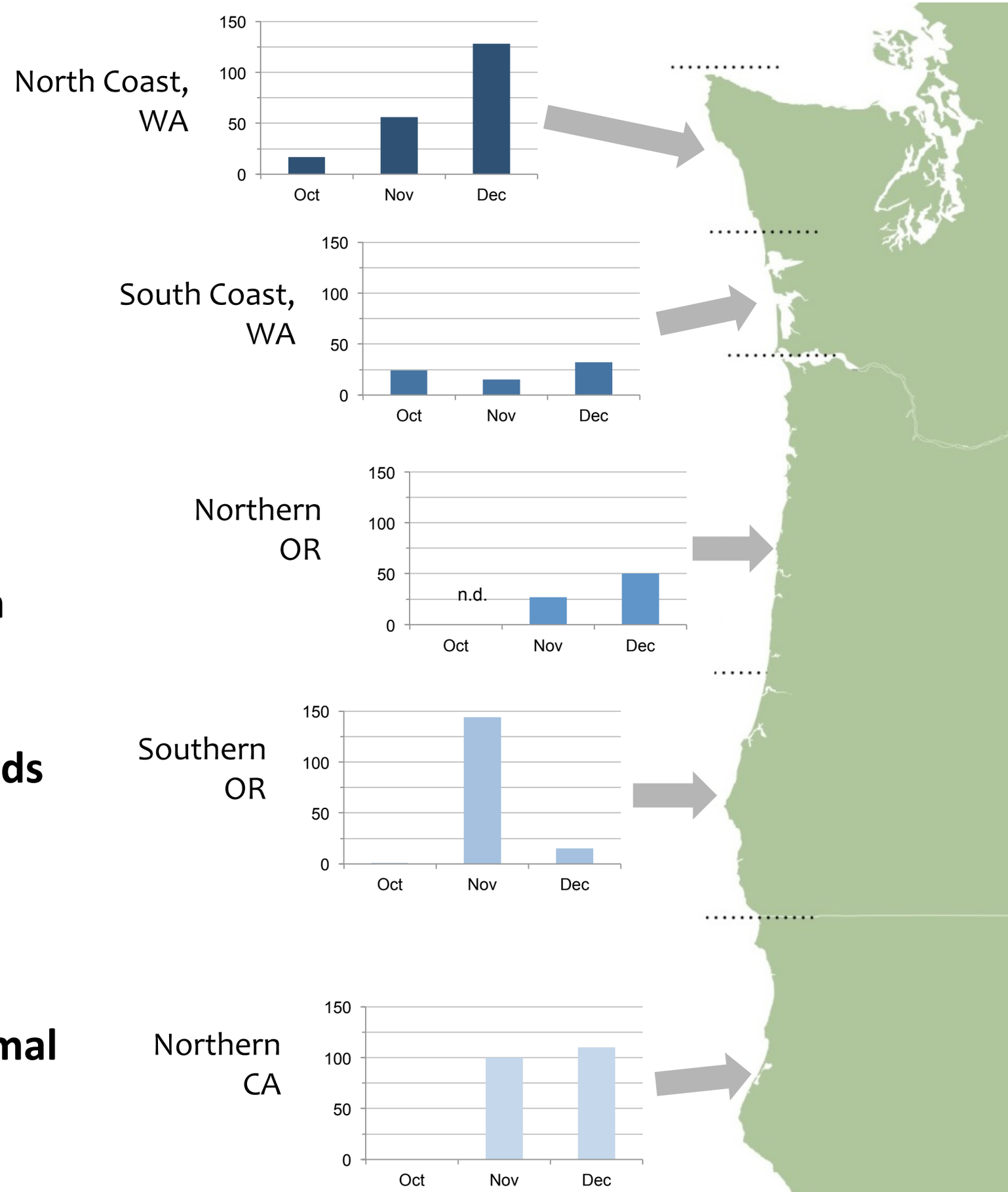
- Pup count for 2014 cohort was fairly normal
- But, pup growth is very poor and mortality likely will be ~70%
- Many mothers have to go further to find food and thus are gone longer and having longer periods between nursing





Cassin's Auklet die-off, 2014-2015

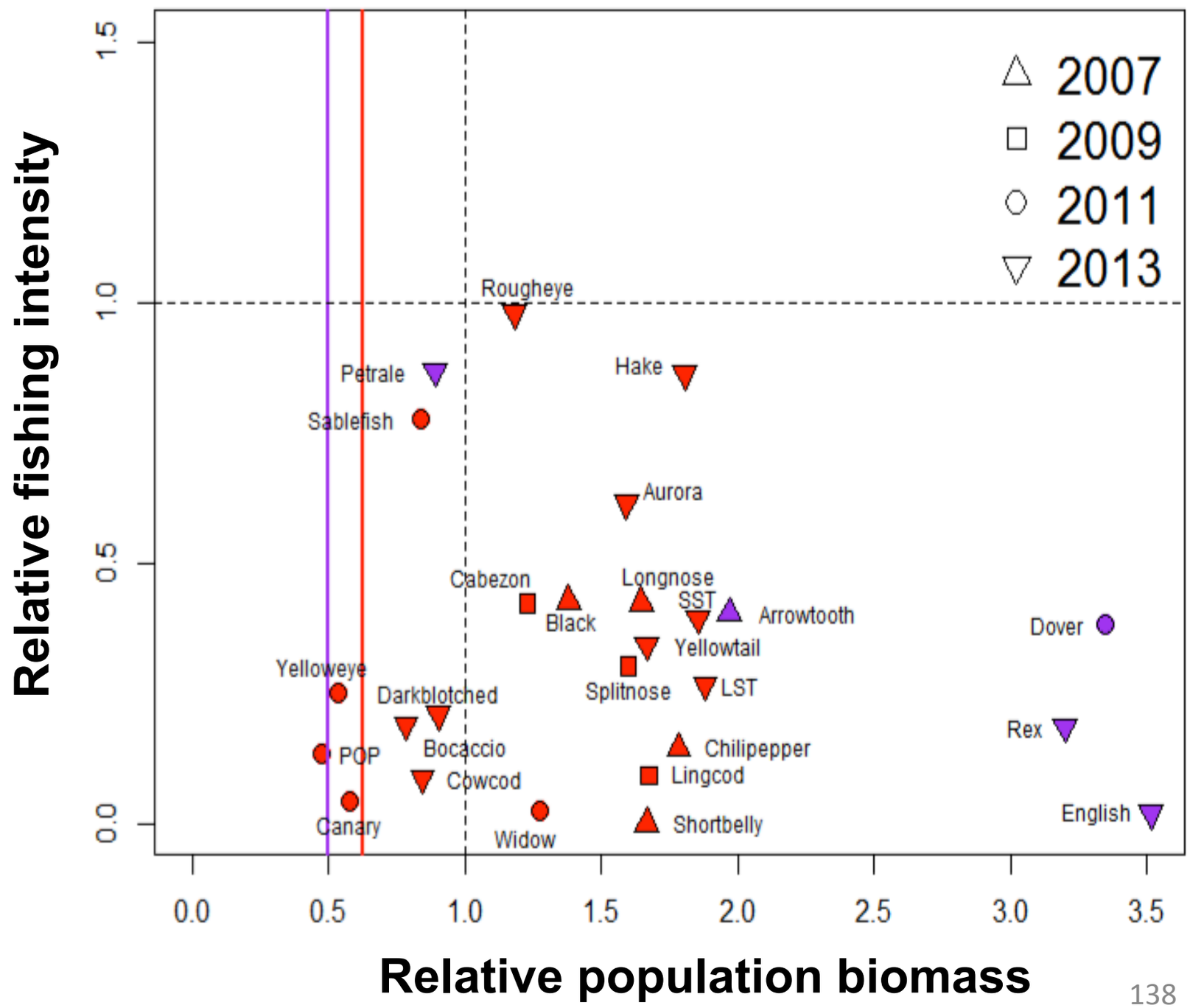
- **The Cassin's auklet is a common seabird that feeds on krill**
- **Data at right: counts of dead birds relative to long-term average**
  - **(i.e., 1 = "normal")**
- **Since last fall, mortality rates of auklets are up to 144 times normal**
- **Cause is still undetermined**



Ecosystem Indicators: Groundfish

- *Based on recently assessed stocks; most recent assessments in 2013*
- Most populations are above biomass management thresholds, some considerably
- Three rockfish remain "overfished"
- All assessed stocks below or well below "overfishing" limit

How will "warm blob" affect recruitment, growth, distribution and reproduction?



Rosy rockfish, corals, sponges and anemones on Cordell Bank. (Rick Starr, NOAA)

3. Indicators of ecological integrity

4. What the IEA can do

Commercial albacore fishing off Oregon.
(Helena Aryafar, NOAA)

Emaciated California sea lion pup, San Nicolas Island, early 2015. (photo: Sharon Melin, NOAA)

Ecological responses to "warm blob"

Canary rockfish in the Olympic Coast National Marine Sanctuary off the Washington coast (NOAA)

Synthesis

Possible Impacts of a Changing Climate

Climate Changes	Physical Chemical Impacts	Biological Impacts	Social Economic Impacts
↑ Atmospheric Greenhouse Gases	Δ Upwelling and Circulation	Δ Productivity	Δ Fishing activities
↑ Air Temperature	Δ Stratification	Δ Life Histories	Δ Revenues and economies
Δ Winds	Δ Nutrients	Δ Species distribution	Δ Industries
Altered Snowpack and Streamflow	Δ Dissolved O_2	Δ Species abundance	Δ Subsistence use
↑ Sea Level	↑ Ocean Acidification	Δ Community composition	Δ Community health

Observed or Projected Changes in Oceanography

Sea Surface Temperature: 1950-2007 + .09 °C
2006-2055 + 0.8-1.0 °C
2050-2100 + 2.25-2.5 °C

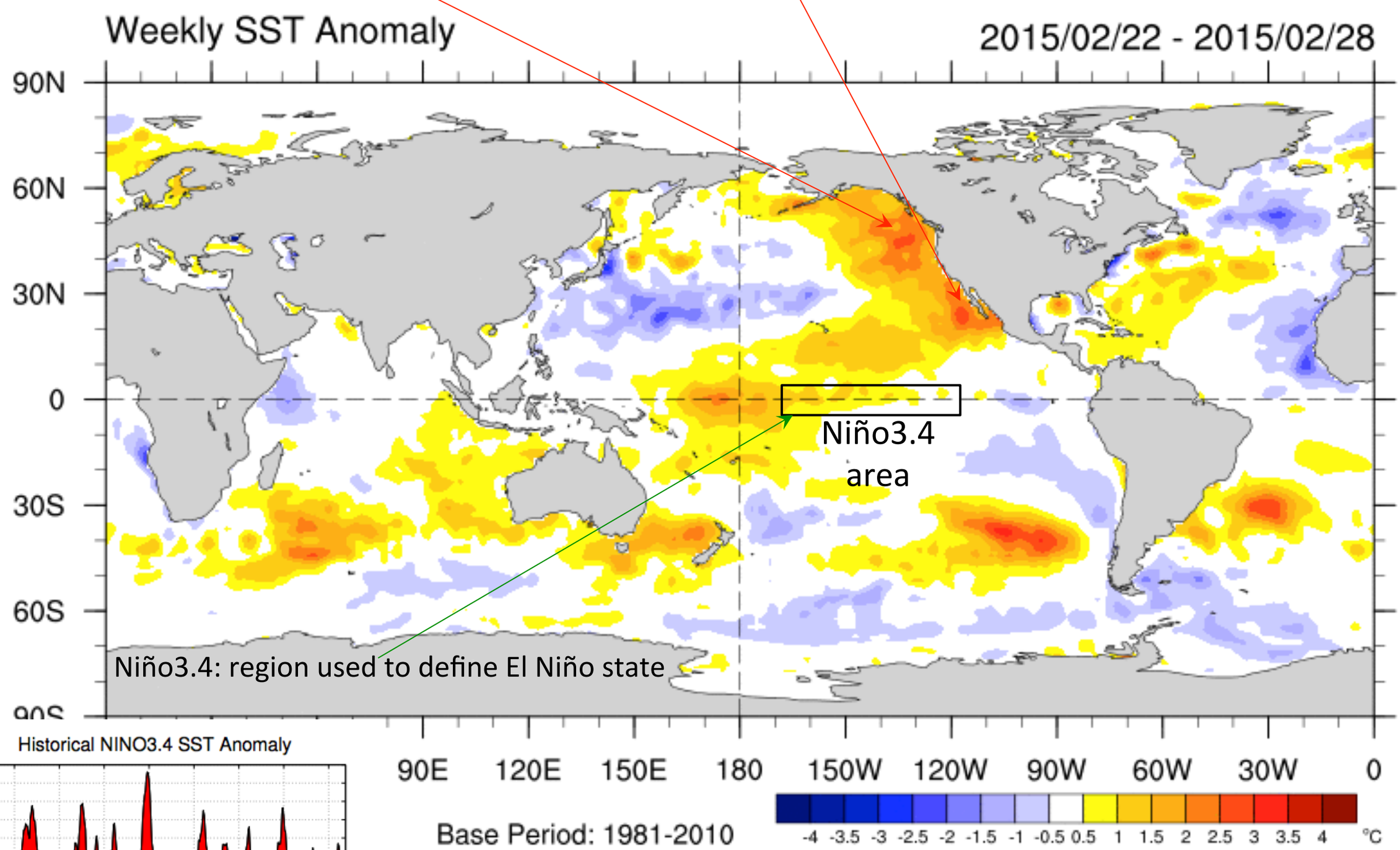
Salinity: 1950-2000 -0.12 psu
2006-2055 - 0.06-0.12 psu
2050-2100 - 0.2-0.3 psu

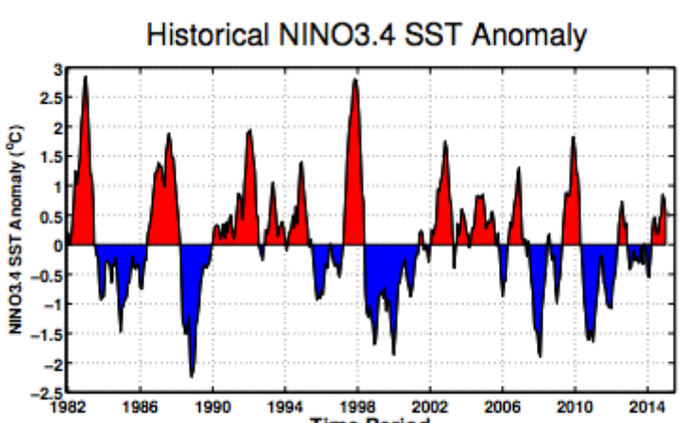
Sea Level: 1897-2013 - 1.89 ± 0.19 mm/yr (SF Tidal Gauge)
2000-2100 + 42 to 167 cm (1.38 to 5.48 ft)

Ocean Acidification: 1900-2000 -0.1 pH
2006-2055 - 0.12 pH
2050-2100 - 0.24 pH

Eastern Pacific sea surface temperatures (SST) were (and are) anomalously warm in 2014-2015

The Gulf of Alaska and the ocean off Baja California were >3°C warmer than average



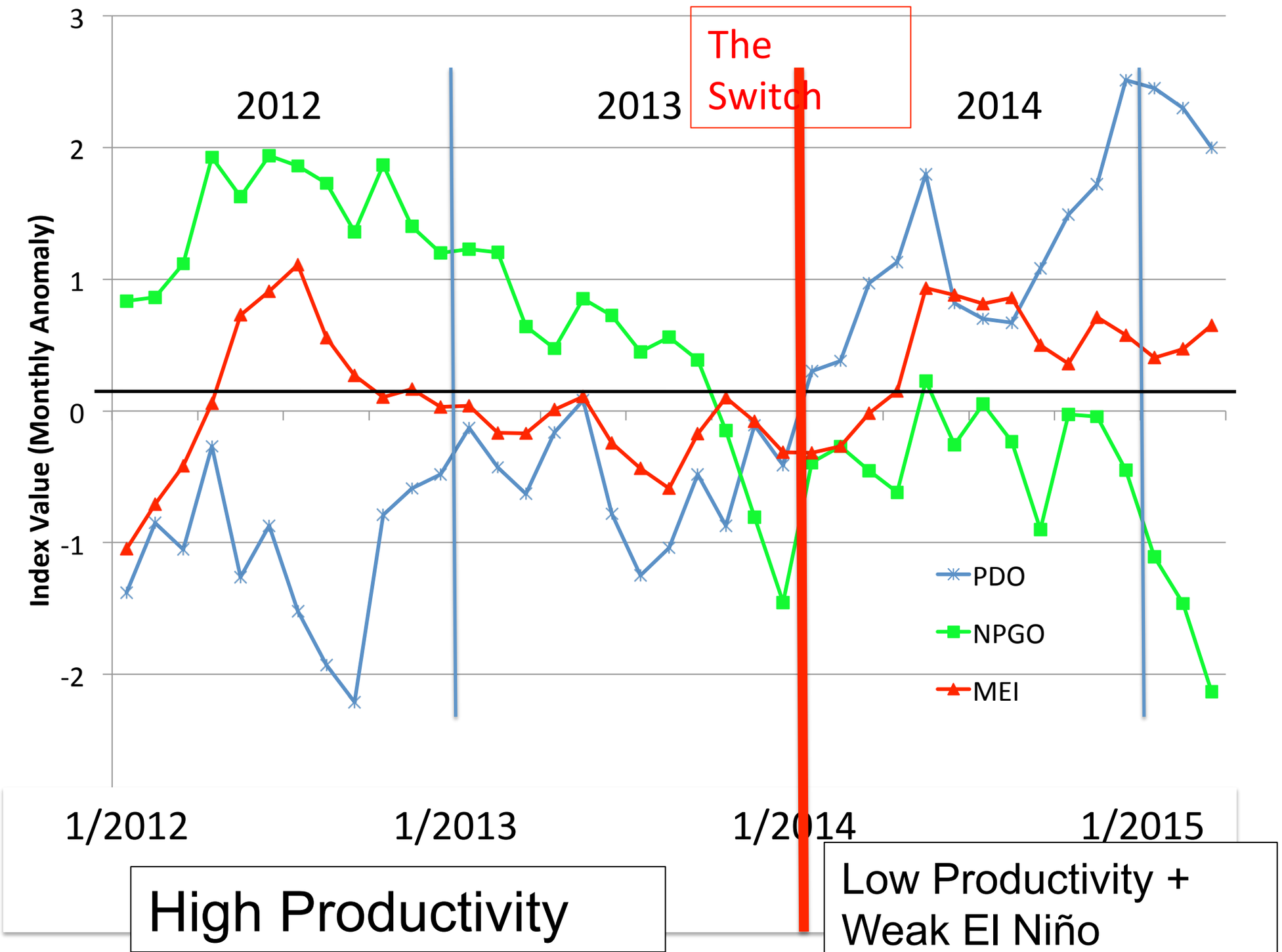


Conditions along the equator were within normal ranges, warm in the west and cooler in the east.

Basin Scale Indicators for the last 3 yrs:

PDO: Pacific Decadal Oscillation index indicating long term temperature shifts,
NPGO: North Pacific Gyre Oscillation Index indicating strength or volume of gyre flow,
MEI: Multivariate El Niño Index indicating interannual variability of temperature

The three indices are suggesting that at the end of 2013 there occurred a transition from favorable productivity conditions to generally low productivity conditions!



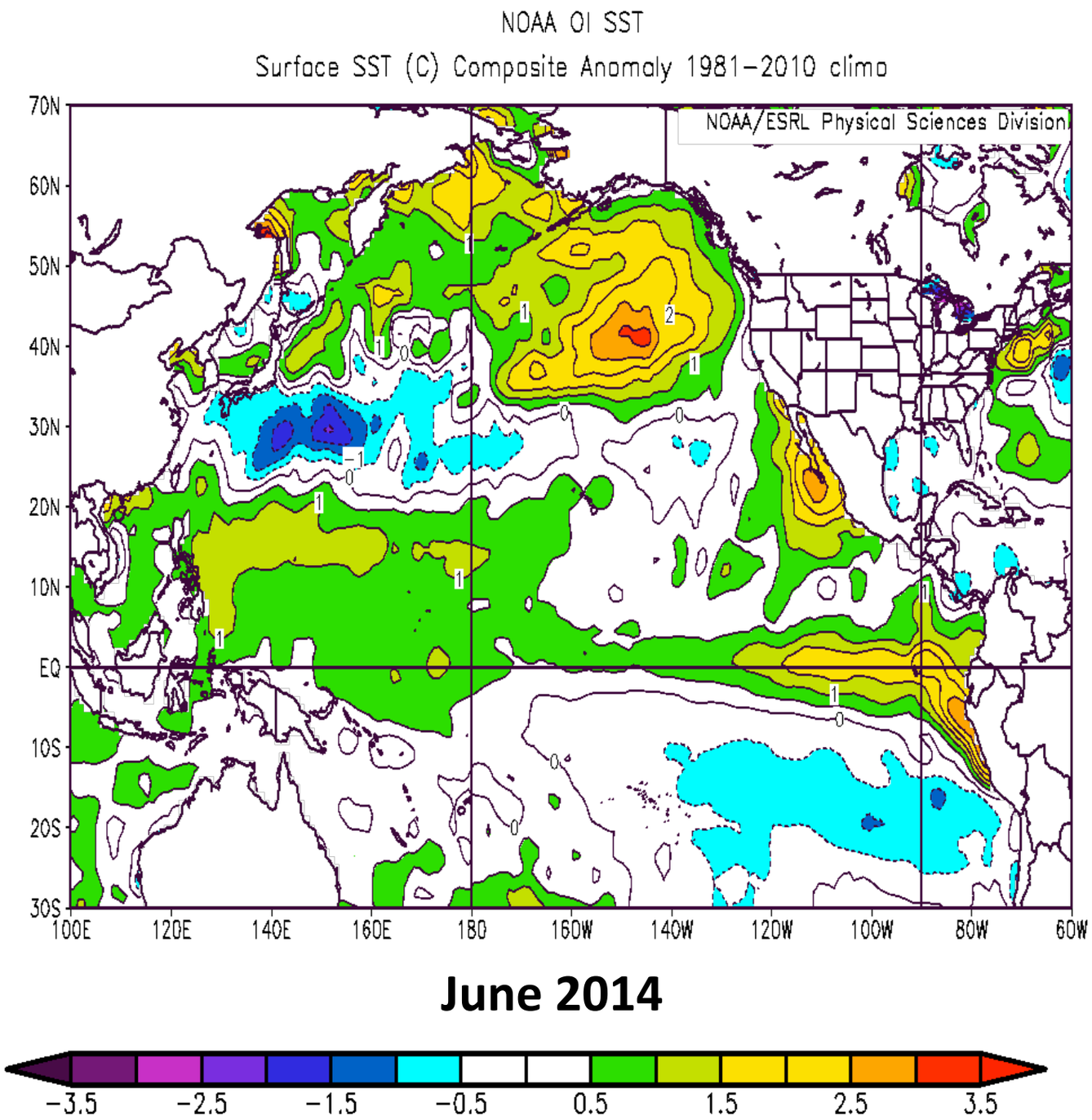
But – Northeast Pacific warmed *before* the Eastern Tropical Pacific warmed

- Gulf of Alaska has been extremely warm for the **past year and a half** (weak winter conditions)

- Baja and So. California near-shore have been warm **since June 2014** (local winds – not

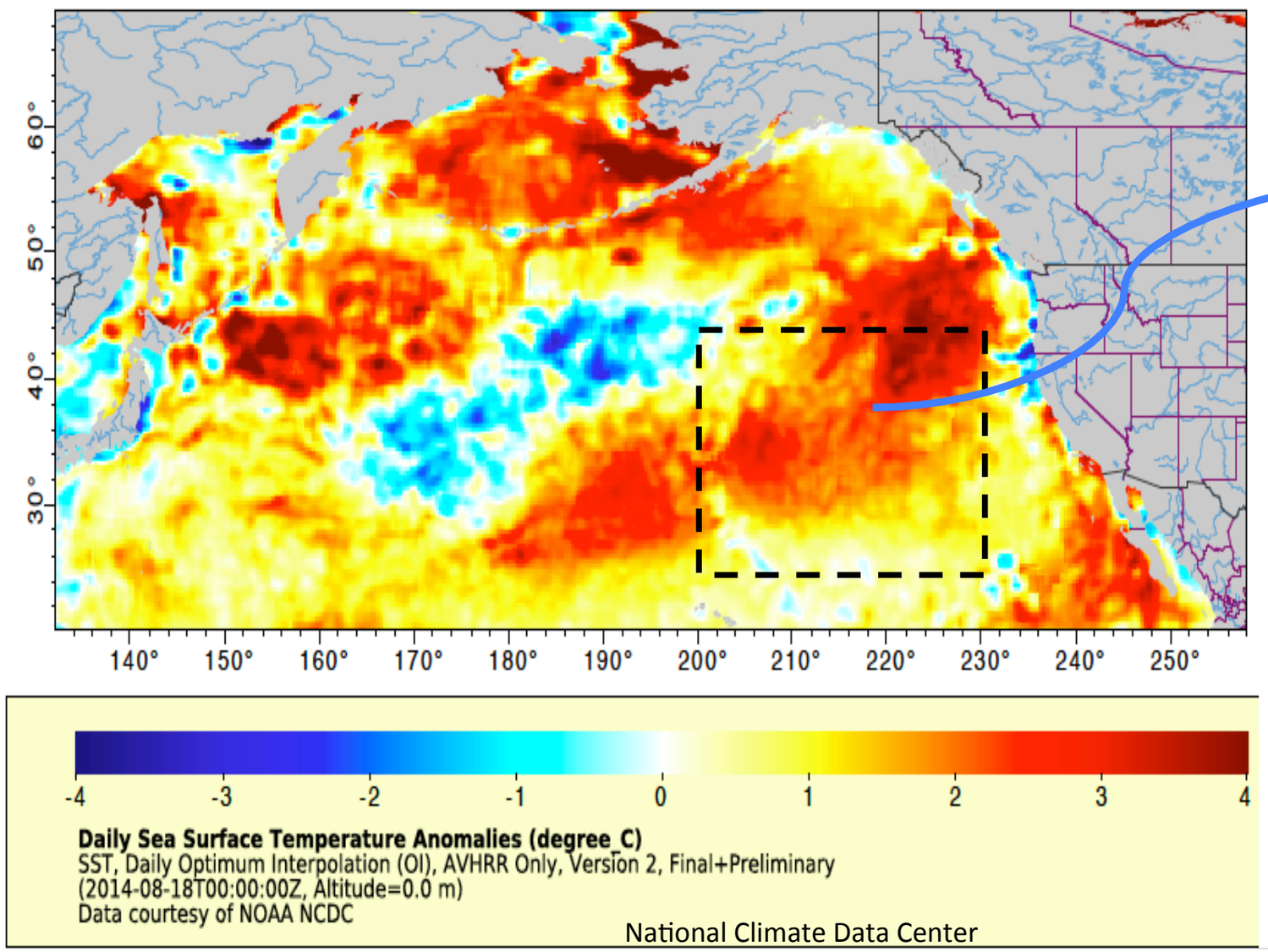
False Killer Whales, 24 Feb 2015; Photo: M. Robbins

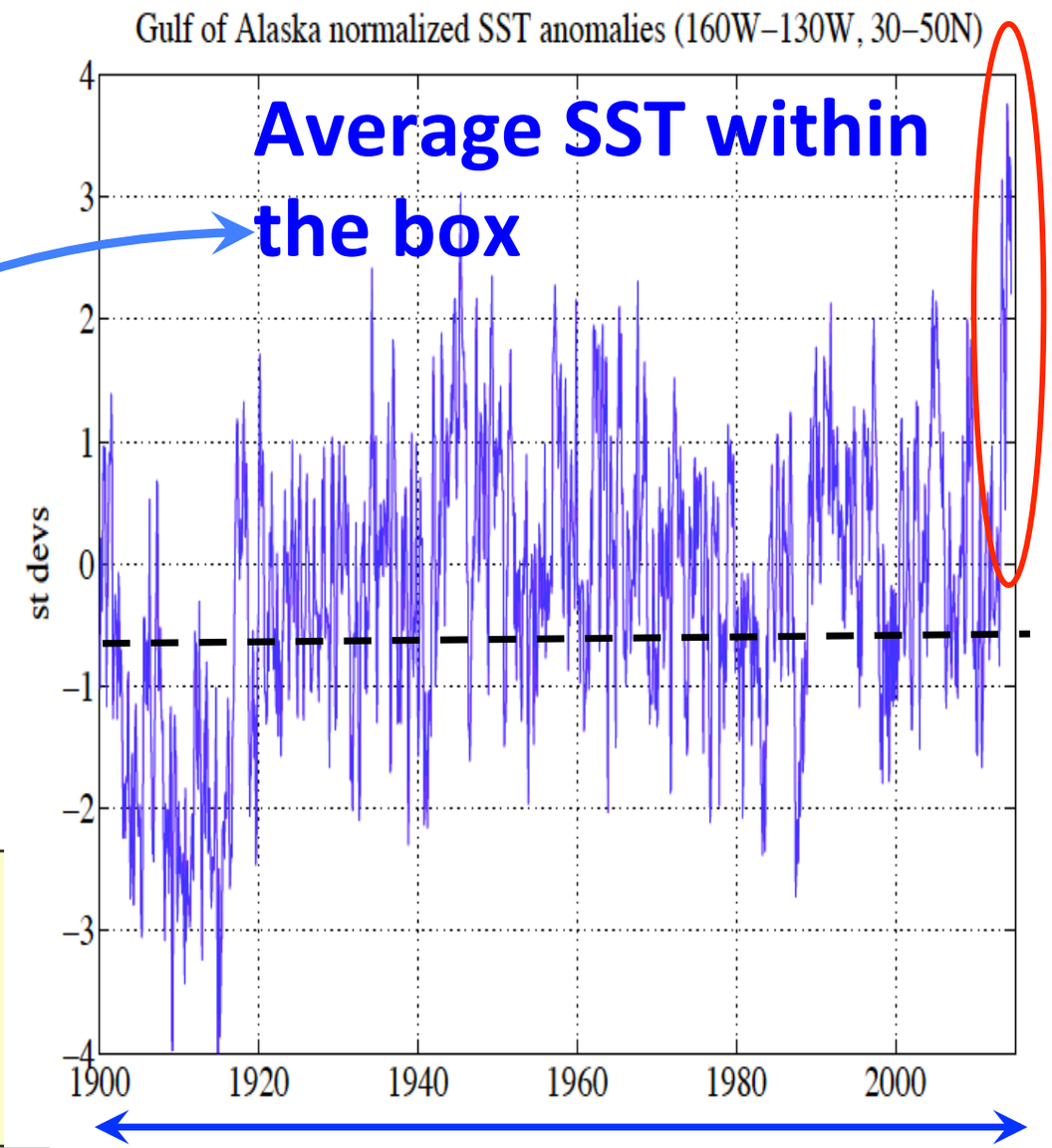
Sea Surface Temperature Anomaly (relative to 1981-2010)



June 2014

The 100+ year time series of Sea Surface Temperature in the eastern Pacific shows this is the warmest on record



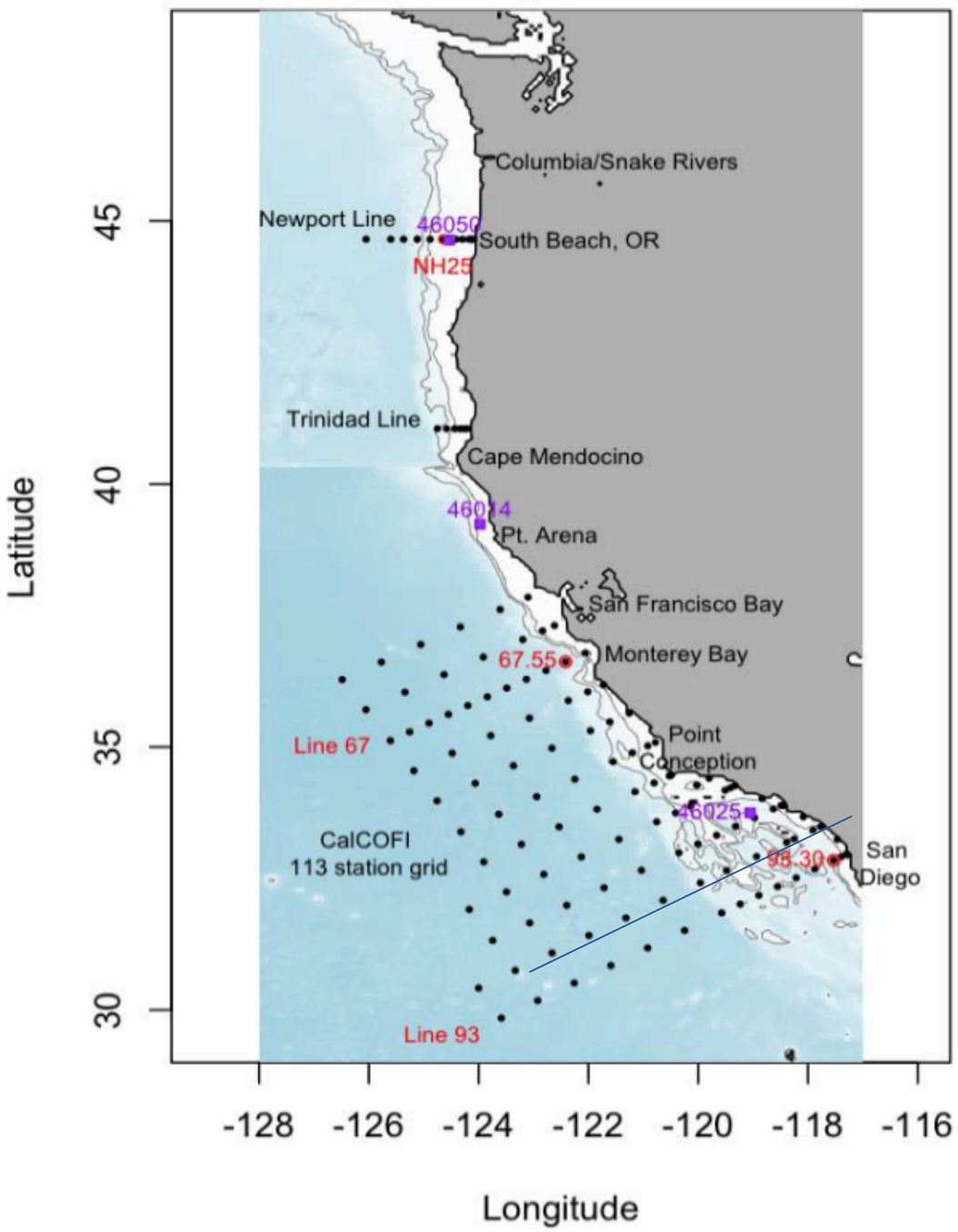


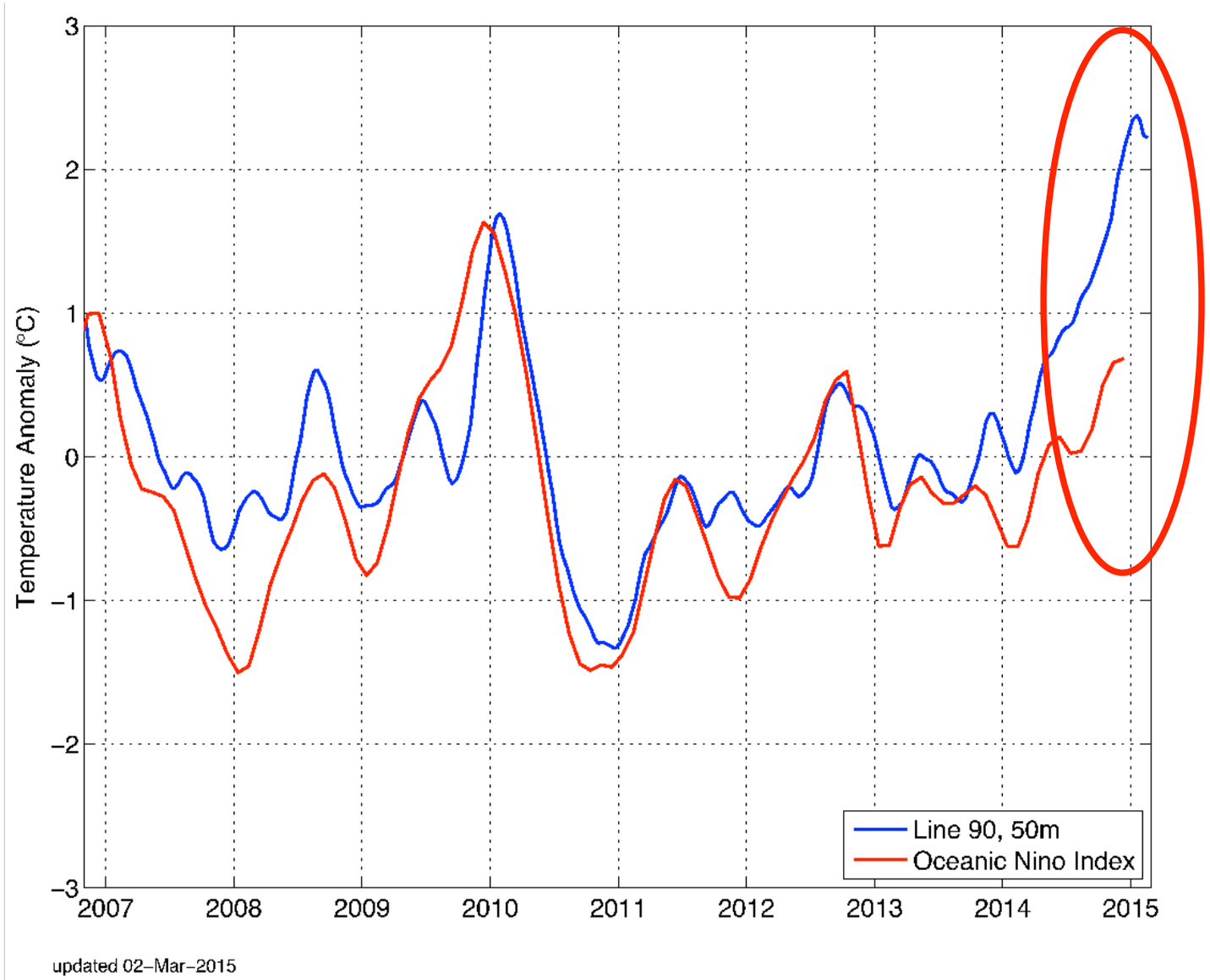
Daily SST anomaly (18 Aug 2014) relative to the 30-year (1982-2010) climatology

114 Years

"There's something happening here, what it is ain't exactly clear…" (Buffalo Springfield)

Southern California Bight SST usually closely reflects the Niño3.4 index. 2014 is very different as the Bight is warmer.





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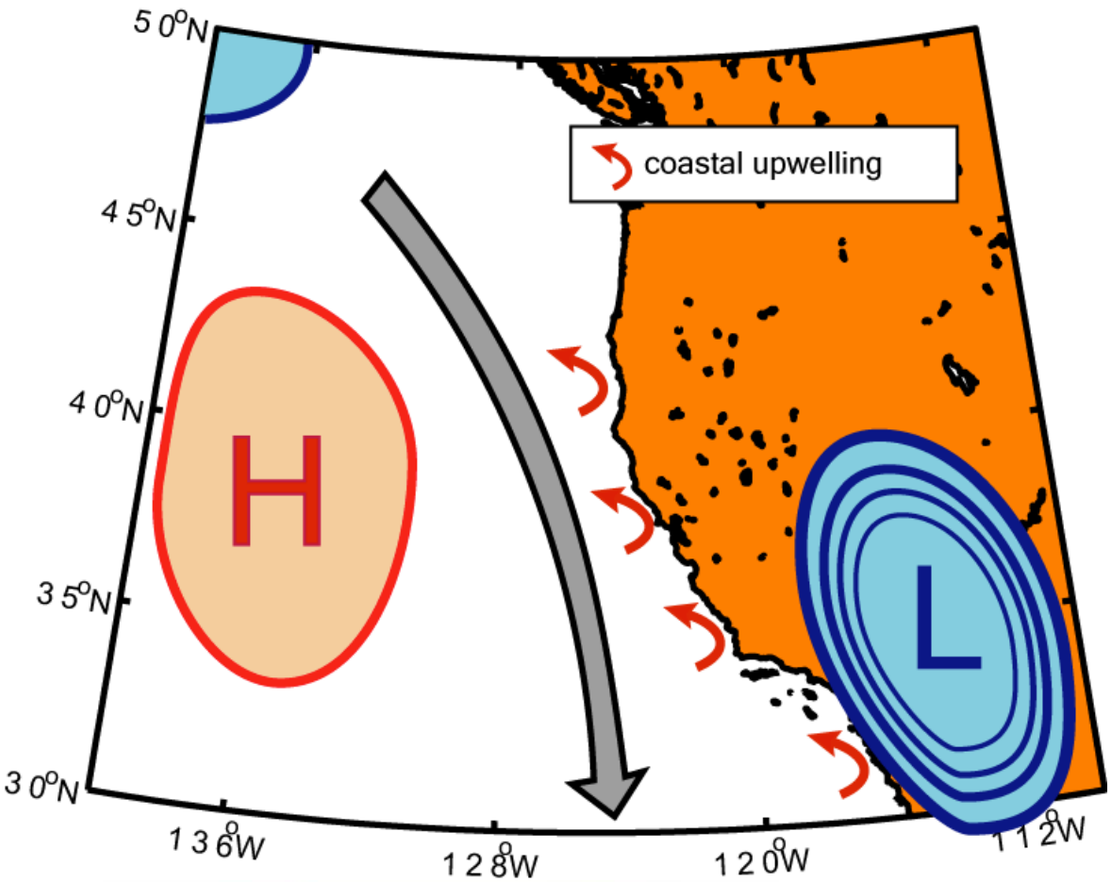
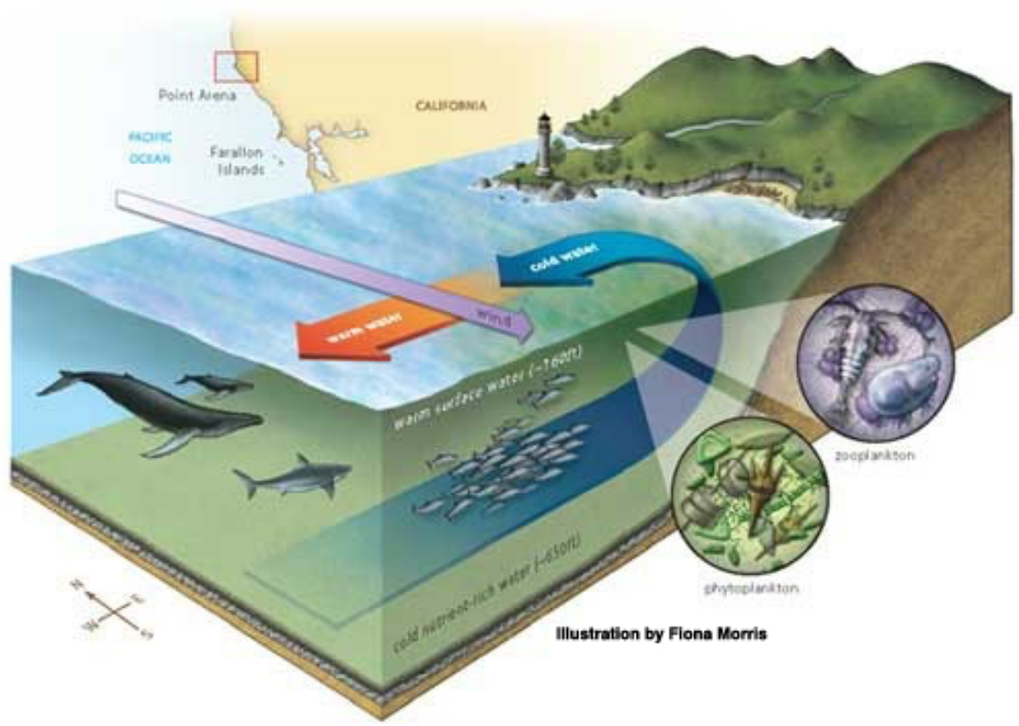
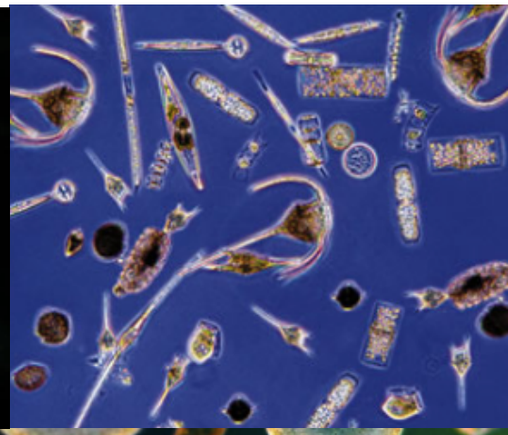
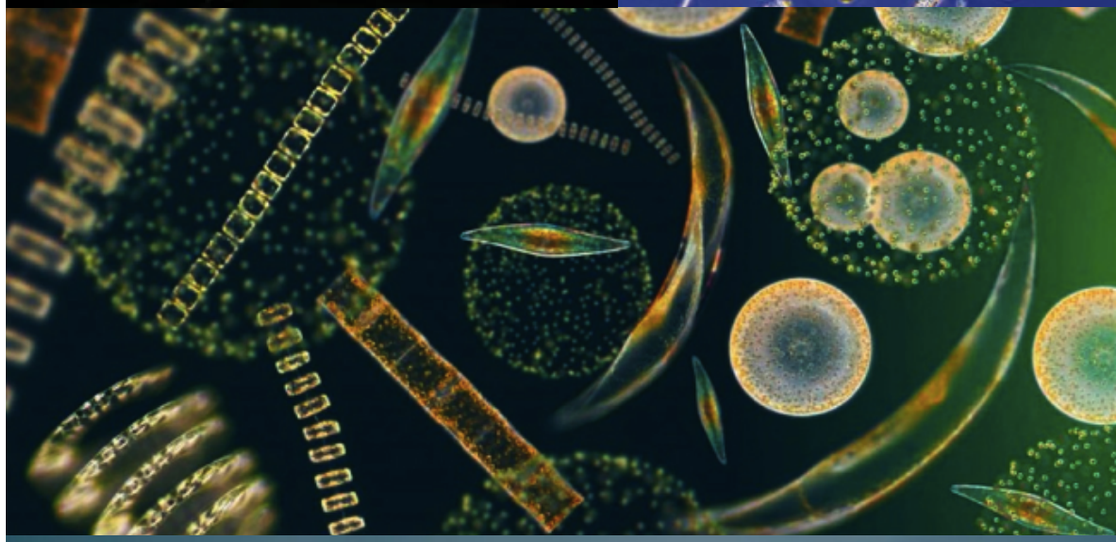
CALIFORNIA CURRENT FOOD WEB DEPENDS ON UPWELLING

The source waters and upwelling strength determine the primary productivity





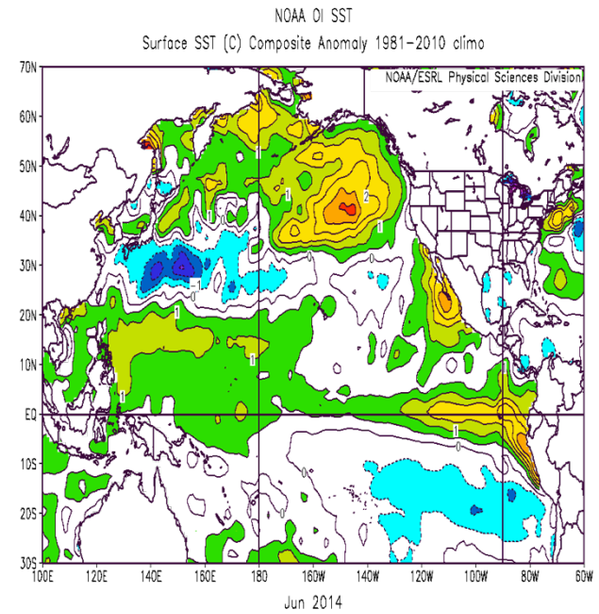


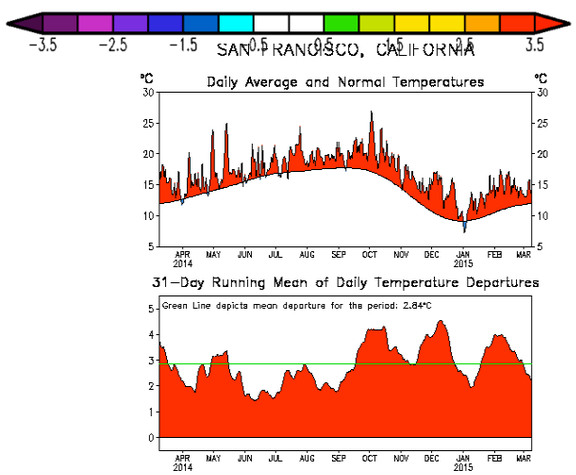


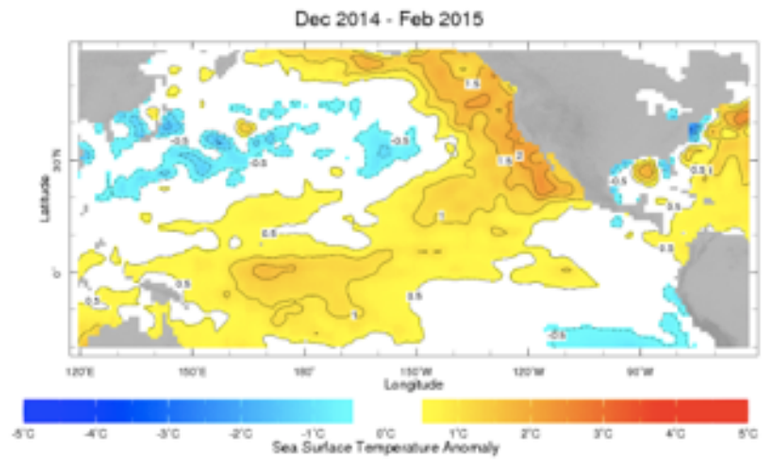
A very unusual year

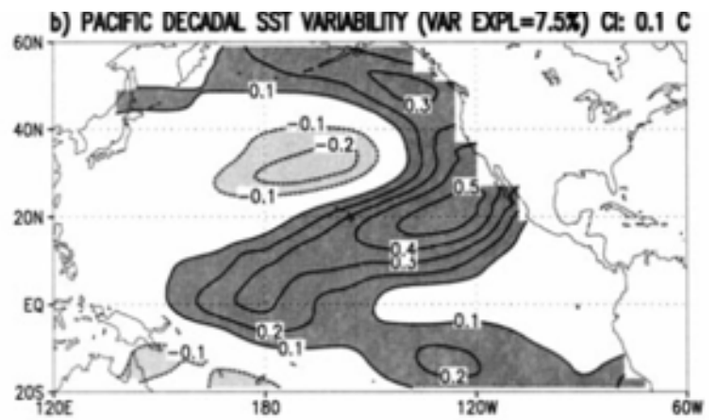
Mild El Niño

Historic “warm blob”

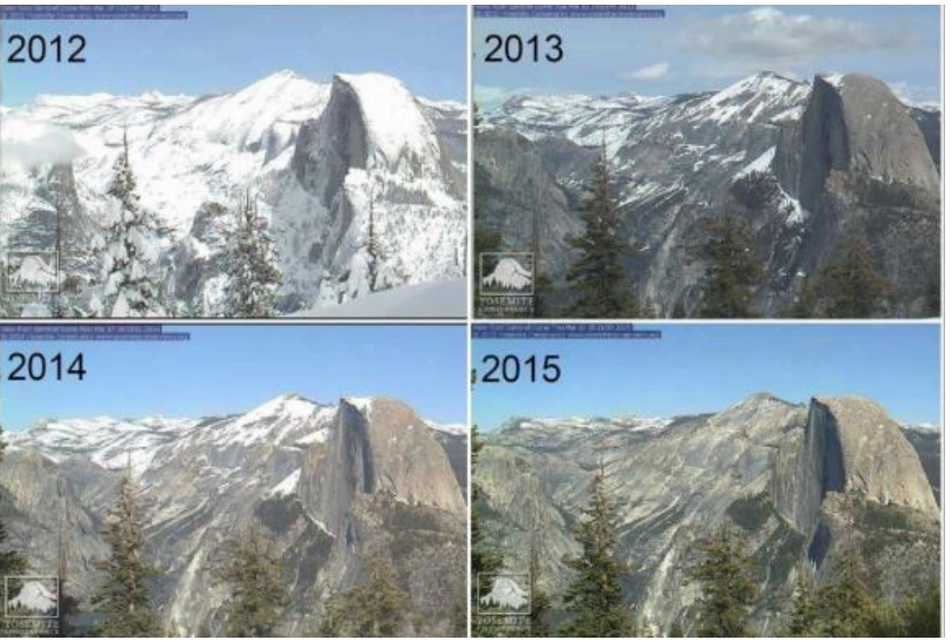


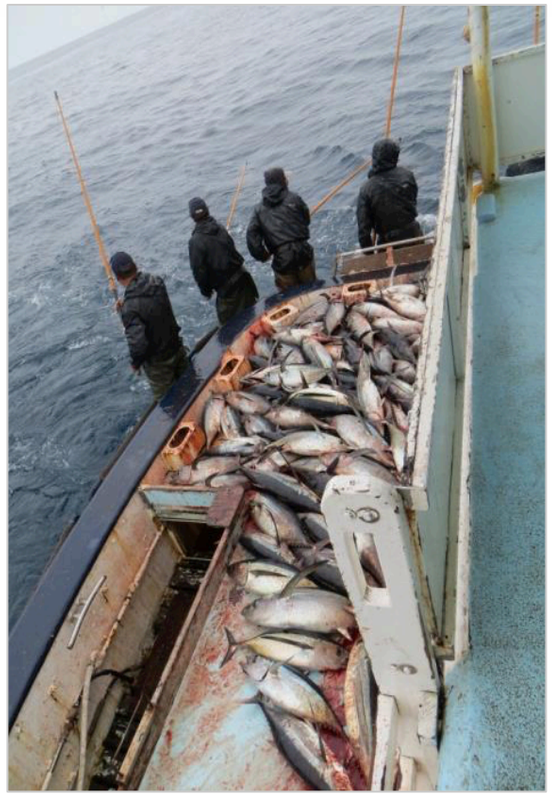






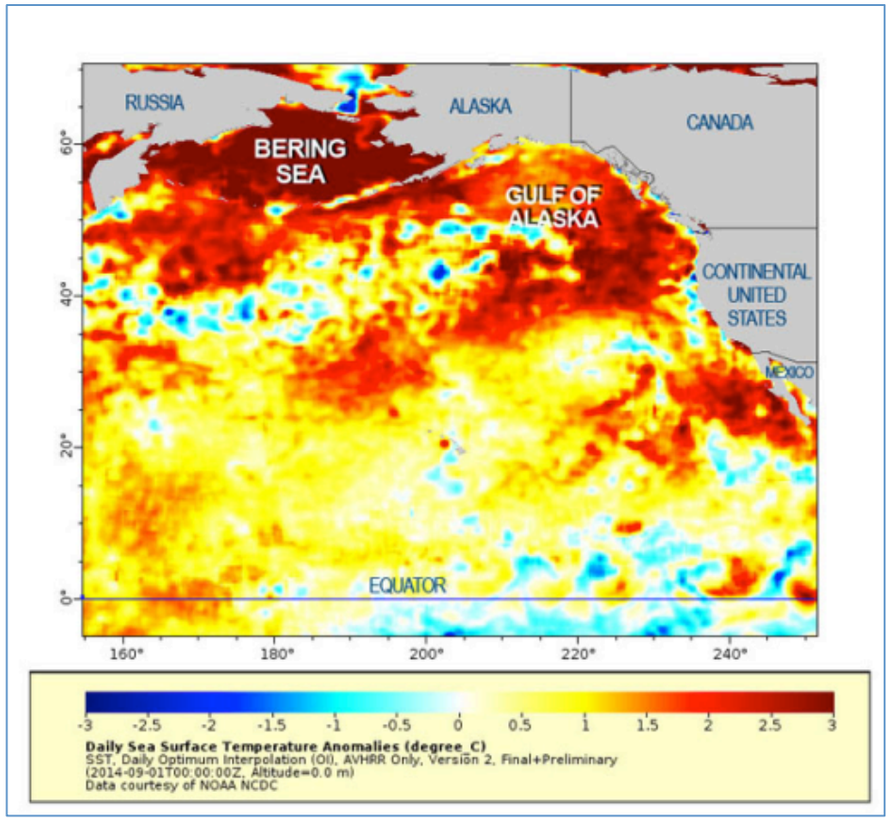
Historic warmth and low snowpack





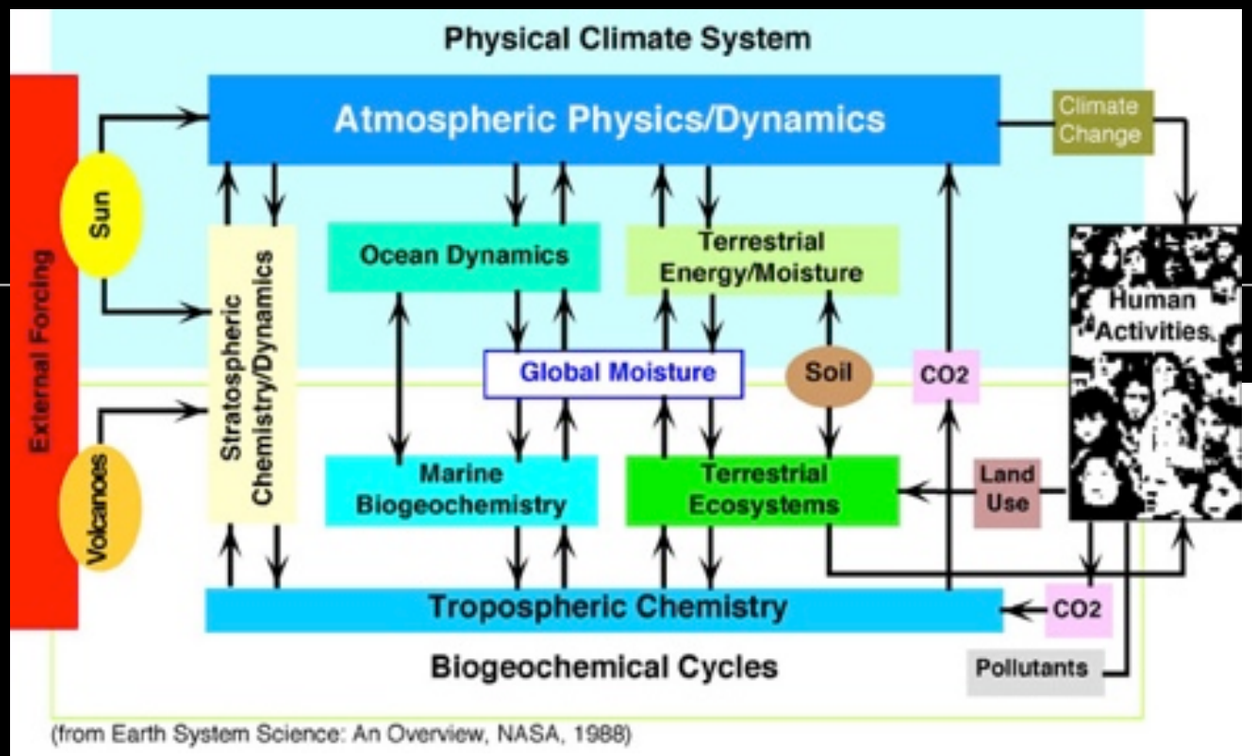
We're in a strange and possibly transitional period

- NE Pacific dominated by "warm blob"
- El Niño has arrived
- Basin scale productivity indices are flipping to "poor"
  - Uncharted territory for climate conditions
- Several leading indicators show that the system is responding to these changes
  - Copepods shifting to less energy-rich "southern" species
  - Cassin's auklets & California sea lion pups distress
  - Water storage in snow pack at record lows in all major river basins

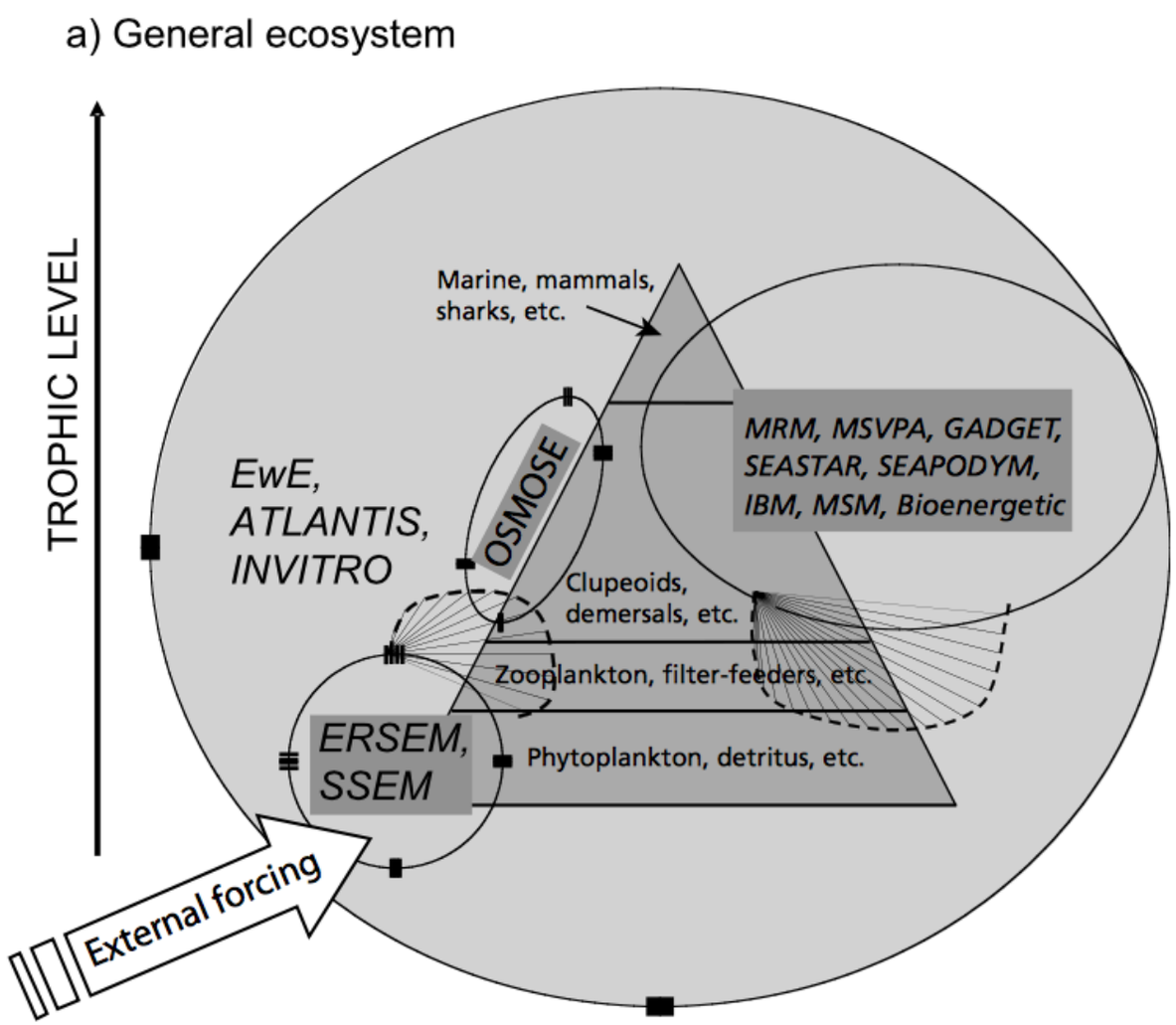


Sea surface temperature anomalies, Sept. 1, 2014 (NOAA National Climate Data Center)

Context relative to other modeling approaches



(from Earth System Science: An Overview, NASA, 1988)



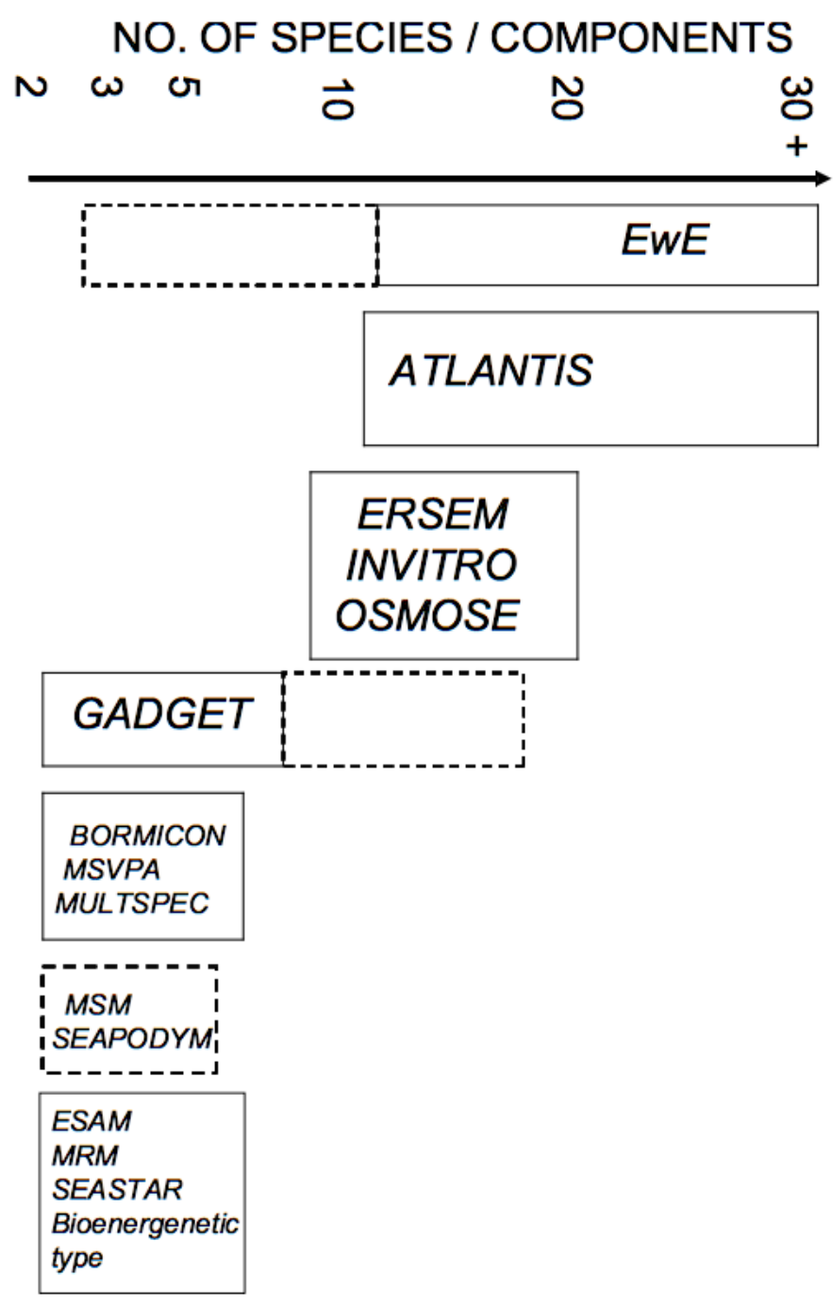


FIGURE 3

Schematic summarizing (approximately) the typical (current) number of modelled species or model compartments for selected models as listed in Table 1. The solid rectangles represent the range whereas the dashed lines indicate either rare/unusual applications or intended future extensions to the model.

(Plagányi, 2007)

Climate-to-fishing

Fishing Fleet

- Targeting sardines in the California Current
- Movement based on engineering, economics, behavior (evaluated once daily in model)
- Maximize revenue based on expected CPUE

- Num. of ports: 6 (CA(3), OR(1), WA(2))
- Num of boats per ports: 10-30
- Average catch per boat: 40-60 tons
- Boat motoring speed: 20 km/h
- Time to fish/process catch: 2 hours
- Average price for catch: 0.1-0.15 $/kg

Correlations: Anchovy

Lag/Variables	-2 years	-1 year	0 year.	+1 year
Adult Worth vs. Age-0 Survival	0.04	**0.02**	-0.20	-0.26
Adult Worth vs. Egg Production	0.70	**0.82**	0.69	0.60
Adult Worth vs. Age-1 Egg Prod.	0.38	**0.37**	0.12	-0.03
Adult Worth vs. Age-2 Egg Prod.	0.62	**0.77**	0.74	0.69
Adult Worth vs. Age-3 Egg Prod.	0.70	**0.75**	0.70	0.71
Adult Worth vs. Age-4 Egg Prod.	0.56	**0.71**	0.57	0.53

Correlations: Sardine

Lag/Variables	-2 years	-1 year	0 year.	+1 year
Adult Worth vs. Age-0 Survival	0.15	**0.30**	-0.15	-0.14
Adult Worth vs. Egg Production	0.82	**0.81**	0.86	0.96
Adult Worth vs. Age-1 Egg Prod.	0.54	**0.50**	0.61	0.52
Adult Worth vs. Age-2 Egg Prod.	0.50	**0.48**	0.62	0.79
Adult Worth vs. Age-3 Egg Prod.	0.53	**0.56**	0.53	0.66
Adult Worth vs. Age-4 Egg Prod.	0.54	**0.54**	0.57	0.52

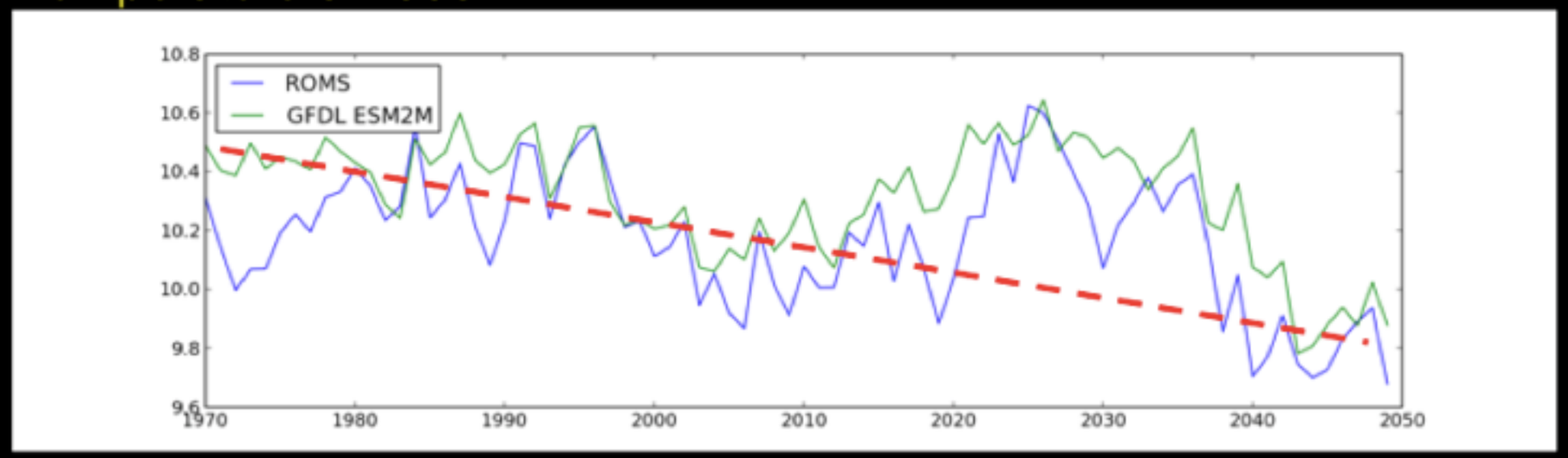
One-way downscaling: Physics (80 year simulation)

conserve heat content and salinity, and

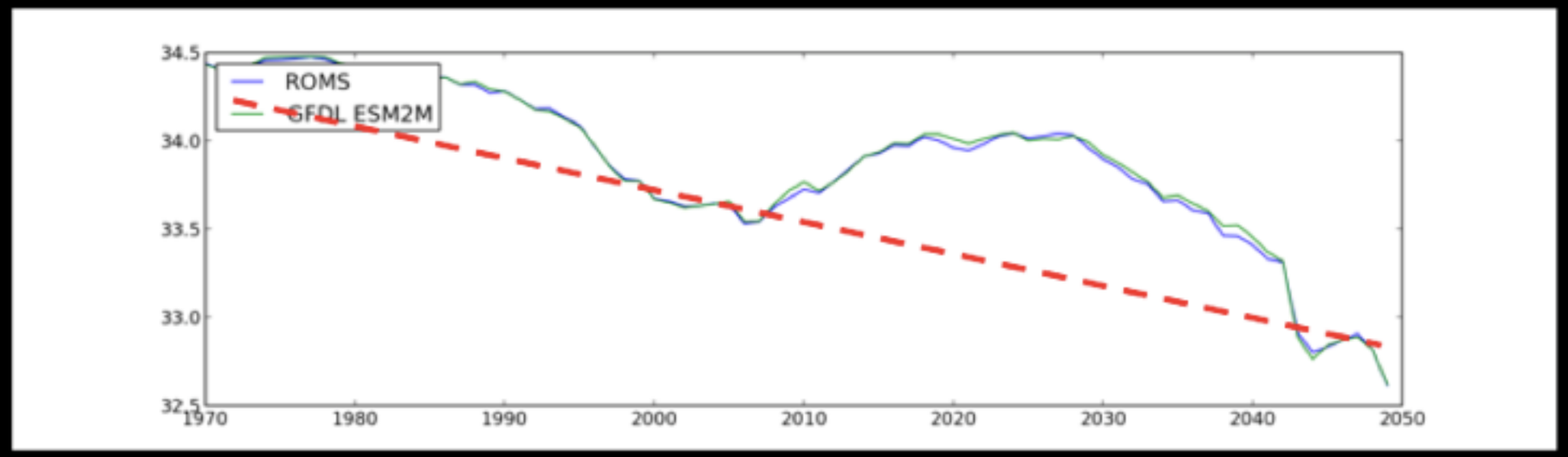
cooling and freshening trend

(southward expansion of Alaskan sub-polar gyre)

Temperature 0-1000m



Salt 0-1000m



1970 2050

Lots of information…
three steps to tease out the drivers

- Step 1: establish the biological processes that control adult sardine and anchovy population dynamics
  - Anchovy: adult population fluctuations are associated with age-1 growth and prey availability.
  - Sardine: adult populations correlated with temperature and age-0 survival.
- Step 2: link changes in processes to variations in environmental conditions
  - Anchovy: years of high growth related to enhanced upwelling in the southern CCS (more productive lower tropic levels)
  - Sardine: years of high age-0 survival related to high temperatures
- Step 3: correlate environmental conditions experienced by the individuals in the model to regional and climate-scale variability in the CCS using ROMS and NEMURO output directly.

Climate-to-fishing

Fishing Fleet

- Targeting sardines in the California Current
- Movement based on engineering, economics, behavior (evaluated once daily in model)
- Maximize revenue based on expected CPUE

- Num. of ports: 6 (CA(3), OR(1), WA(2))
- Num of boats per ports: 10-30
- Average catch per boat: 40-60 tons
- Boat motoring speed: 20 km/h
- Time to fish/process catch: 2 hours
- Average price for catch: 0.1-0.15 $/kg

Correlations: Anchovy

Lag/Variables	-2 years	-1 year	0 year.	+1 year
Adult Worth vs. Age-0 Survival	0.04	**0.02**	-0.20	-0.26
Adult Worth vs. Egg Production	0.70	**0.82**	0.69	0.60
Adult Worth vs. Age-1 Egg Prod.	0.38	**0.37**	0.12	-0.03
Adult Worth vs. Age-2 Egg Prod.	0.62	**0.77**	0.74	0.69
Adult Worth vs. Age-3 Egg Prod.	0.70	**0.75**	0.70	0.71
Adult Worth vs. Age-4 Egg Prod.	0.56	**0.71**	0.57	0.53

Correlations: Sardine

Lag/Variables	-2 years	-1 year	0 year.	+1 year
Adult Worth vs. Age-0 Survival	0.15	**0.30**	-0.15	-0.14
Adult Worth vs. Egg Production	0.82	**0.81**	0.86	0.96
Adult Worth vs. Age-1 Egg Prod.	0.54	**0.50**	0.61	0.52
Adult Worth vs. Age-2 Egg Prod.	0.50	**0.48**	0.62	0.79
Adult Worth vs. Age-3 Egg Prod.	0.53	**0.56**	0.53	0.66
Adult Worth vs. Age-4 Egg Prod.	0.54	**0.54**	0.57	0.52

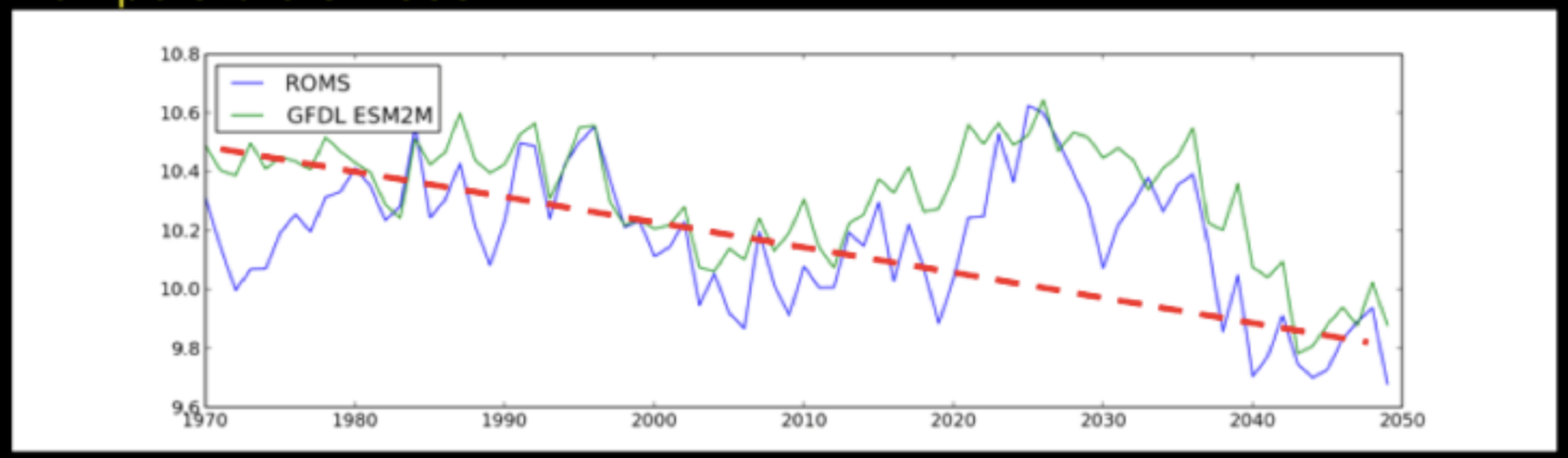
One-way downscaling: Physics (80 year simulation)

conserve heat content and salinity, and

cooling and freshening trend

(southward expansion of Alaskan sub-polar gyre)

Temperature 0-1000m



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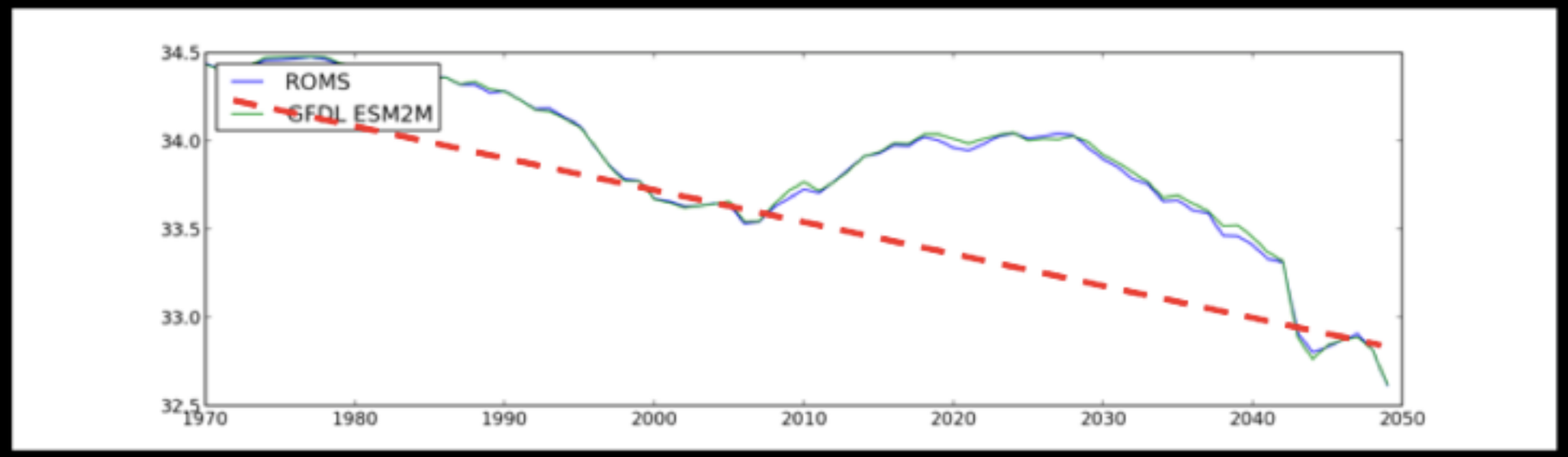

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