NOAA FISHERIES
PIFSC

OceanWatch Central Pacific

Applications of Satellite data

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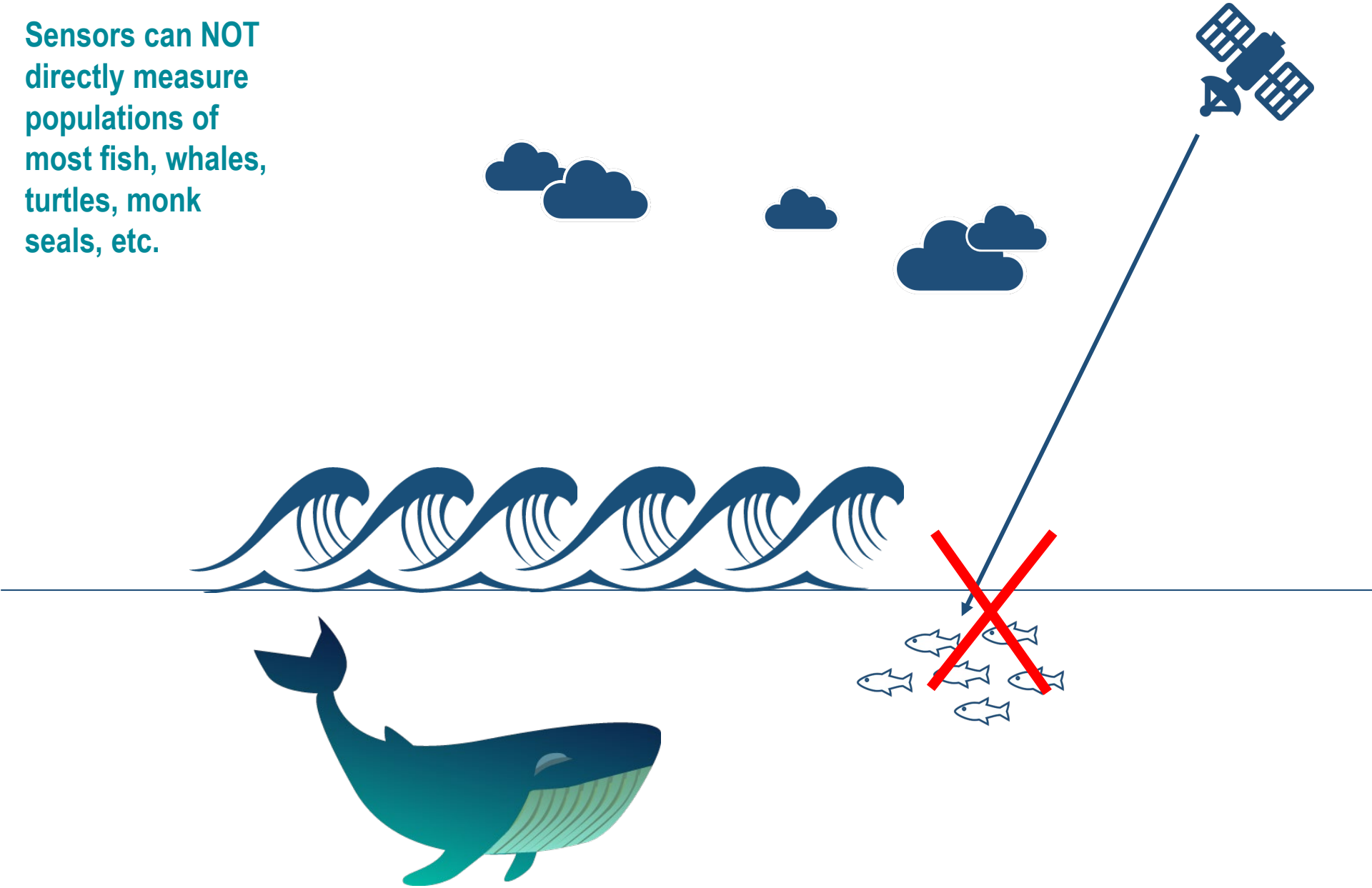
With slides from:
Cara Wilson, CWOW West Coast Node

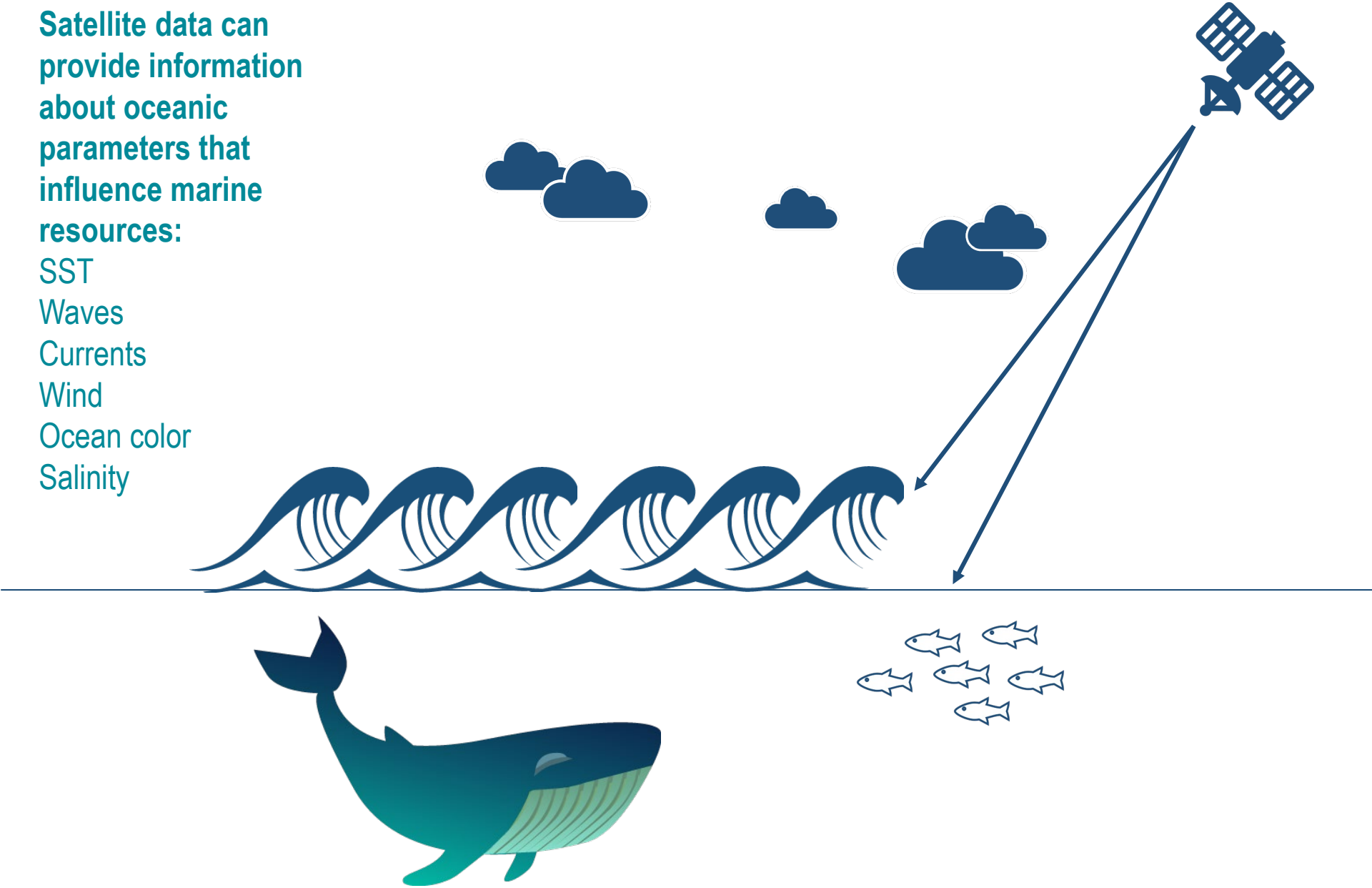
Last updated: 11/15/2018

Sensors can NOT directly measure populations of most fish, whales, turtles, monk seals, etc.

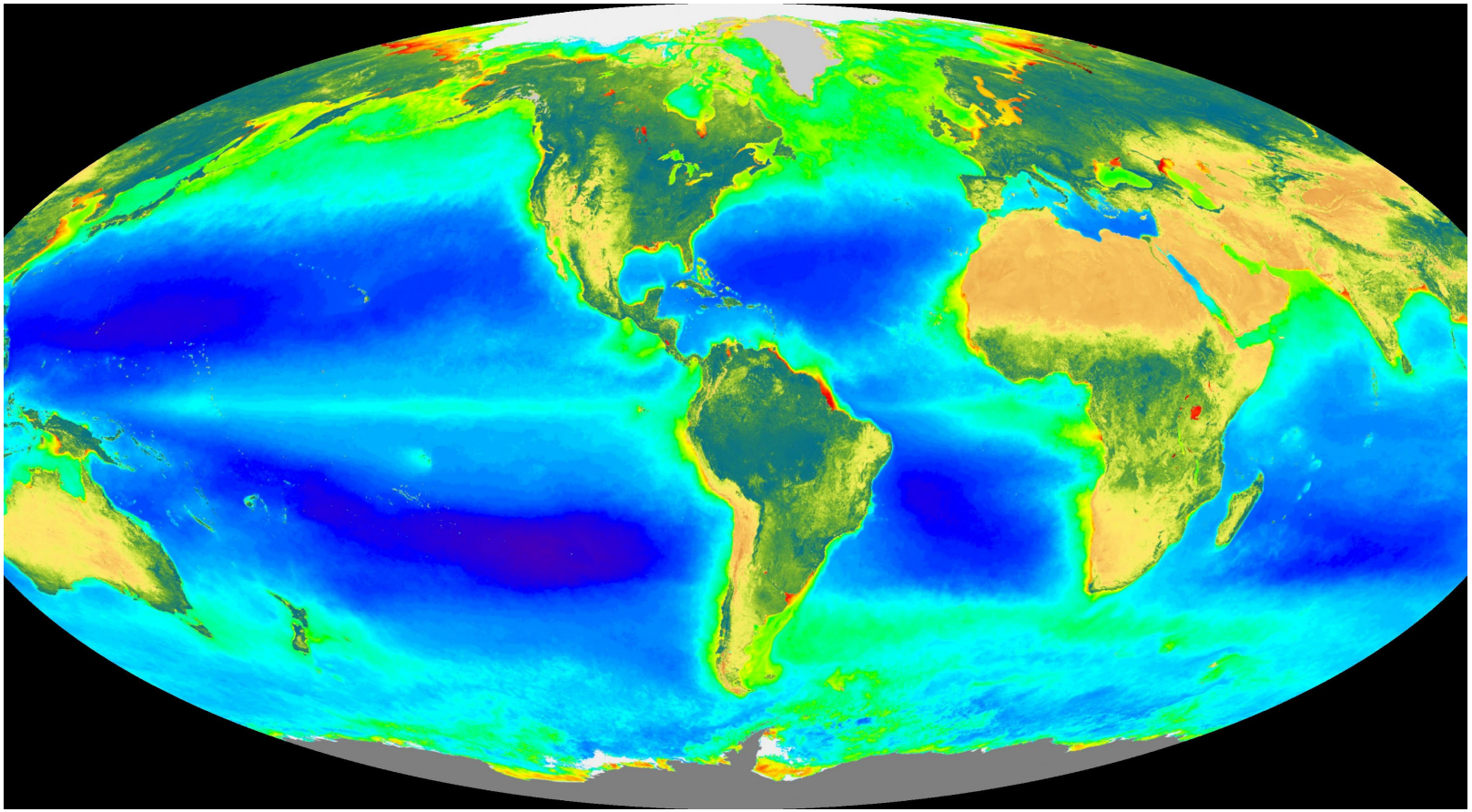


Satellite data can provide information about oceanic parameters that influence marine resources:

SST
Waves
Currents
Wind
Ocean color
Salinity



Surface Chlorophyll - Modis



Ocean Features Important to Ecosystems

- Ocean ‘fronts’, boundaries, ‘edges’
- River plumes
- Mesoscale circulation patterns: eddies, meanders, ‘loops’
- Convergence zones
- Subsurface thermal structure: MLD, thermocline
- Ocean surface winds
- Ocean currents
- Wave heights

All of these ocean features can be measured, detected or inferred by satellite data

Temporal Events Important to Ecosystems

- Upwelling
- Harmful Algae Blooms (HABs)
- Oil Spills
- Seasonal Transitions
- El Niño events
- Regime Shifts (i.e. PDO)
- Global Climate Change

- Climate change can affect the timing and/or intensity of many of the processes
- Climate Data Records (CDRs) of satellite measurements need to be maintained

Satellite remote sensing for an ecosystem approach to fisheries management

- Near-real time to support fishing operations/research cruises
- Understand link between oceanography and marine resources habitats
- Input to habitat models
- Define and monitor spatial distribution of biomes
- As input or validation to ecosystem/earth system models
- Identify ecosystem carrying capacity

Chassot et al. 2011. Satellite remote sensing for an ecosystem approach to fisheries management. *ICES*68(4)

Ways remote sensing can contribute to conservation

- Contribute to a habitat model for species distribution and abundance
- Put animal movement in an oceanographic context
- Monitor and predict ecosystem responses from multiple stressors including climate change
- Inform configurations of protected areas

Rose et al. 2014. Ten ways remote sensing can contribute to conservation. *Conservation Biology*

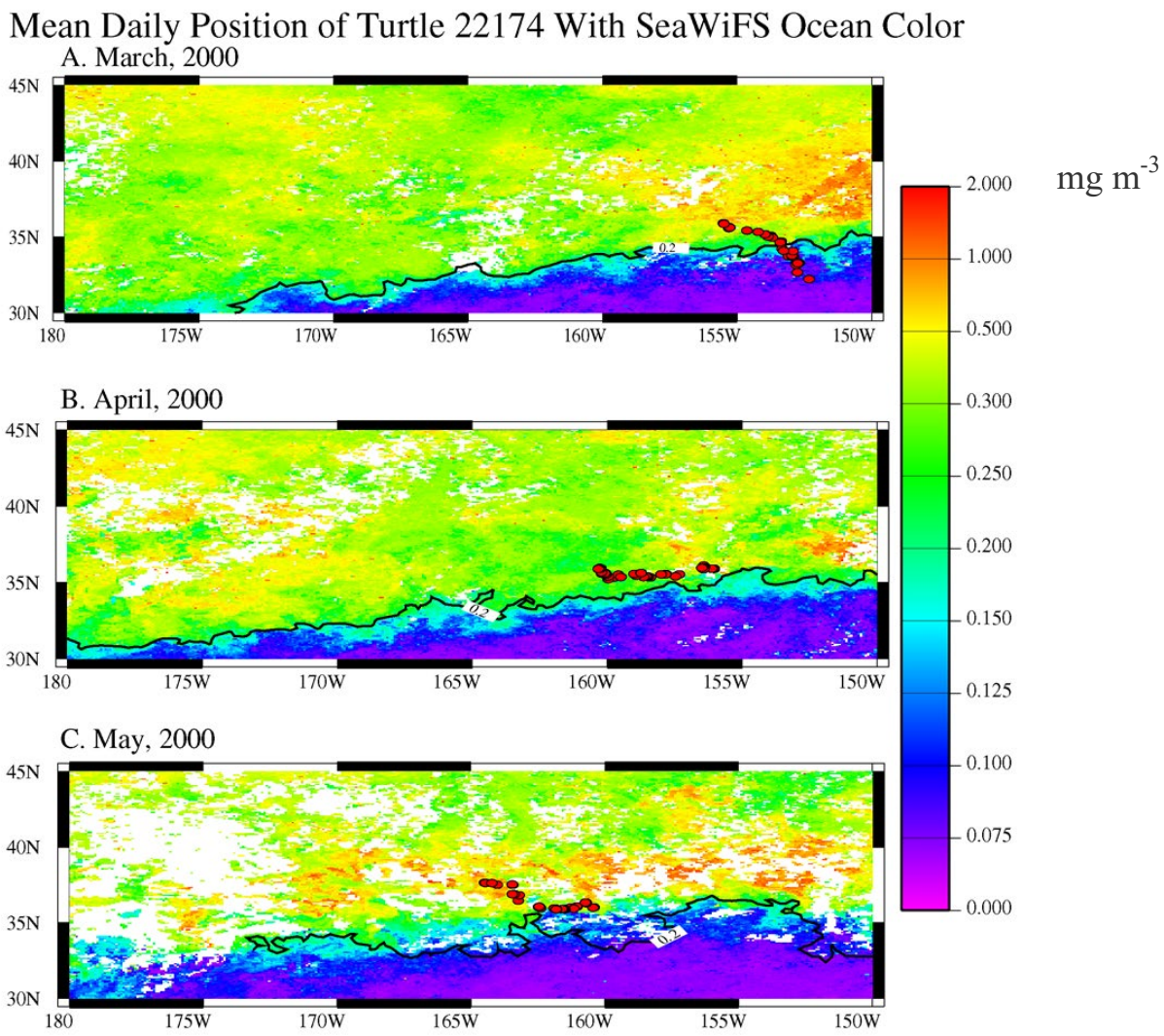
Examples of uses of satellite data

- To describe ocean features that define the foraging habitats of loggerhead sea turtles, albacore and bluefin tunas, and Hawaiian monk seal.
- In fisheries bycatch studies with sea turtles and sea birds
- In habitat models for loggerhead sea turtles, and pelagic fishes
- To develop ecological indicators (coral reef bleaching, biome dynamics, phytoplankton size)

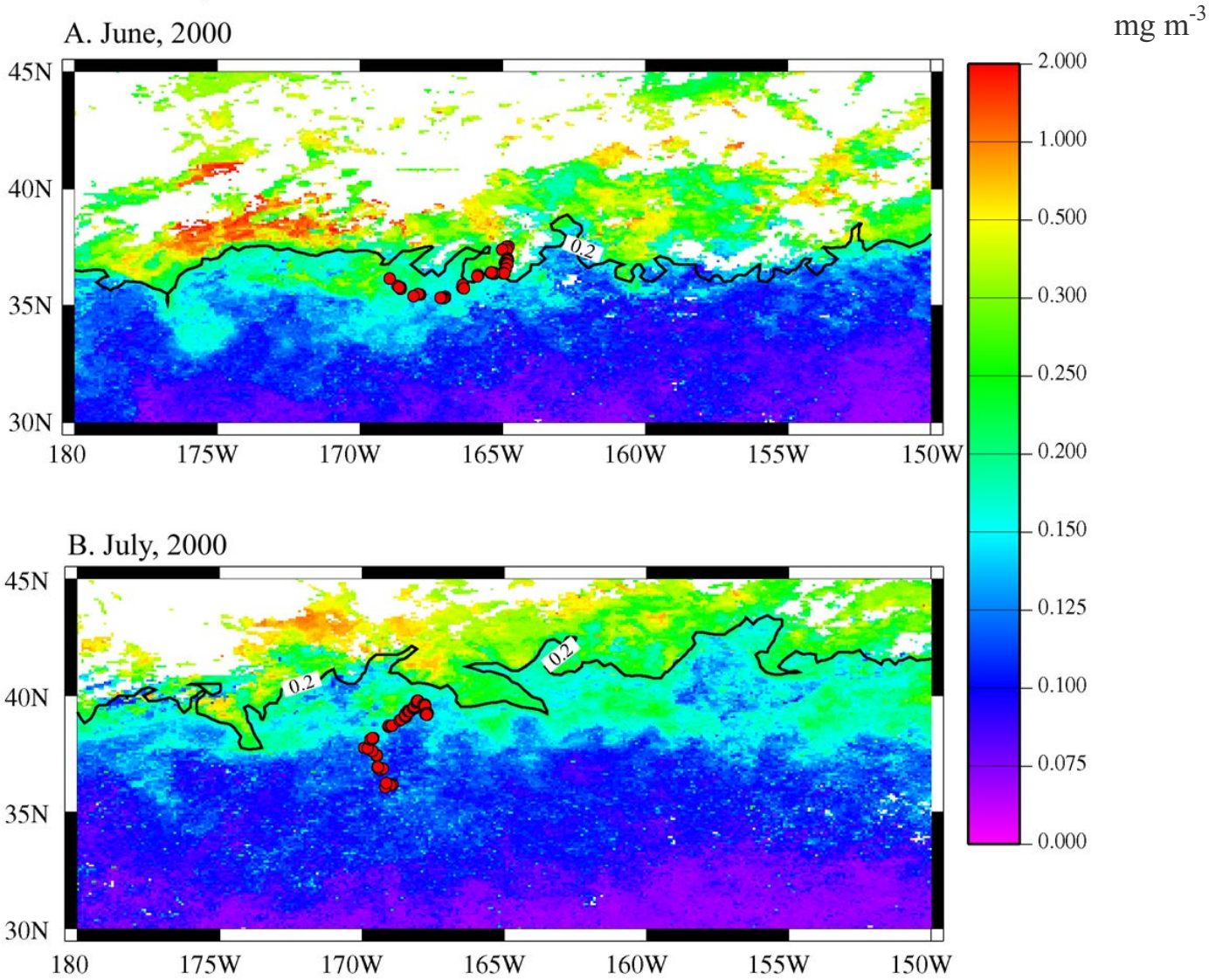
Qualitative Approaches

- Overlays and histograms with tagging and fisheries data to describe ocean features and habitats animals use.
- Descriptive oceanography to understand the oceanographic basis of foraging habitats.

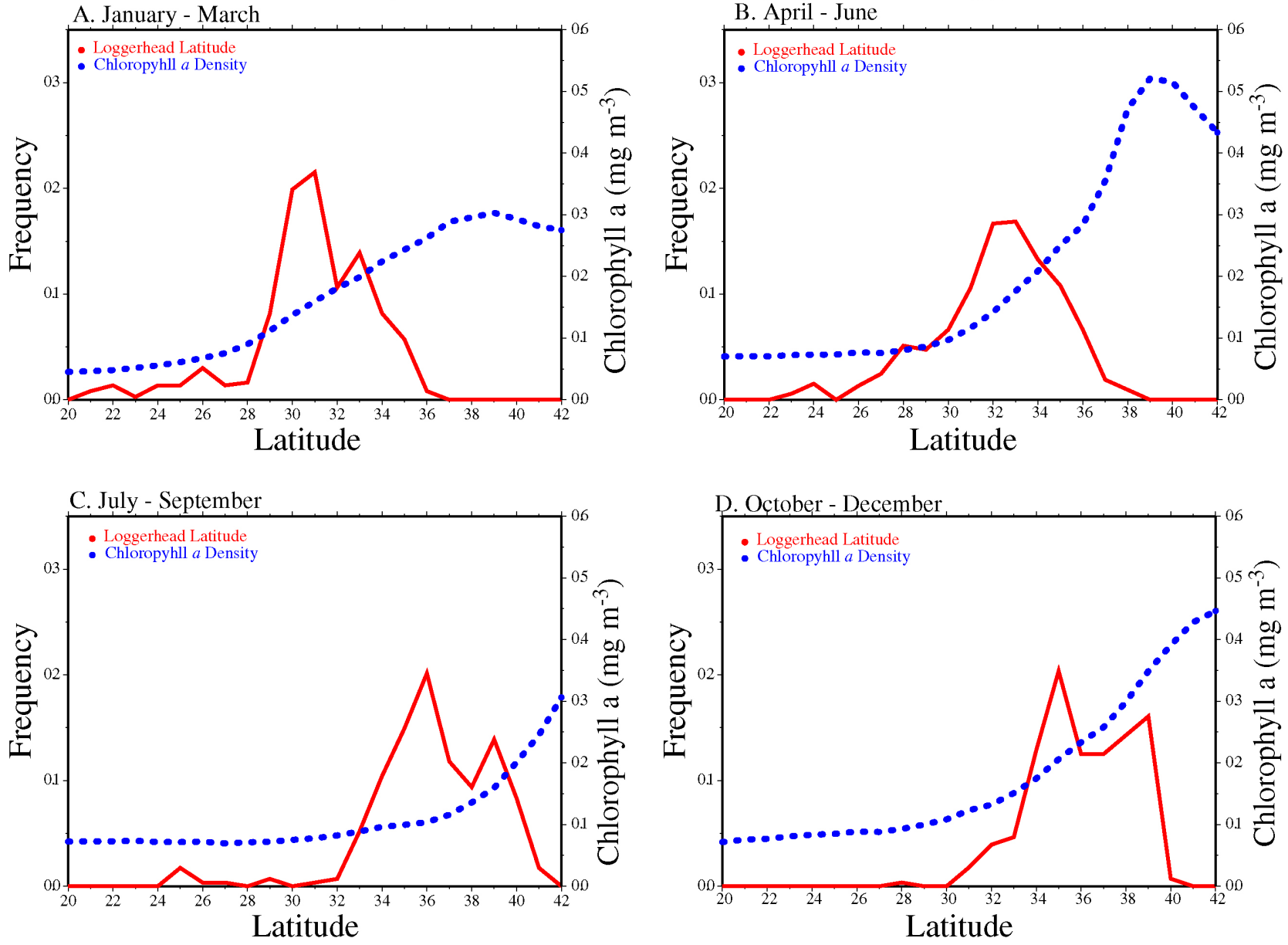
Loggerhead turtles habitat



Mean Daily Position of Turtle 22174 With SeaWiFS Ocean Color



Latitude Frequency Distribution and Chlorophyll A for Loggerhead Turtles



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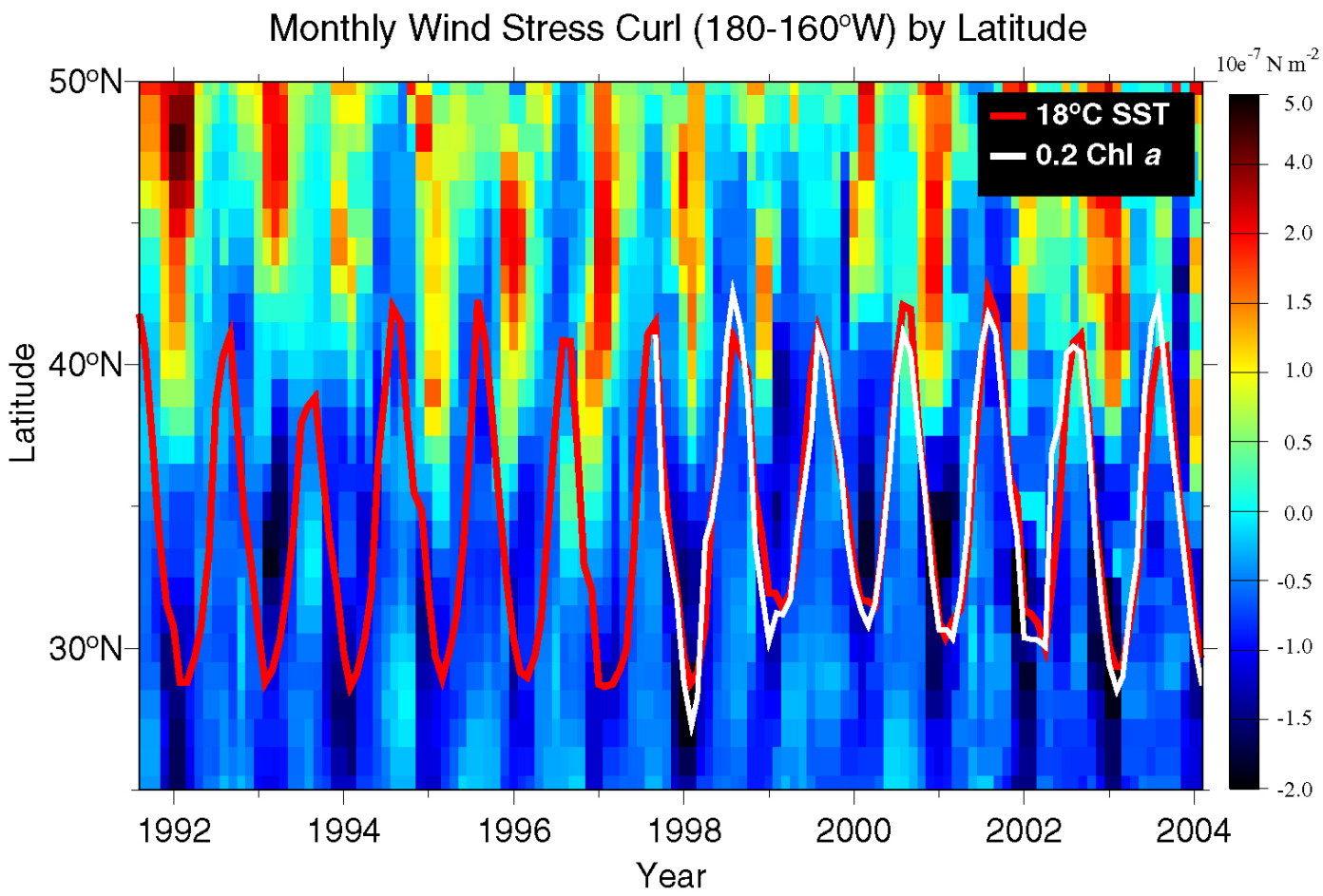
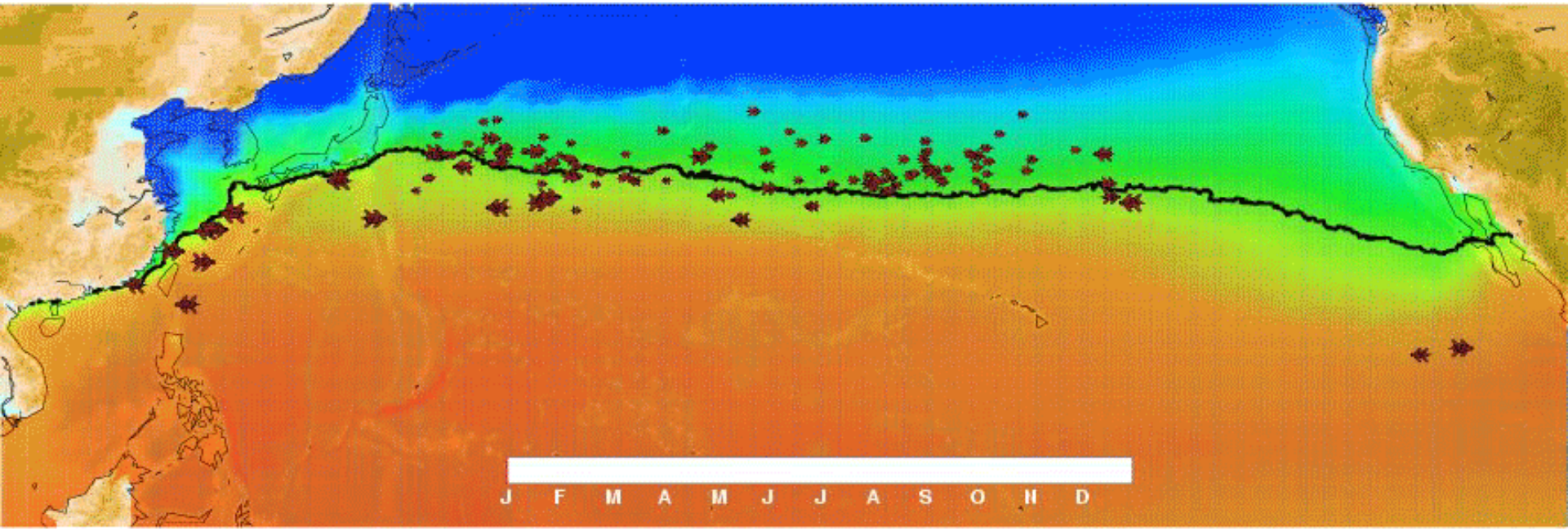
Polovina et al. 2000

Wind Stress Curl, Surface Chlorophyll *a*, and 18ºC SST for 180-160ºW



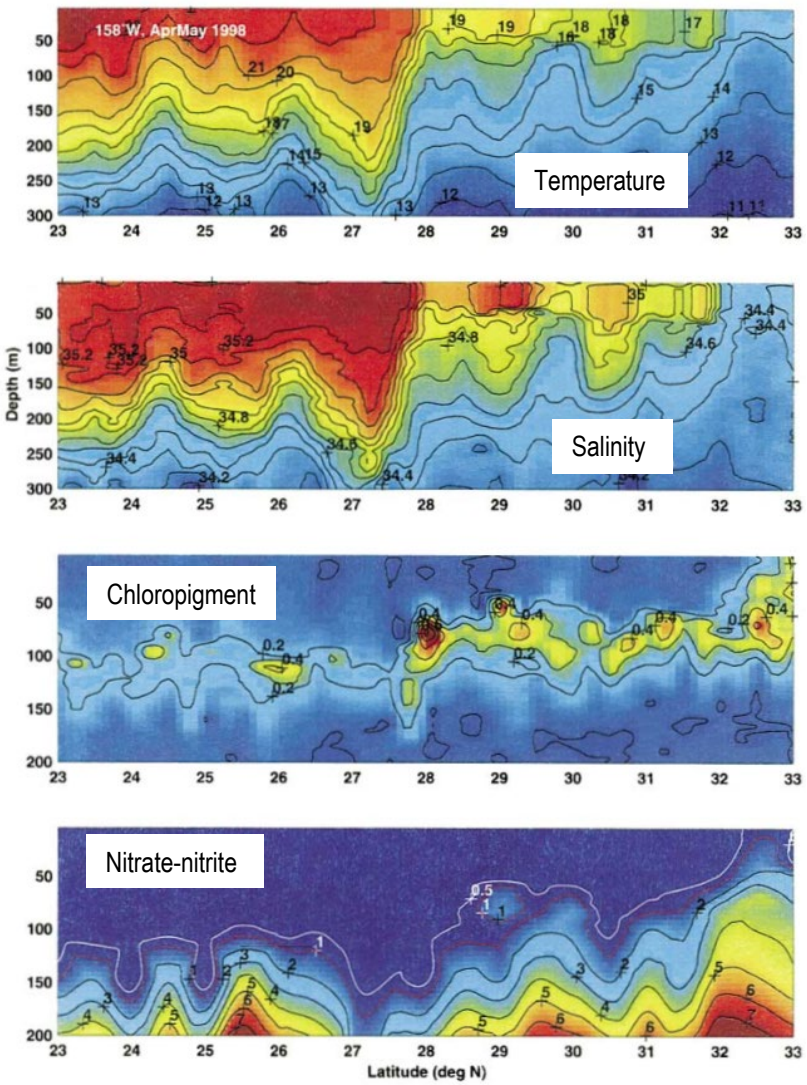
Foley, pers. Comm.



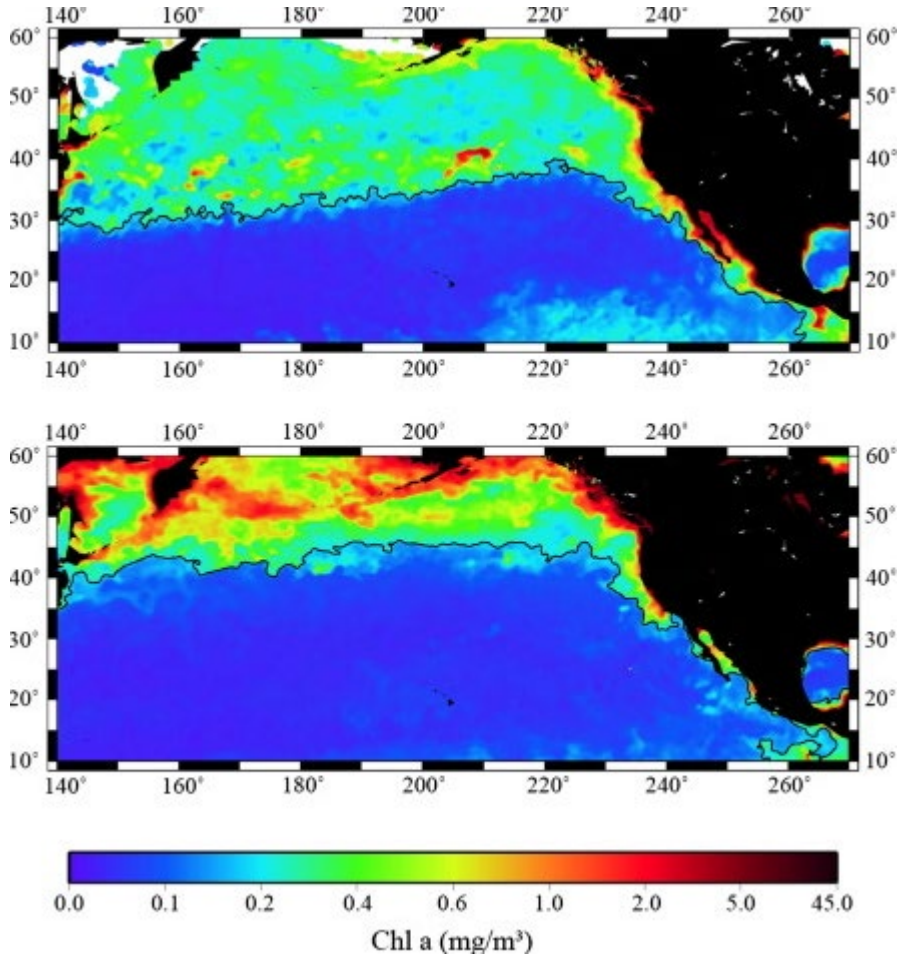
- All tracks remapped to a single calendar year
- Climatological SST field, contour at 18.5°C for reference

Produced by D Kobayashi

Vertical profiles (Polovina et al 2001)

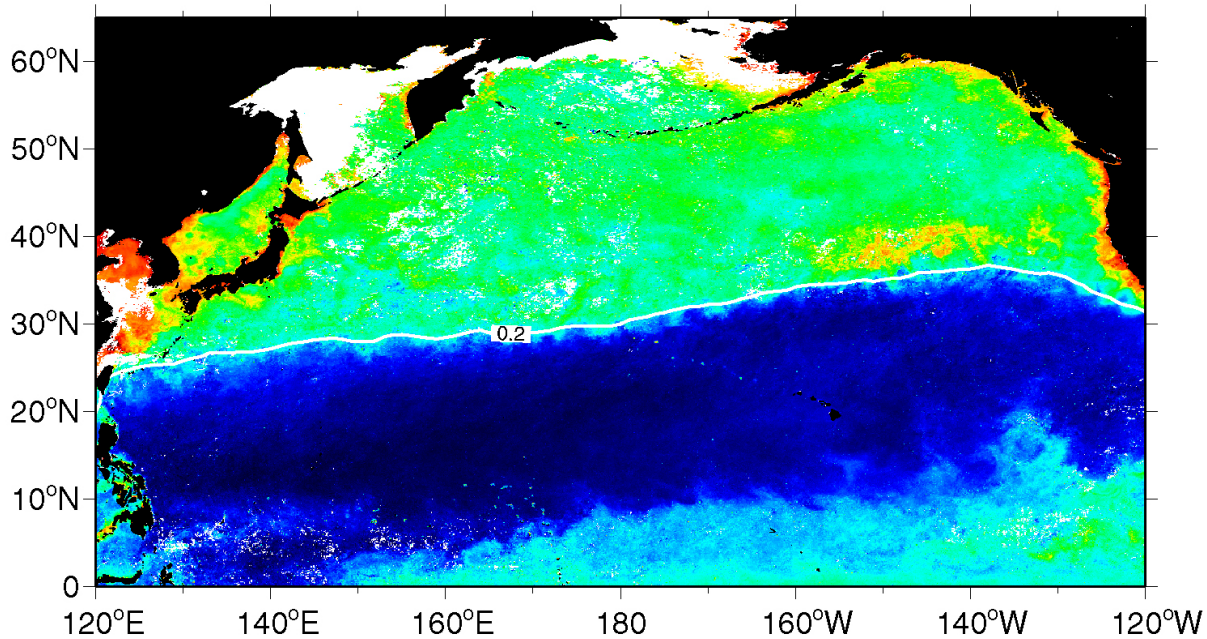


Transition Zone Chlorophyll Front (TZCF)



Polovina et al. 2015

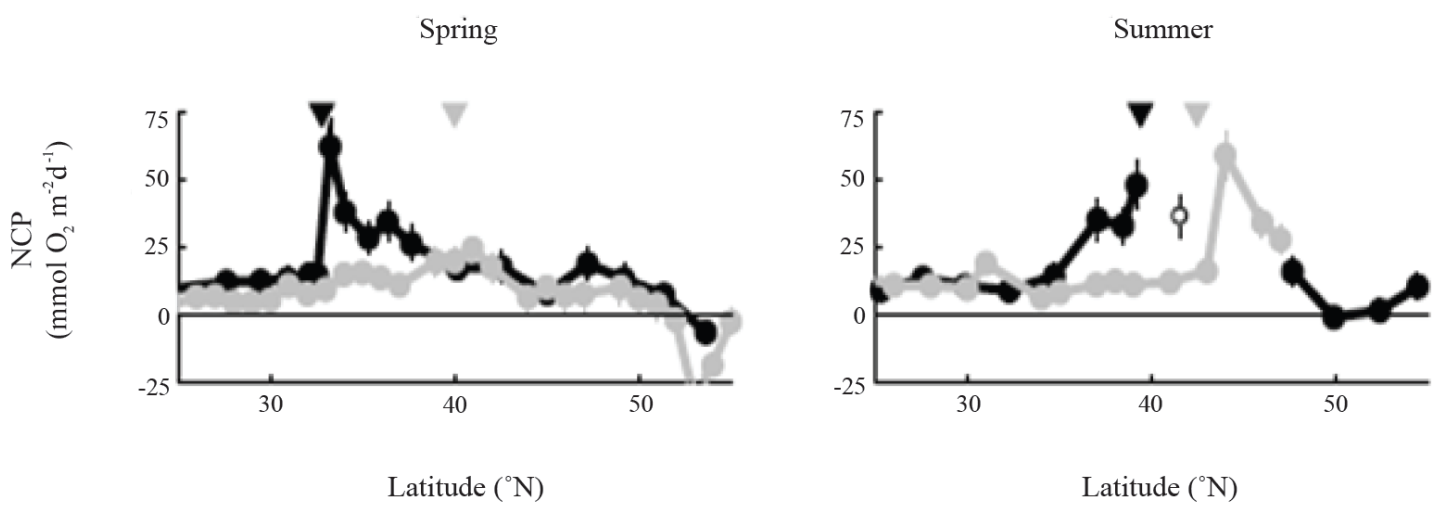
Transition Zone Chlorophyll Front (TZCF)



Polovina et al. 2001

Polovina et al. 2017

Net community maximum production (Juranek et al. 2012)



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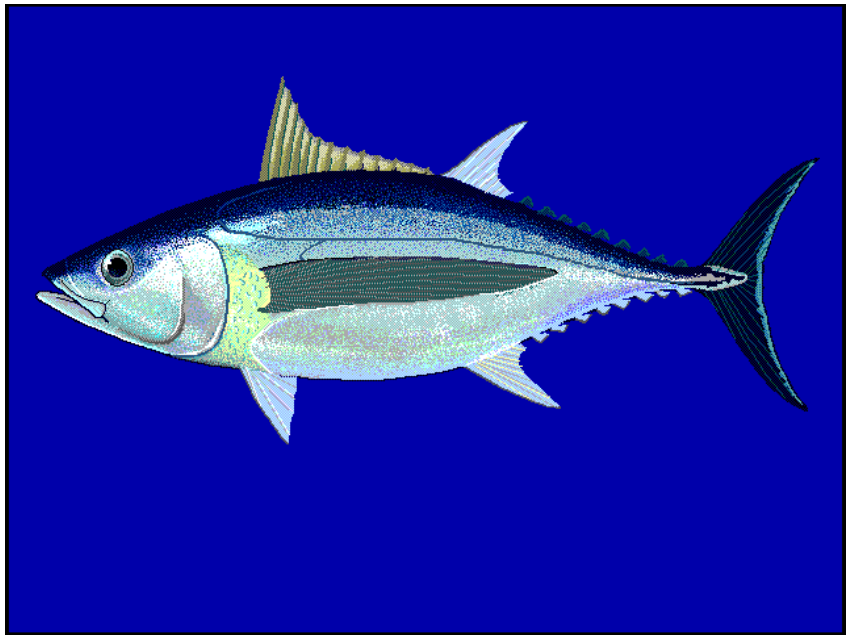
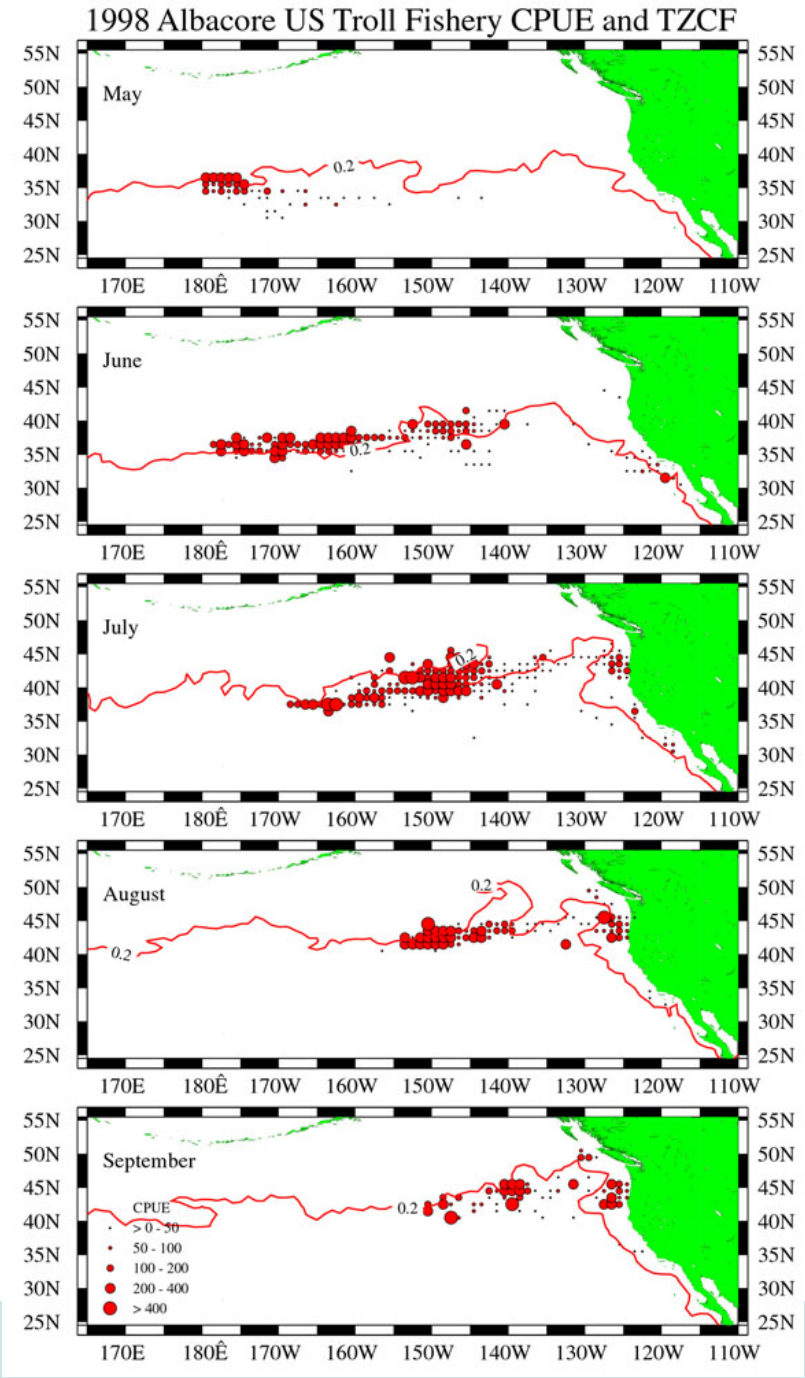
Albacore tuna habitat

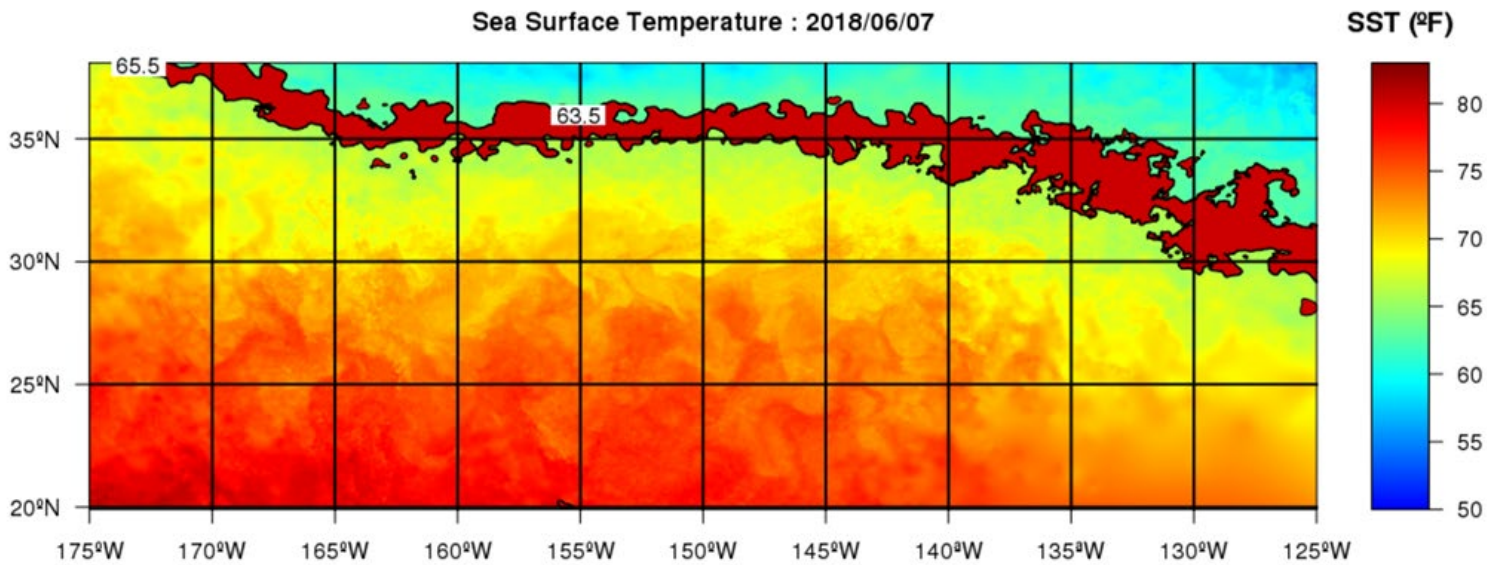




TurtleWatch

EXPERIMENTAL PRODUCT

Avoid fishing between solid black 63.5°F and 65.5°F lines to help reduce loggerhead sea turtle interactions



PACIFIC ISLANDS FISHERIES SCIENCE CENTER
ECOSYSTEM SCIENCES DIVISION
1845 Wasp Blvd, Honolulu, HI 96818
http://www.pifsc.noaa.gov/eod/turtlewatch.php
contact: melanie.abecassis@noaa.gov

Data provided by the OceanWatch - Central Pacific node

TurtleWatch

From 2004, larger hooks and different bait greatly reduced turtle interactions in the swordfish fishery. Additionally, based on loggerhead's use of the TZCF, we developed TurtleWatch to advise fishers of the zone of highest probability of interaction

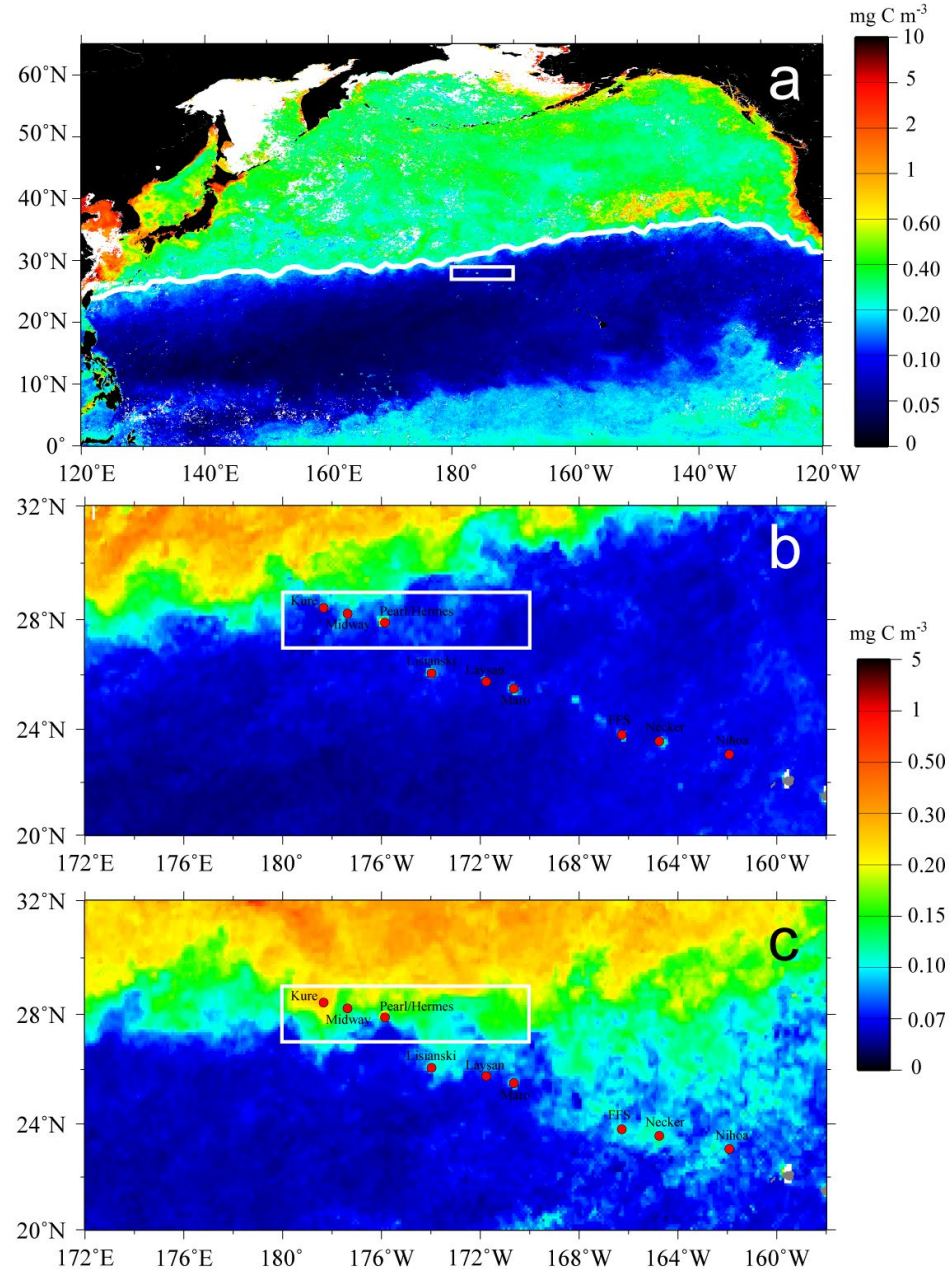
Monk seal pups survival

Surface chlorophyll in:

- March 2000 (top, middle)
- March 2004 (bottom)

provide an example of interannual variation in northward extent of oligotrophic waters.

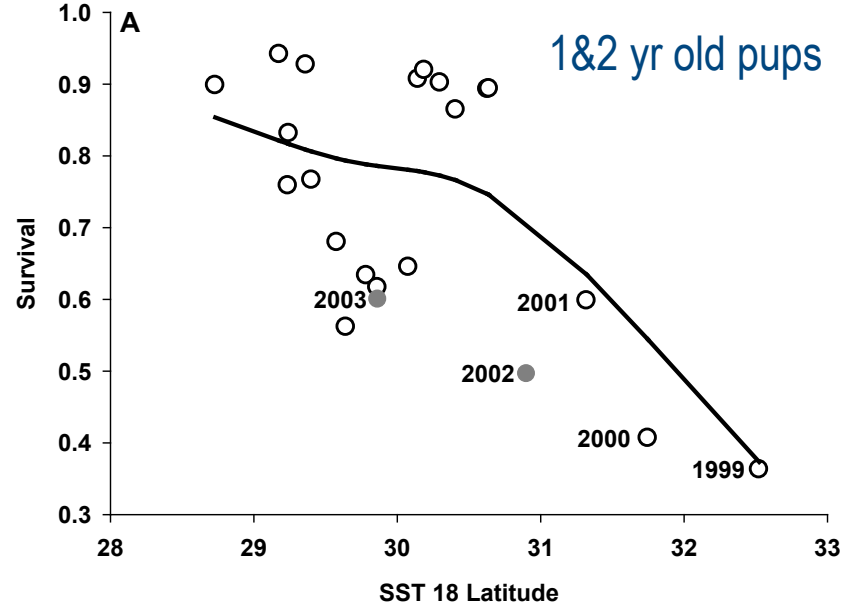
Baker et al. 2007

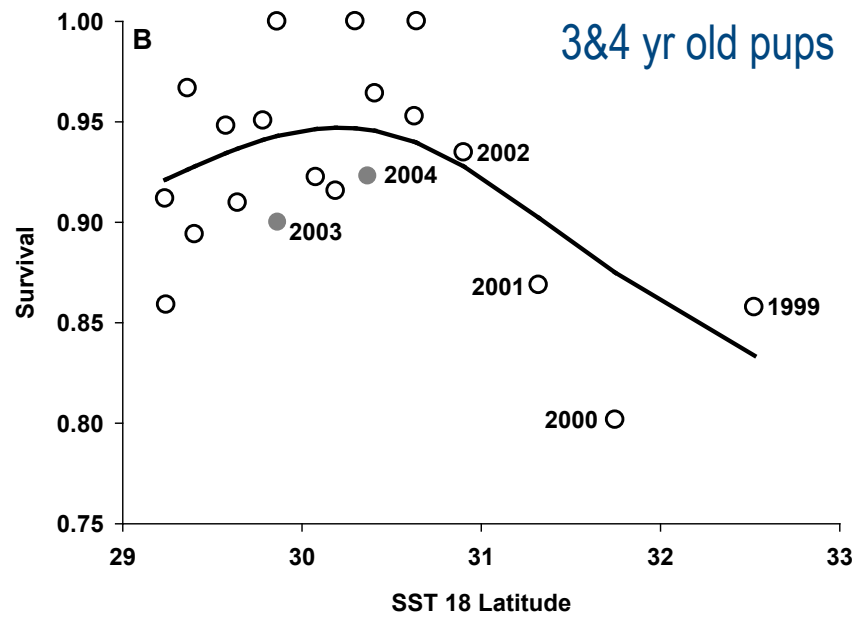


Monk seal pups survival

Survival of pups at northern Hawaiian atolls is linked to the location of the 18° SST isotherm, a proxy for the TZCF, 1985-2003.

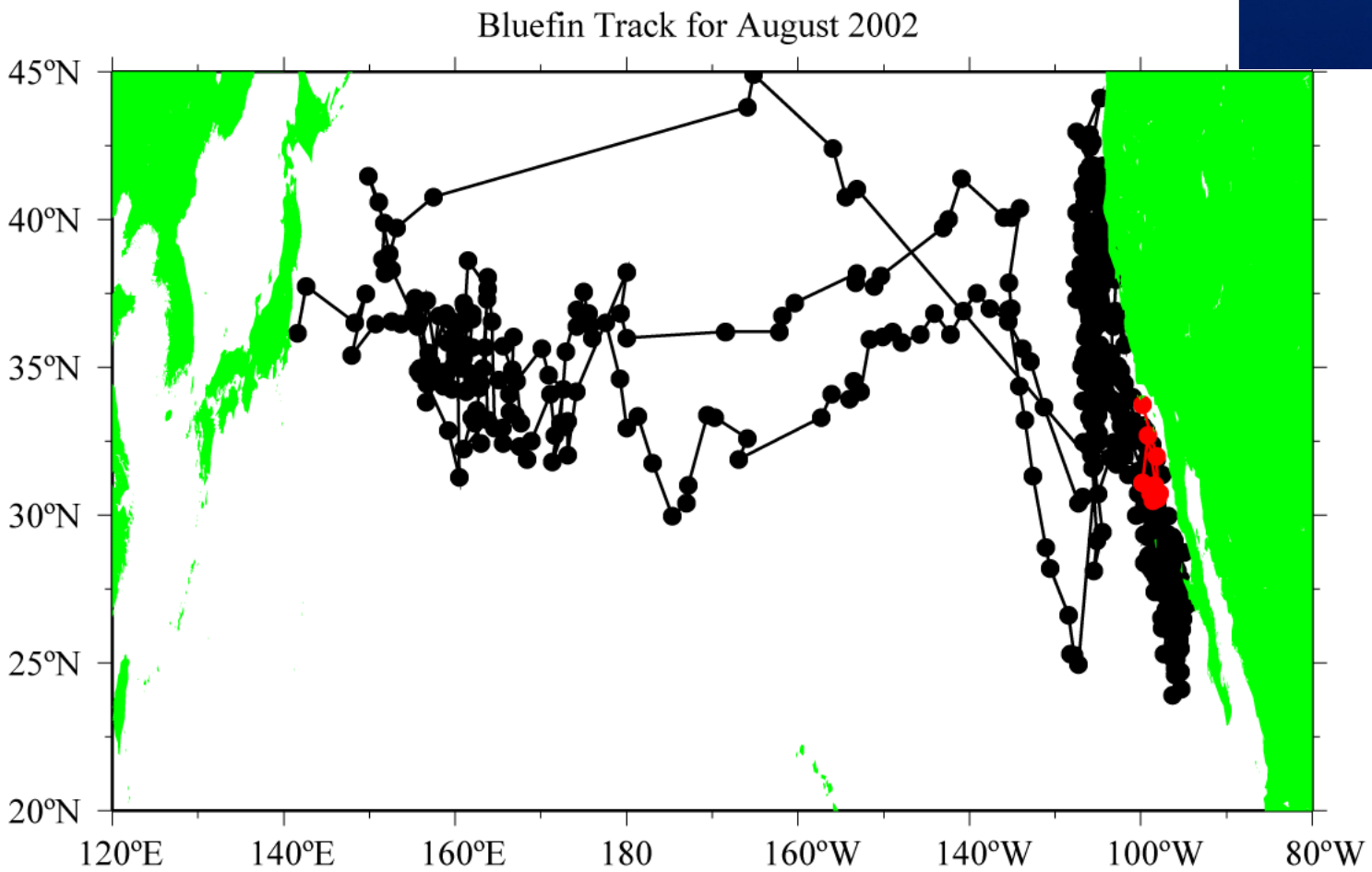
When the front is too far north, productive waters don't reach the atolls and pup survival is lower.





Baker et al. 2007

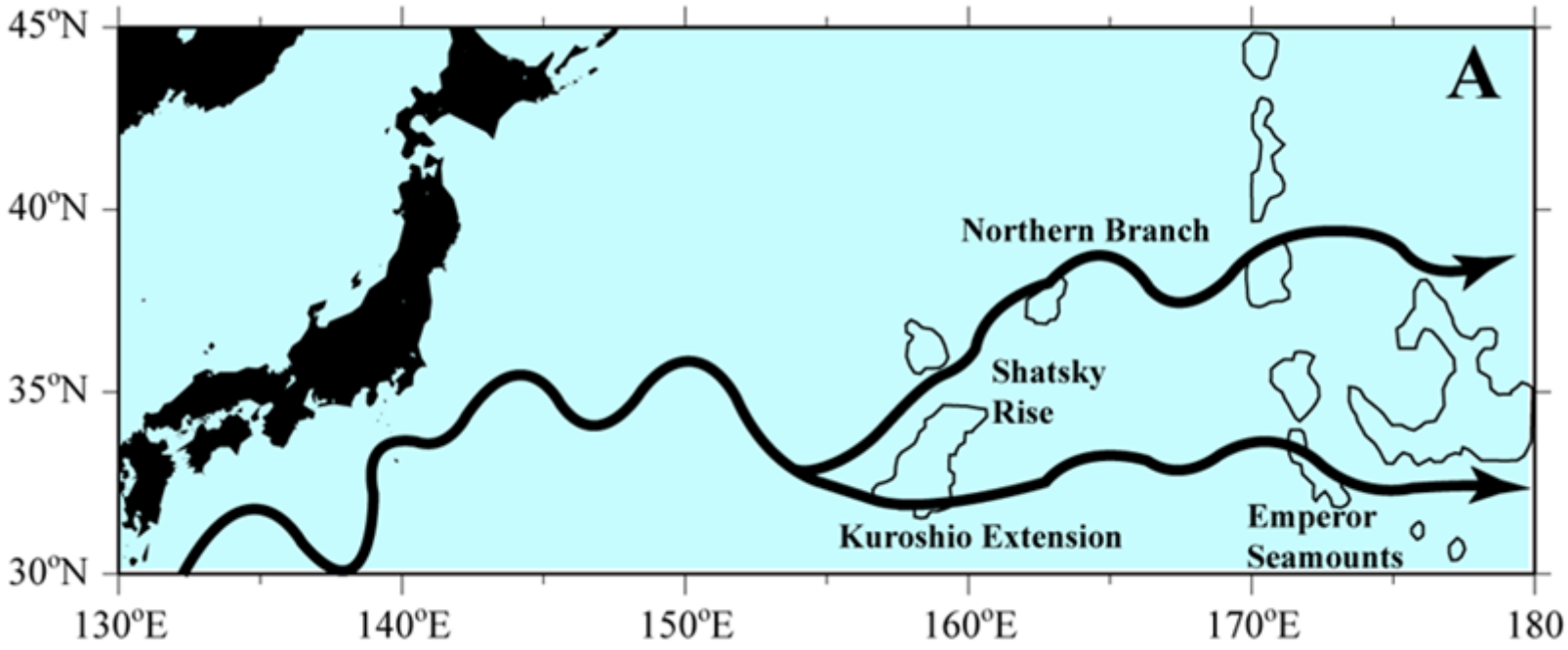
NPTZ as forage habitat- Bluefin tuna



Kuroshio Extension Bifurcation Region (KBR) April – July 2003, April – June 2004

Courtesy B. Block, TOPP

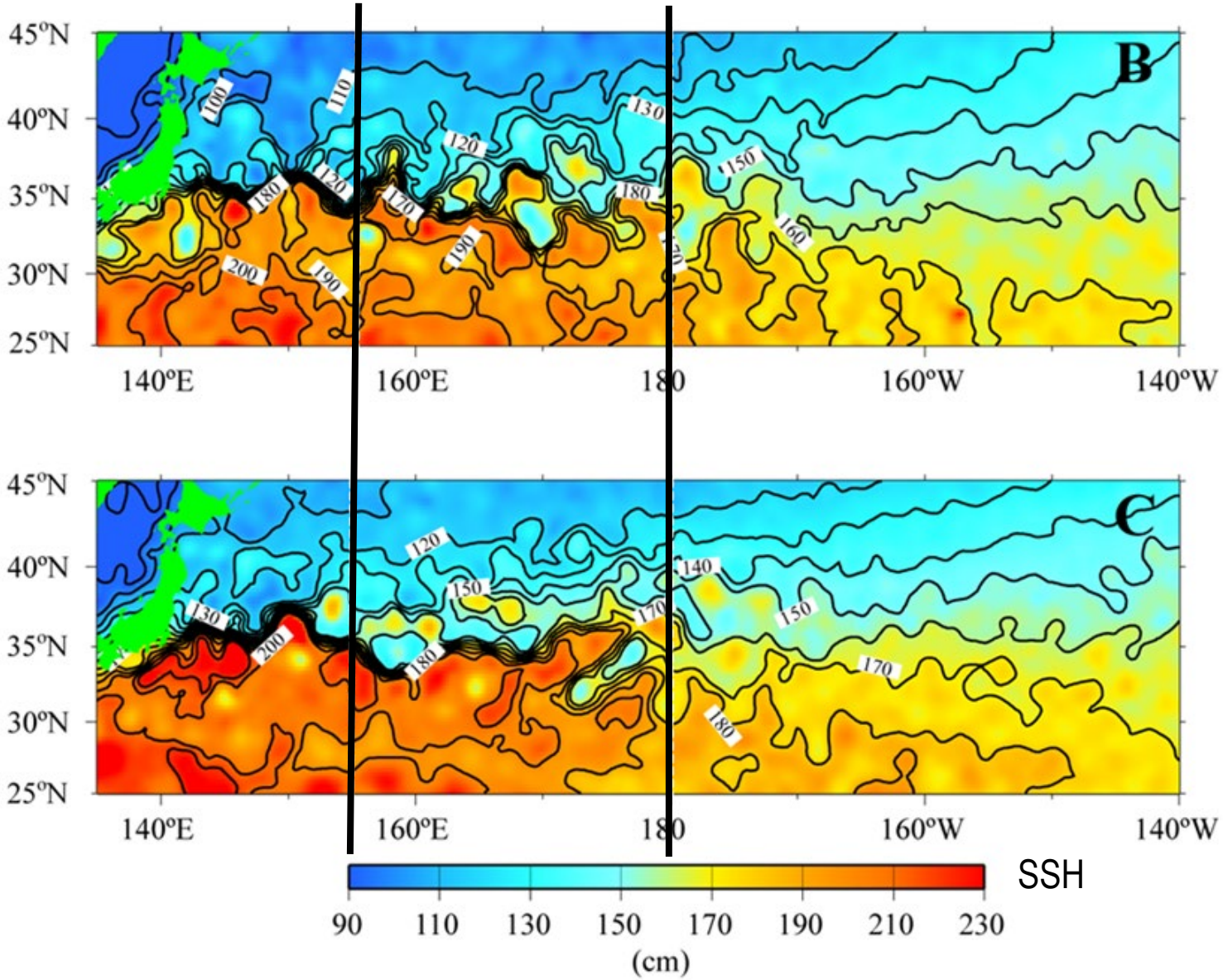
The Kuroshio Extension Bifurcation Region (KEBR)



Meanders in the KEBR from AVISO altimetry

March 2003

September 2003



Polovina et al. 2006

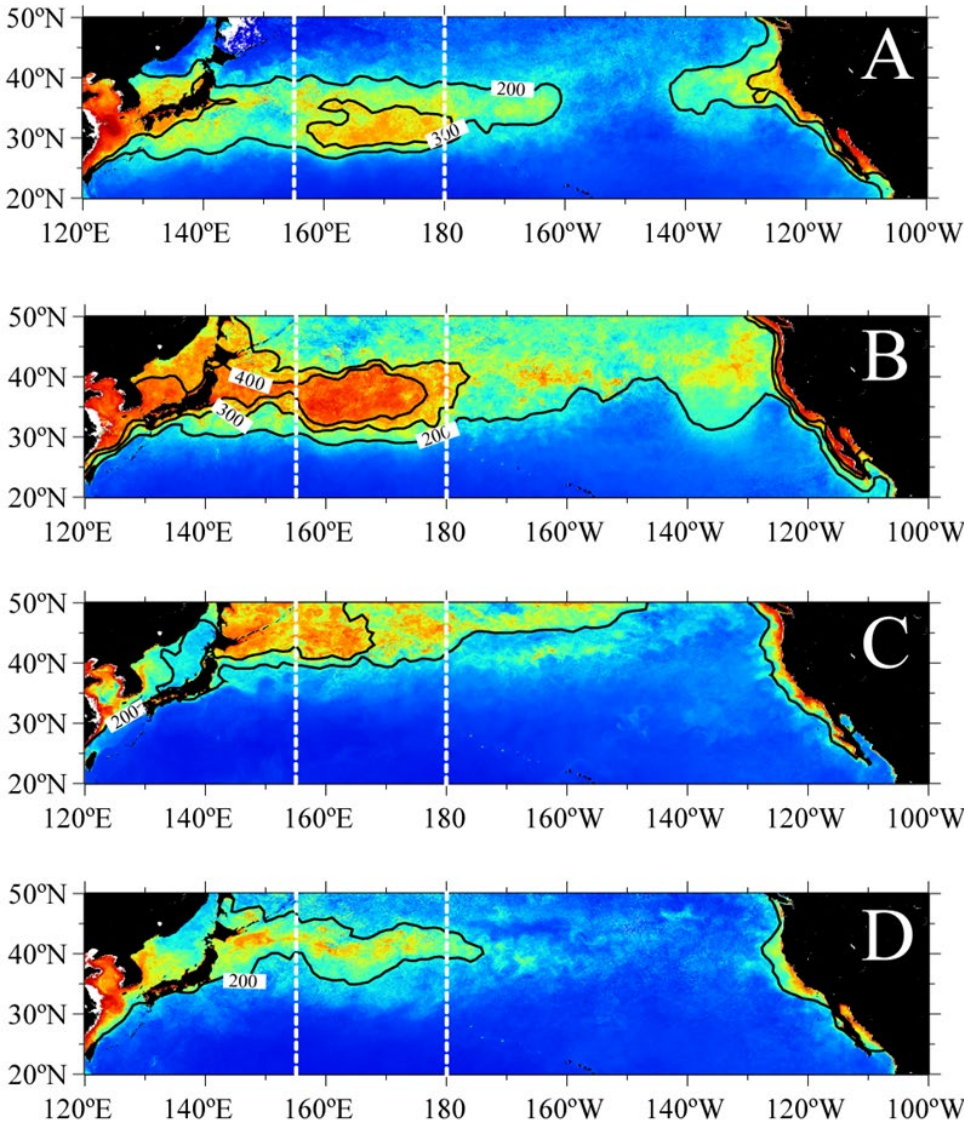
Primary productivity in the KEBR

Quarter 1, 2003

Quarter 2, 2003

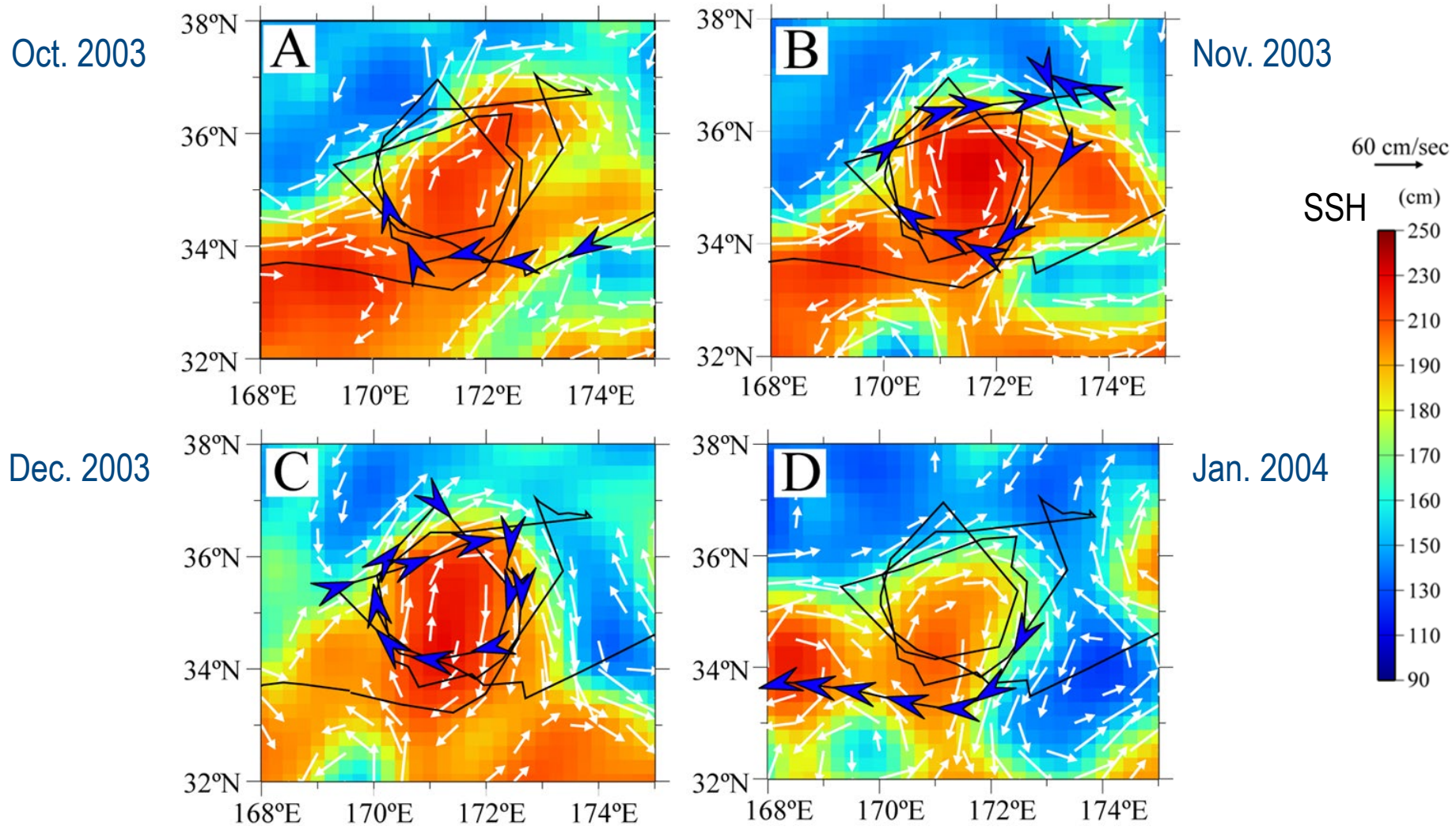
Quarter 3, 2003

Quarter 4, 2003

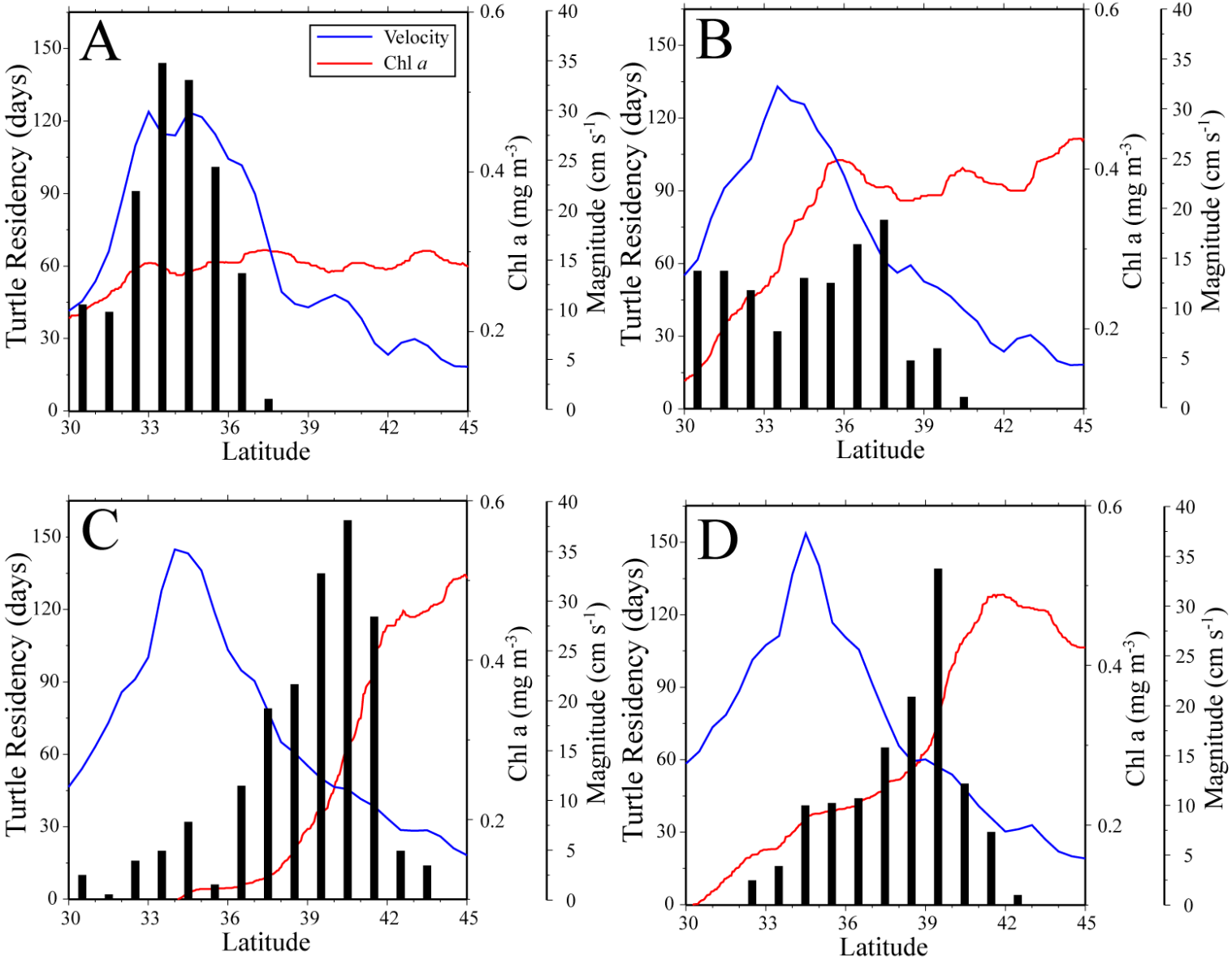


www.science.oregonstate.edu/ocean.productivity

Loggerhead turtle track: use of eddies in the KEBR

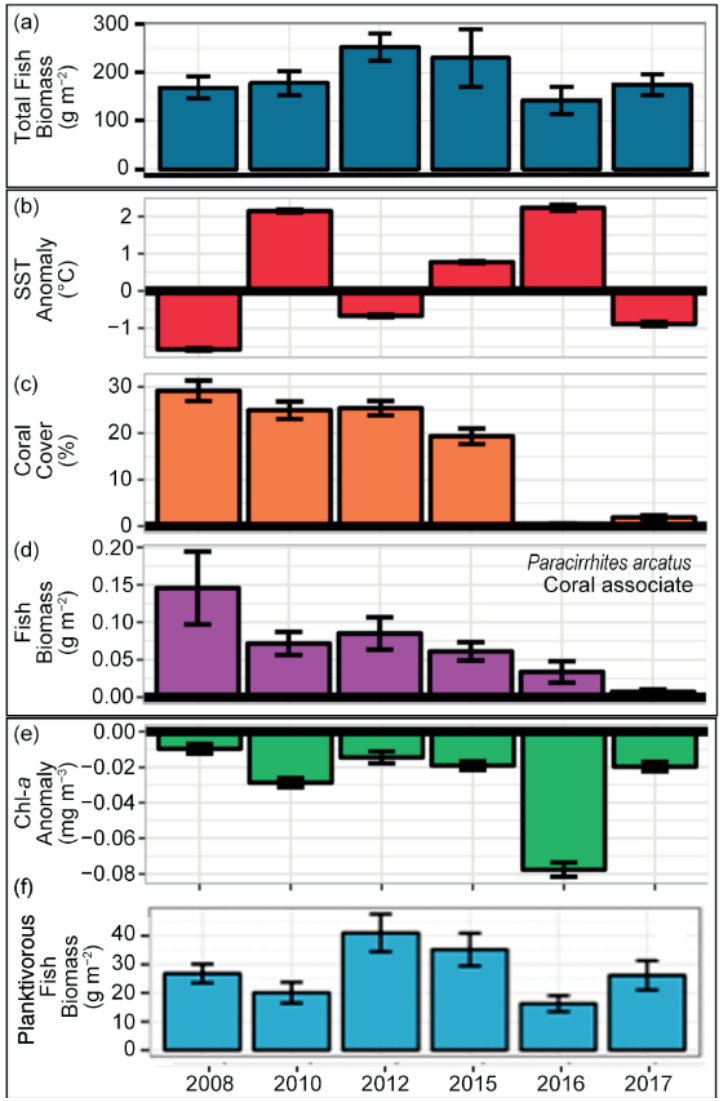


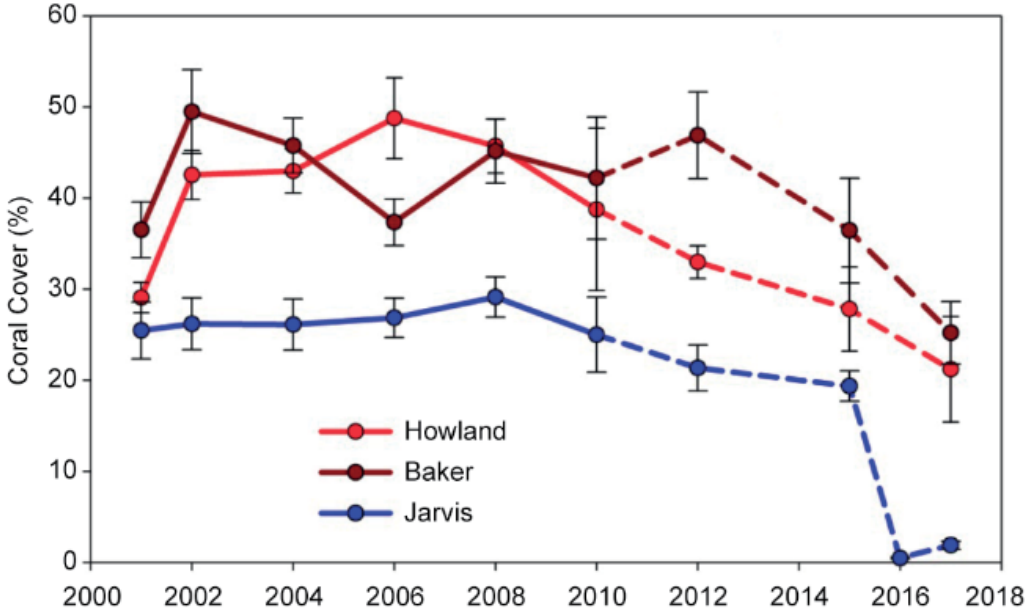
Frequency distributions for loggerhead turtles released from Japan



Impacts of the 2015/2016 El Niño on coral reefs

Jarvis



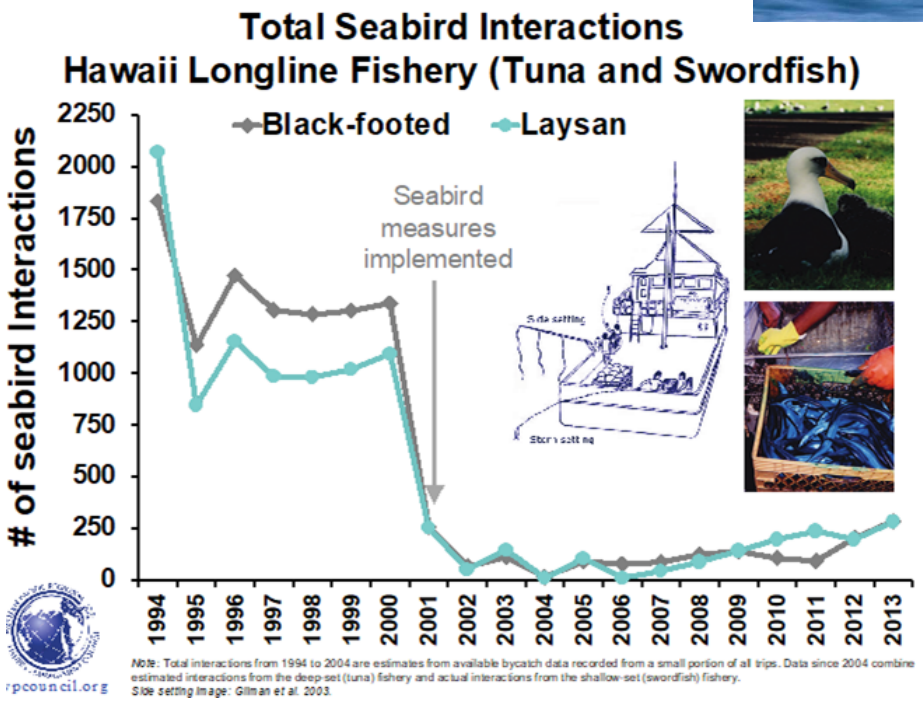


Brainard et al., 2018

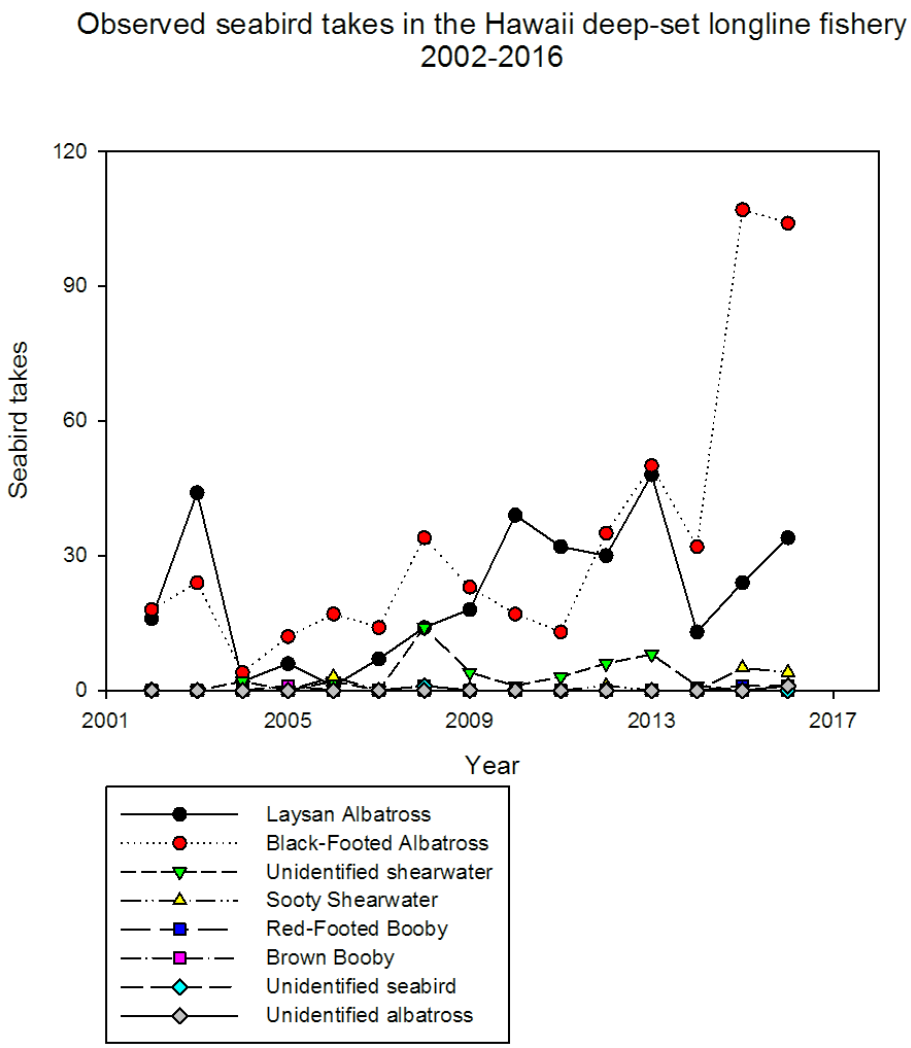
Quantitative Approaches

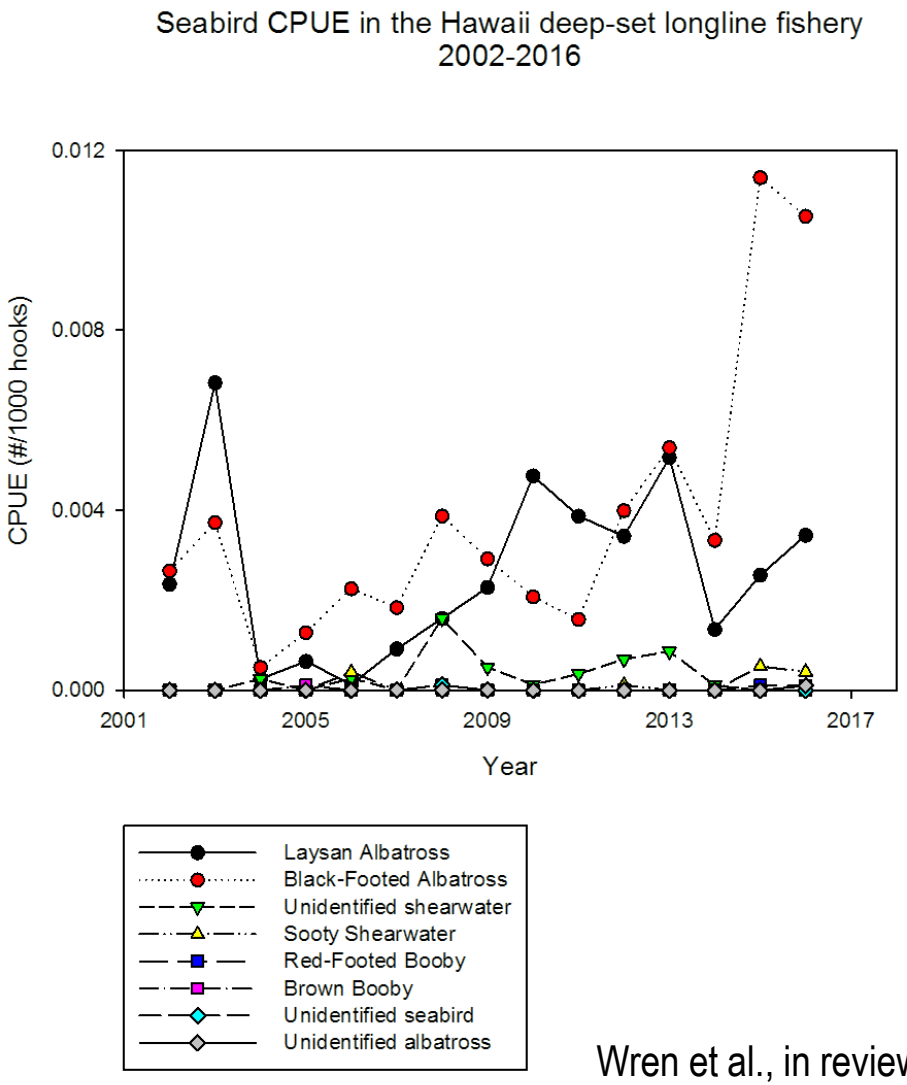
- Use in GLM and GAMS to build bycatch or habitat models.
- Construct and compare frequency distributions to map habitat
- Map biomes
- Estimate fishery catch or ecosystem carrying capacity.

Pelagic Longline Bycatch



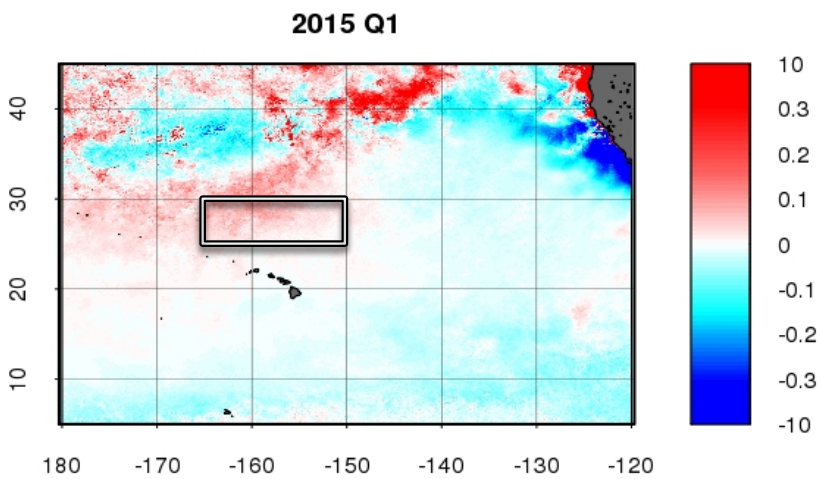
Seabird bycatch in the longline fishery

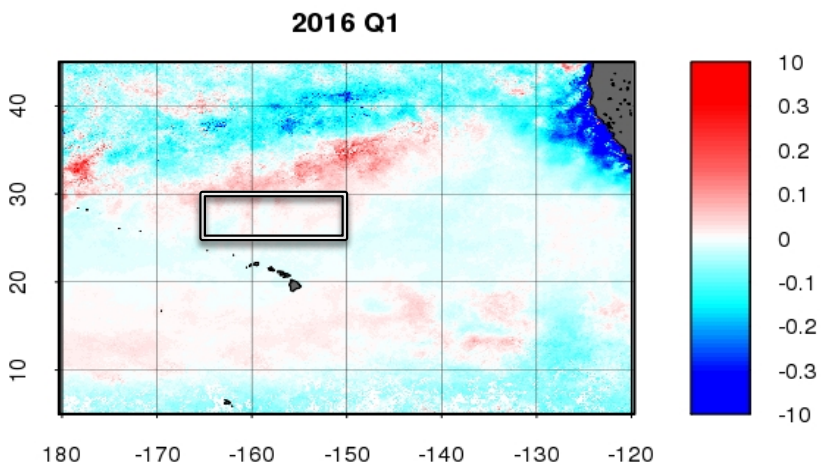




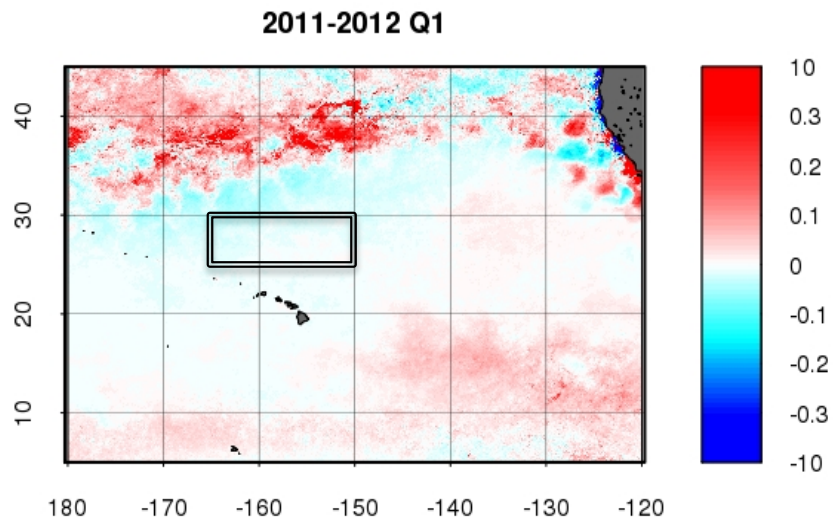
Wren et al., in review

El Nino and positive PDO Chlorophyll Anomaly





La Nina and negative PDO Chlorophyll Anomaly

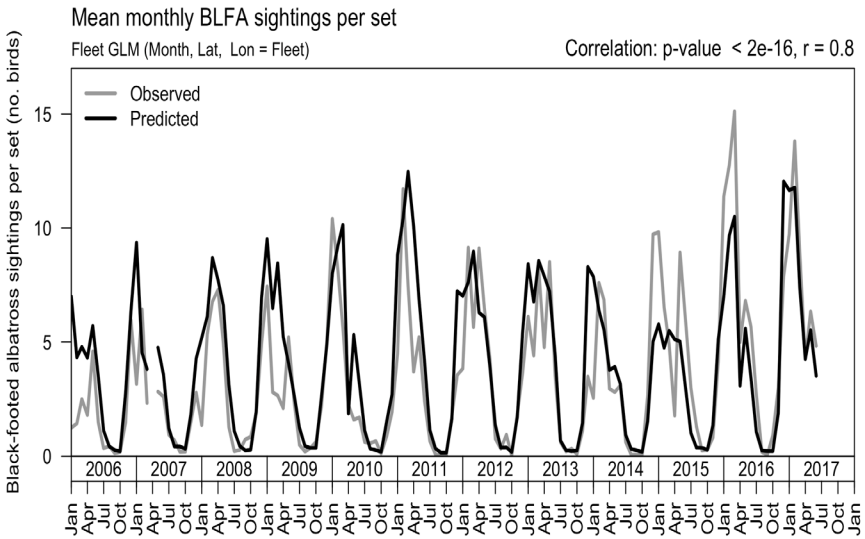


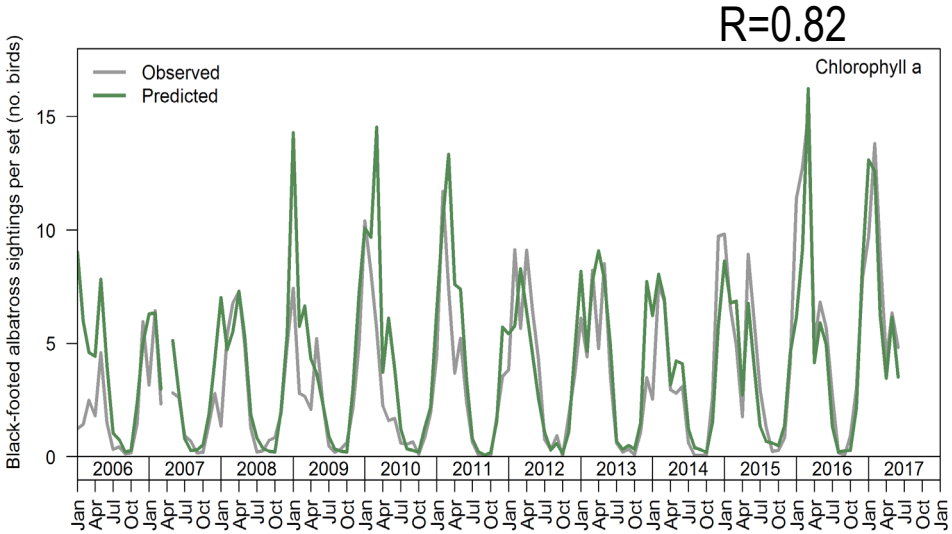
Model Setup

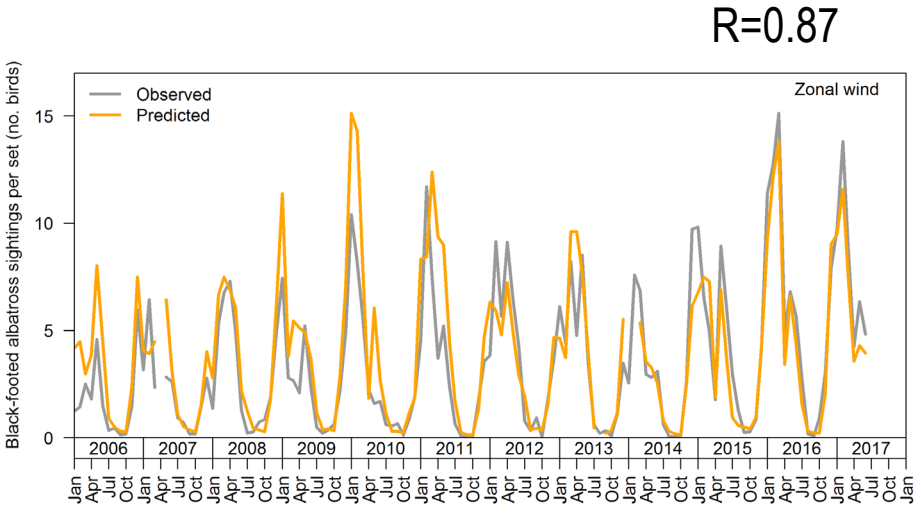
Fleet dynamics	Local Climate Variables	Large-scale Climate Variables	Biological Variables
Seasonality: Month	Sea surface temperature (SST)	Pacific Decadal Oscillation index (PDO)	Nesting pair counts
Latitude & Longitude	SST standard deviation	Multivariate ENSO Index (MEI)	Reproductive success
	Chlorophyll a		Total fish catch
	Wind stress curl		Total Mahimahi catch
	Meridional wind velocity		
	Zonal wind velocity		

Wren et al. 2018, in review

Monthly albatross sightings







GAM model:

1. Sightings = F(long, lat, month)
2. Sightings = F(long, lat, month, Chl)
3. Sightings = F(long, lat, month, zonal wind)

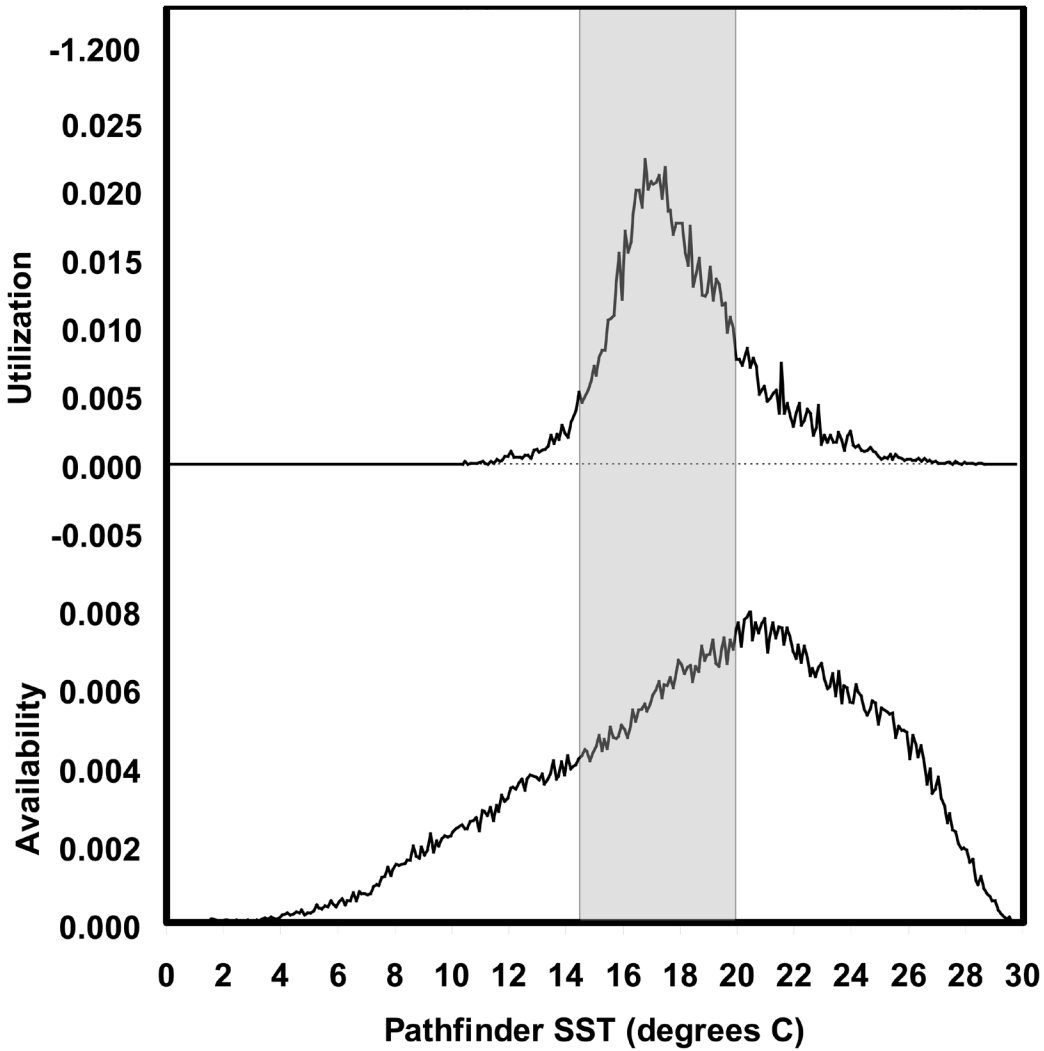
Wren et al. 2018, in review

Possible variables that characterize loggerhead sea turtle habitat

Environmental variable	Kolmogorov-Smirnov D_{max} value	Value at D_{max}	Significance
SeaWiFS chlorophyll-a	0.3596	0.1050	***
Pathfinder sea surface temperature	0.2985	19.8500	***
IGRF-10 magnetic declination	0.2669	12.1485	***
IGRF-10 magnetic total force	0.1998	44136.5	***
IGRF-10 magnetic inclination	0.1866	53.8970	**
AVISO geostrophic u-component	0.1516	4.5000	ns
Smith & Sandwell bathymetry	0.1486	-5485	ns
AVISO sea surface height	0.1476	171.5	ns
Pathfinder sea surface temperature gradient	0.1303	0.1350	ns
ERS/QuikSCAT winds u-component	0.1106	-0.0212	ns
IGRF-10 magnetic orthogonality index	0.1097	0.0786	ns
ERS/QuikSCAT winds v-component	0.1002	-0.0042	ns
AVISO geostrophic v-component	0.0707	-8.5	ns
ERS/QuikSCAT winds total magnitude	0.0665	0.1859	ns
Smith & Sandwell bathymetric EW gradient	0.0300	-315	ns
Smith & Sandwell bathymetric NS gradient	0.0133	-625	ns

Kobayashi et al. 2008

Utilization vs. Availability – Loggerhead turtles



Kobayashi et al. 2008

<= What the animal actually experienced.

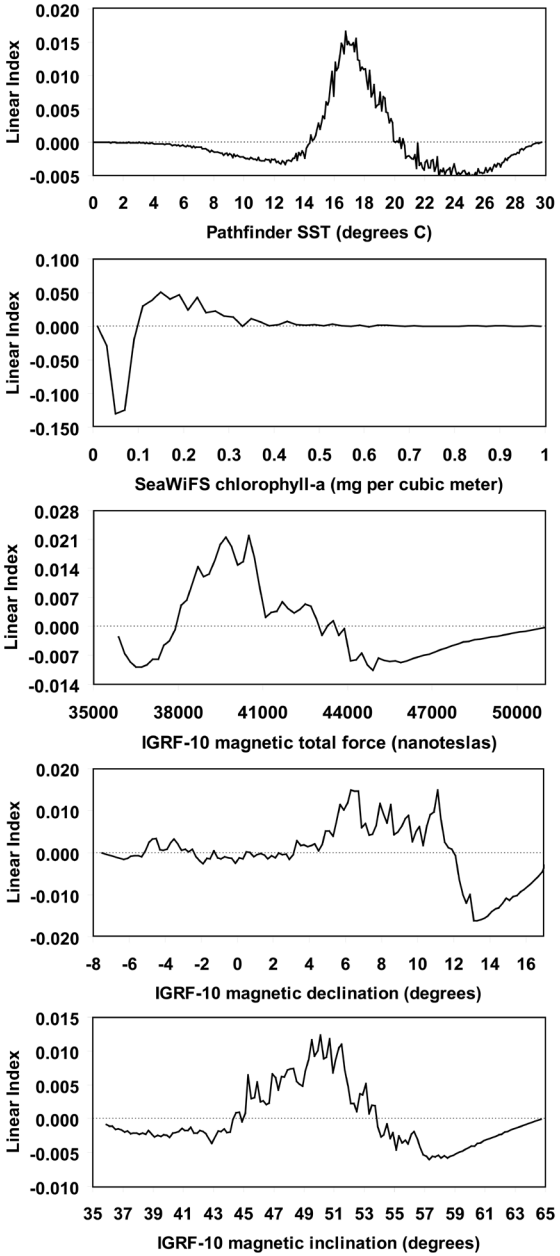
=utilization

<= What the animal could potentially encounter.

=availability

Knowledge of BOTH is critical towards characterizing habitat preference.

Habitat selectivity

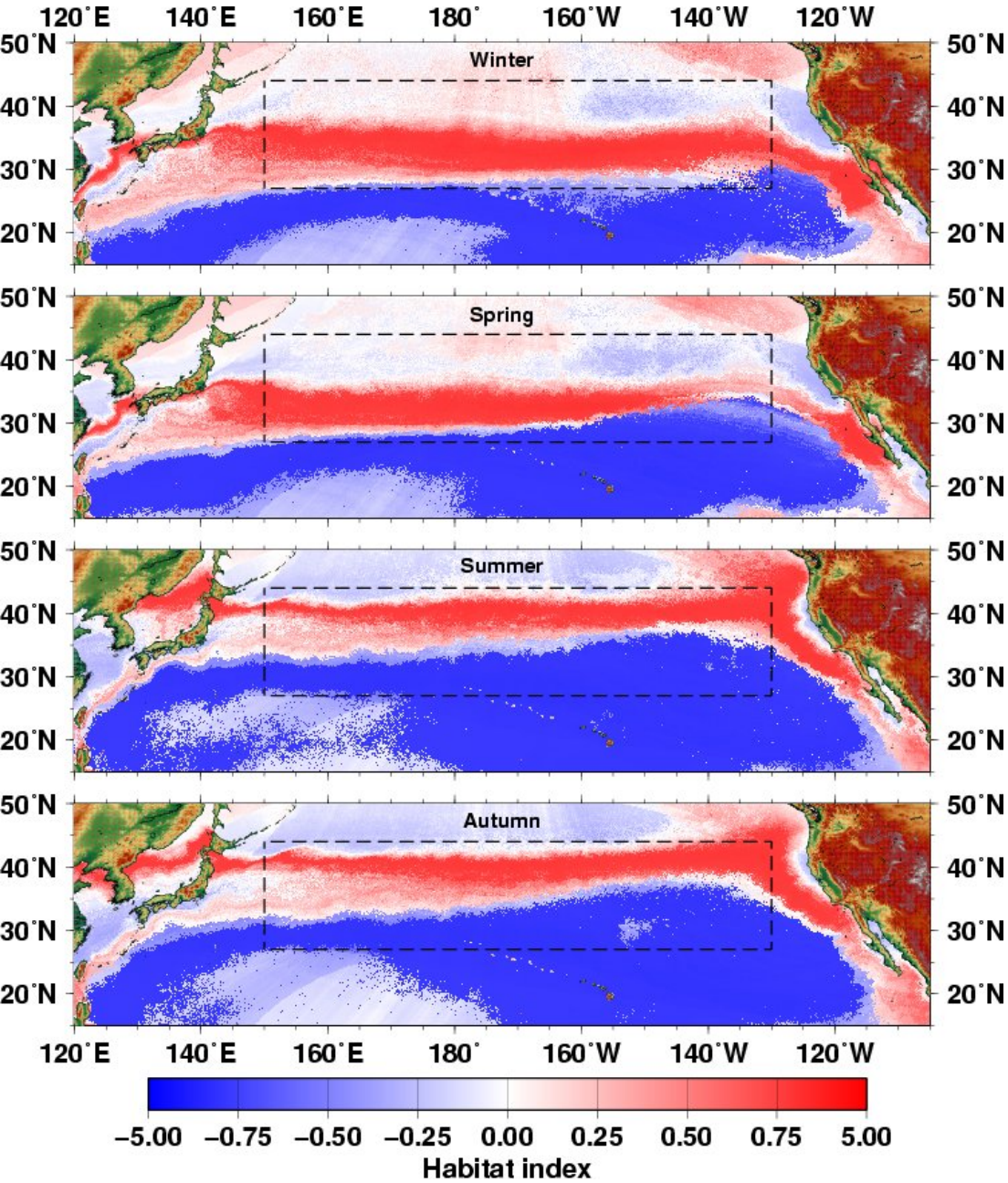


- From Strauss (1979), calculated as

  LI = utilization – availability
- LI for each of:
  - SST
  - Chlorophyll-*a*
  - Magnetic total force, declination & inclination
- Use positive values of LI to delineate habitat
- Sum individual indices to produce overall habitat index.

Variable	Range definition for habitat
Pathfinder SST	14.45°C to 19.95°C
SeaWiFS chlorophyll-a	0.11 mg per cubic meter to 0.31 mg per cubic meter
IGRF-10 magnetic force	38100 nanteslas to 42900 nanoteslas
IGRF-10 magnetic declination	-5.1° to -2.5°, 3.3° to 11.9°
IGRF-10 magnetic inclination	44.5° to 53.7°

Kobayashi et al. 2008



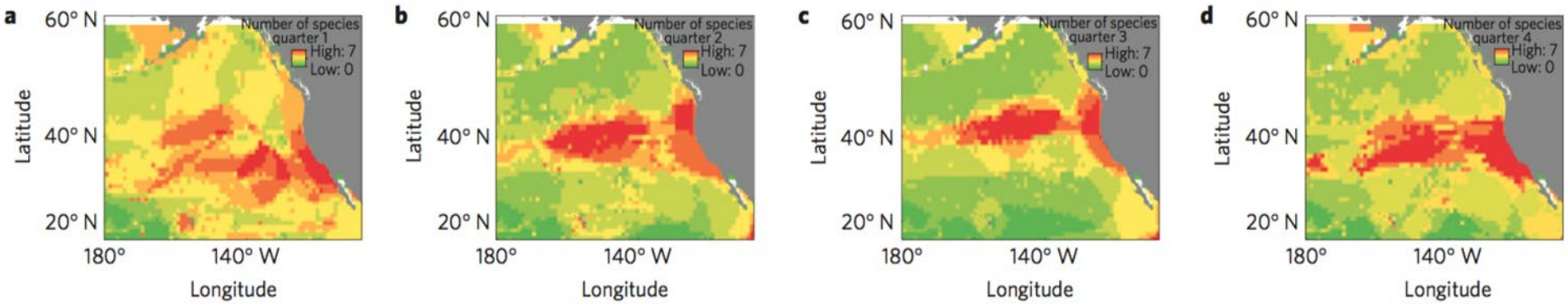
Model Output

- Seasonal climatological habitat indices, for example.
- Habitat maps can be produced for any time interval, and forecast for short-term or long-term.
- Habitat predictions based on climate change, El Niño, La Niña patterns.

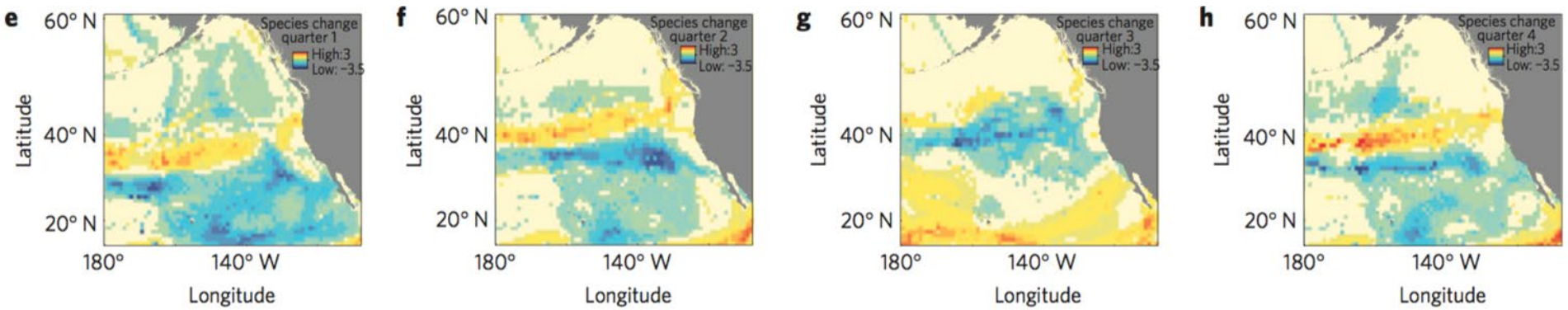
Kobayashi et al. 2008

Quarterly species richness for 23 pelagic species

2000 - 2010



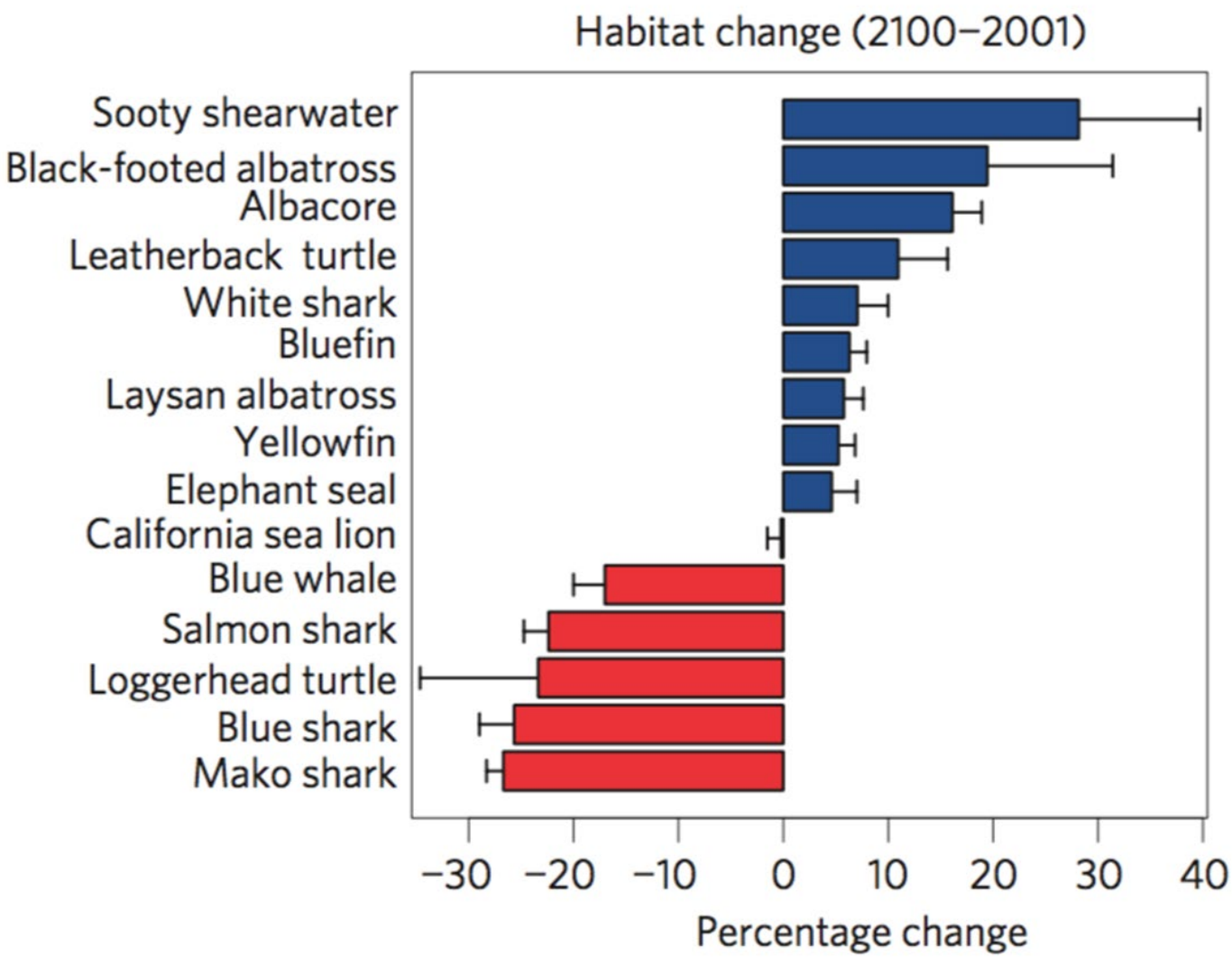
2081 - 2100



Based on 4300 electronic tags, satellite SST and Chl-a, habitat models, and GFDL Earth Systems Model projections.

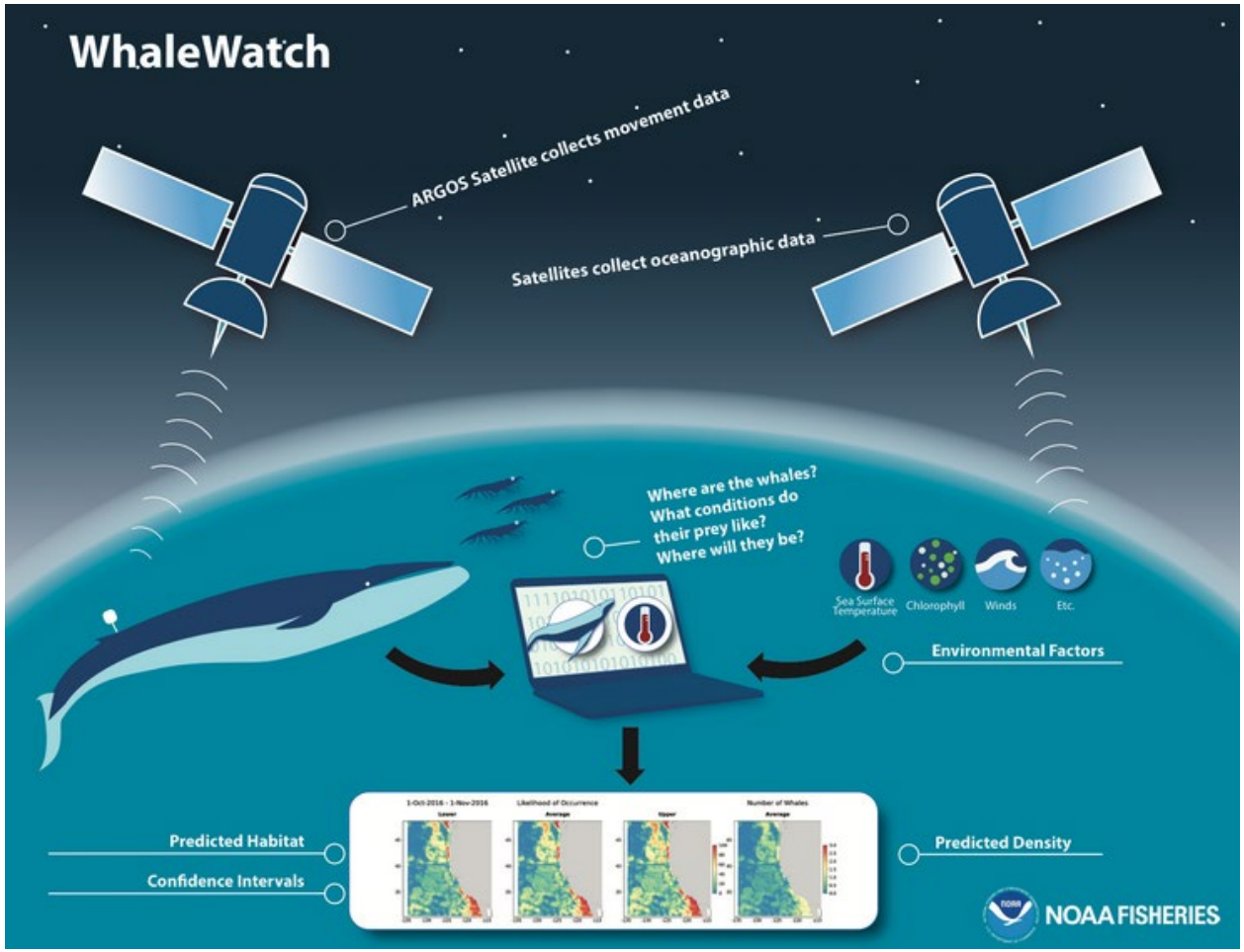
Hazen et al. 2012. Nature Climate Change

Winners and losers?



Hazen et al. 2012. Nature Climate Change

Whale Watch



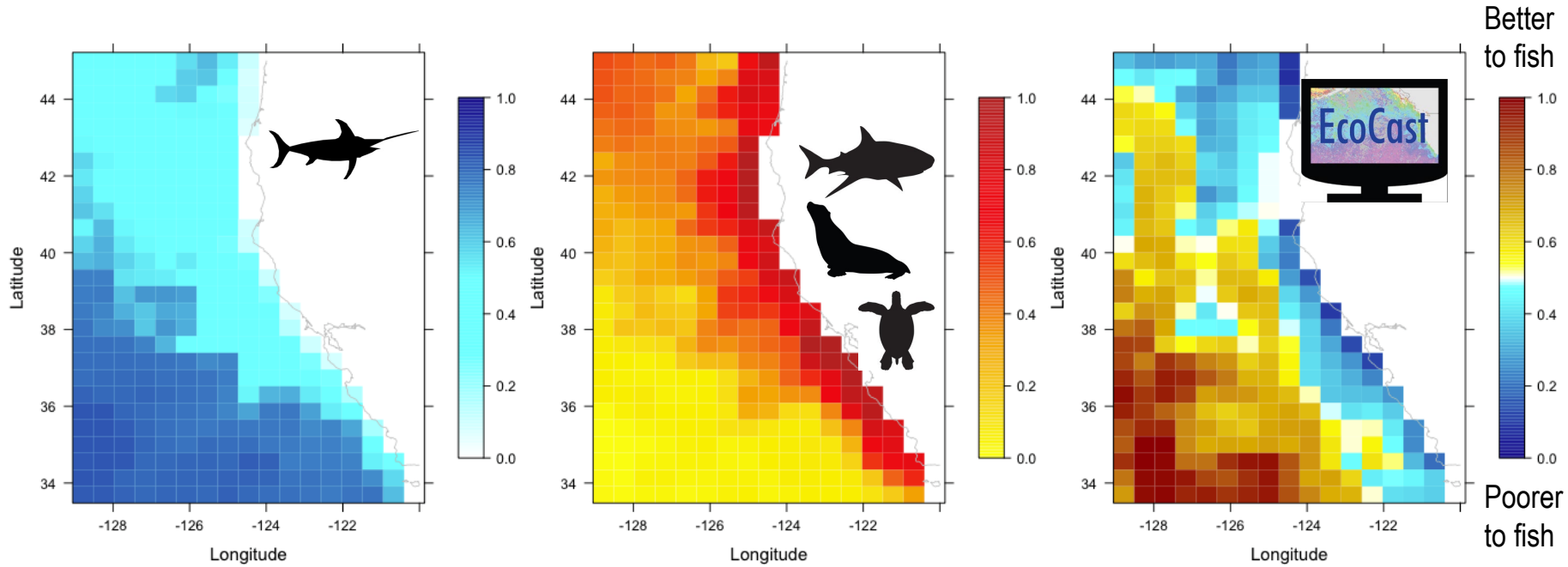
- Use satellite data to model blue whales & ship strike risk in near real time
- 104 OSU Blue Whale tracks
- NASA funded

Elliott Hazen et al. 2016

EcoCast

Predicting fishery bycatch for management

Predicted catch + **Predicted bycatch** ➔ **EcoCast**



Using remotely-sensed products, EcoCast maps are produced in near-real time for use by managers and fishers and aim to minimize fisheries bycatch and maximize fisheries target catch. This is a NASA-funded project.

Elliott Hazen et al. 2018, https://coastwatch.pfeg.noaa.gov/ecocast/about.html

EcoCast

An Eco-informatic Tool for Fisheries Sustainability

Experimental Product

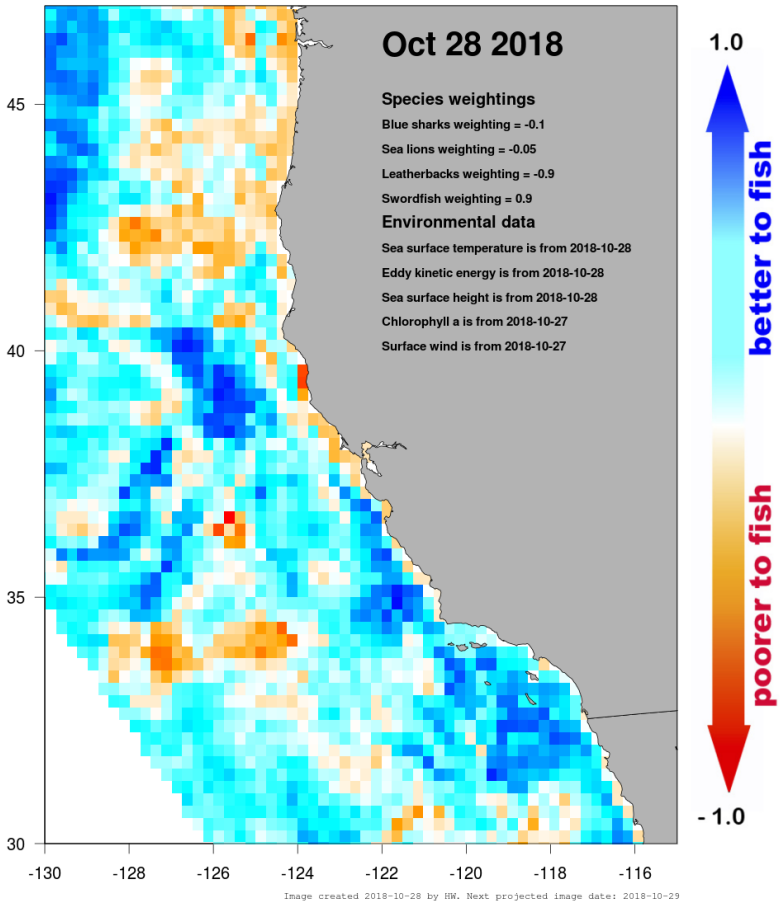
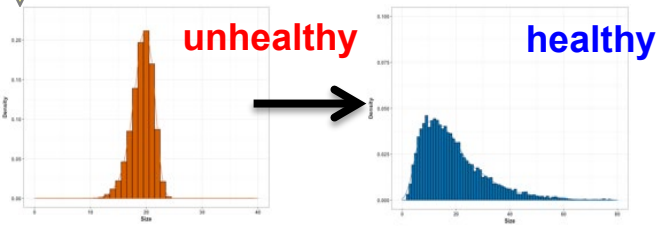


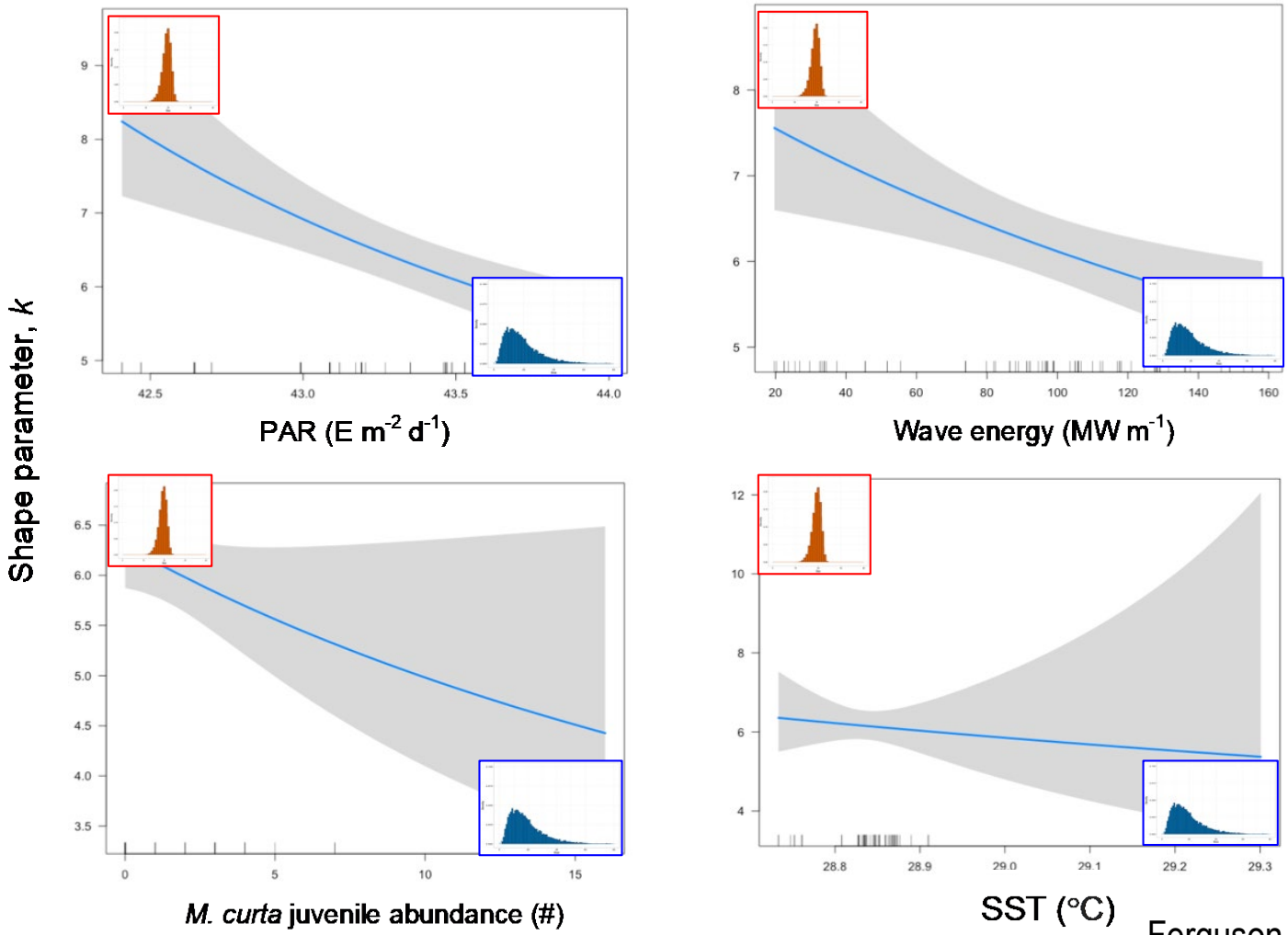
Image created 2018-10-28 by HW. Next projected image date: 2018-10-29

EcoCast is a dynamic ocean management tool that aims to minimize fisheries bycatch and maximize fisheries target catch in real-time. Map shows daily relative bycatch:target catch probabilities. Species weightings reflect management priorities and recent catch events. Environmental data are used to predict where species are likely to be each day.

Contacts: elliott.hazen@noaa.gov and heather.welch@noaa.gov
Environmental Research Division, SWFSC, NMFS, NOAA
99 Pacific Street, Monterey CA 93940, USA

Montastrea curta population health

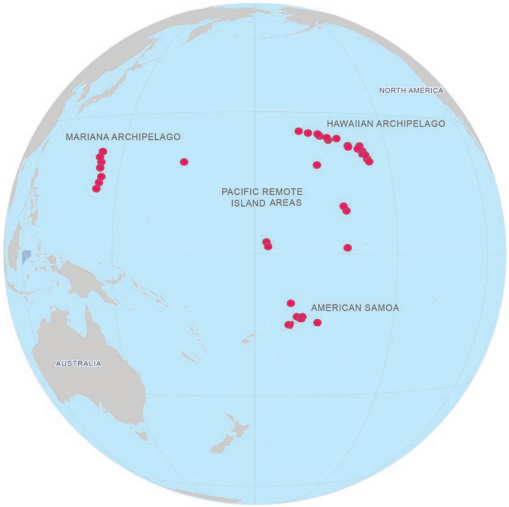




Ferguson et al, 2018

Crown-of-thorns spawning

Does <u>nutrient enhancement</u> during spawning season increase the probability of outbreak occurrence of the coral-eating crown-of-thorns sea star in the U.S. Pacific Islands?



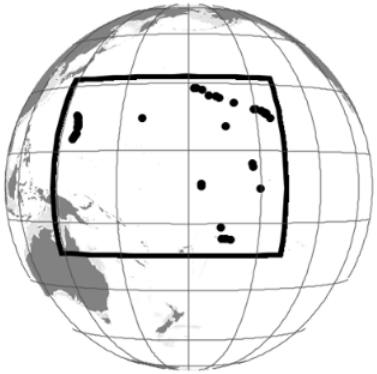
Nutrient Enrichment Hypothesis

↑ Nutrients = ↑ Phytoplankton Biomass = ↑ Larval Survivorship = ↑ Metamorphosis and thus Settlement

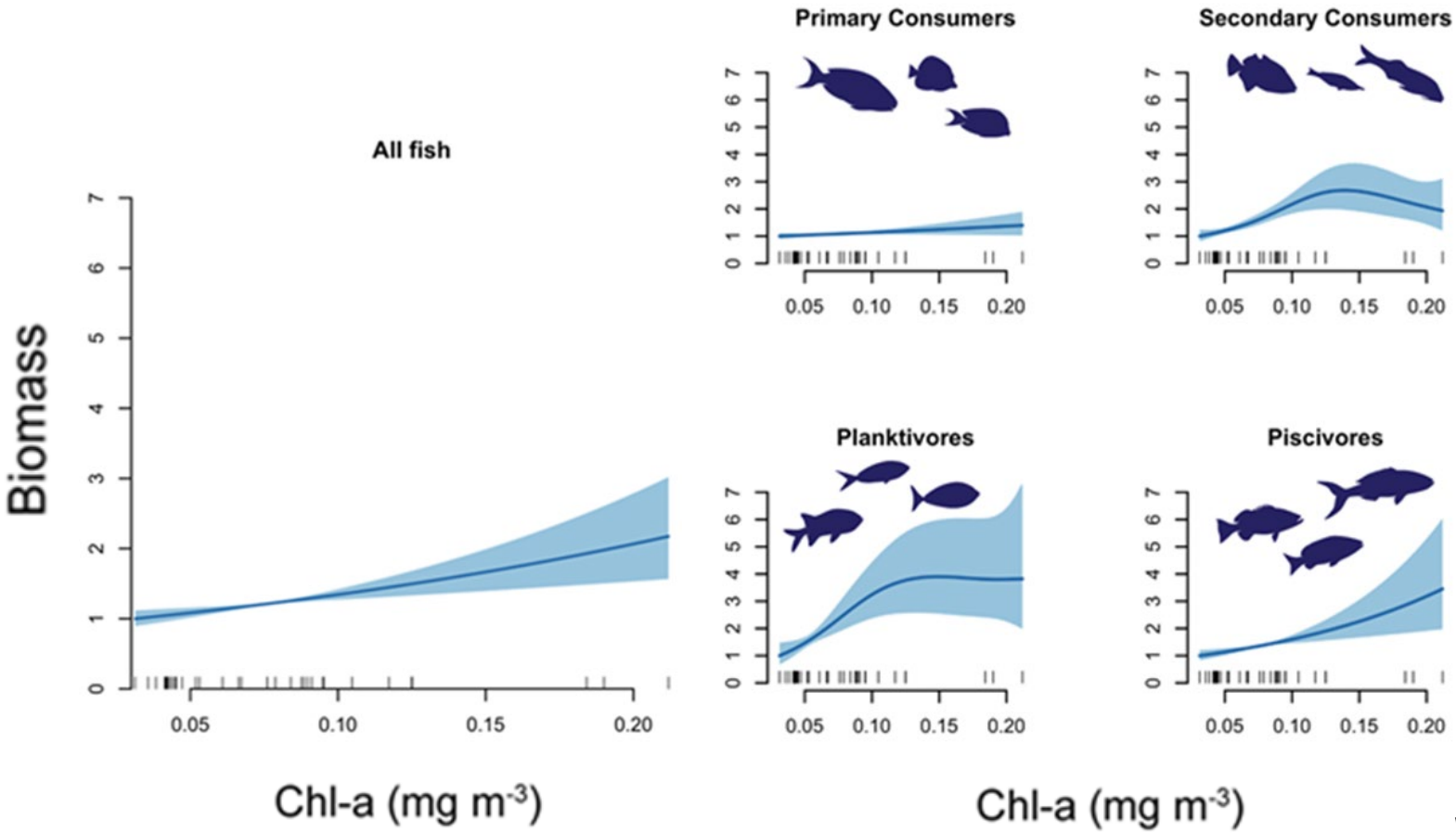
Satellite-based Nutrient Proxies to be tested = 1) Chl – **MODIS;** 2) K490 – **MODIS;** 3) Rainfall **– TRMM**

Timmers, in prep

Coral Reef Fish Assemblages

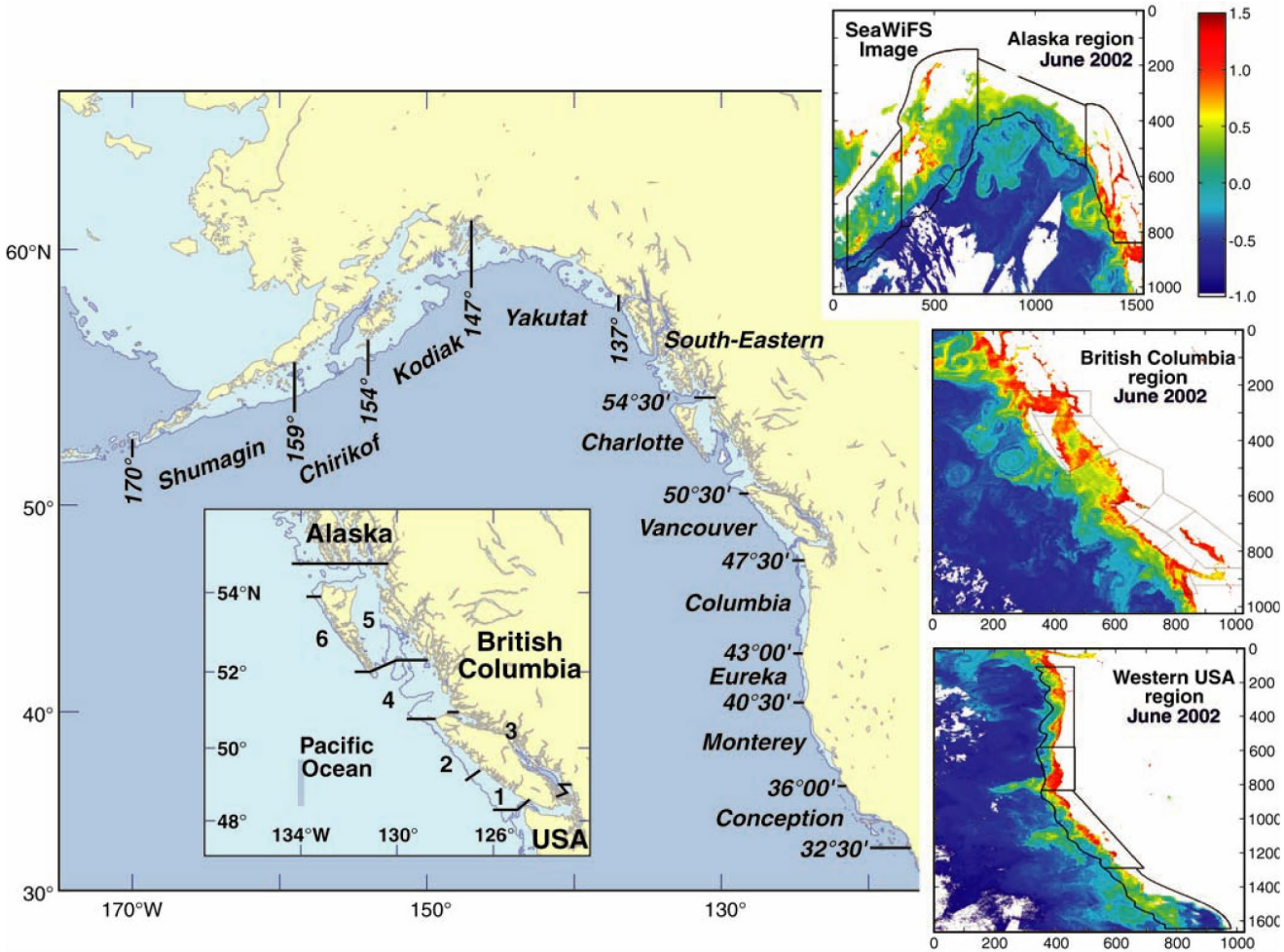


Adjusting for other factors, the highest levels of oceanic productivity were associated with more than double the biomass of reef fishes compared to islands with lowest oceanic productivity.



Williams et al, 2015

Bottom-Up Ecosystem Trophic Dynamics Determine Fish Production in the Northeast Pacific

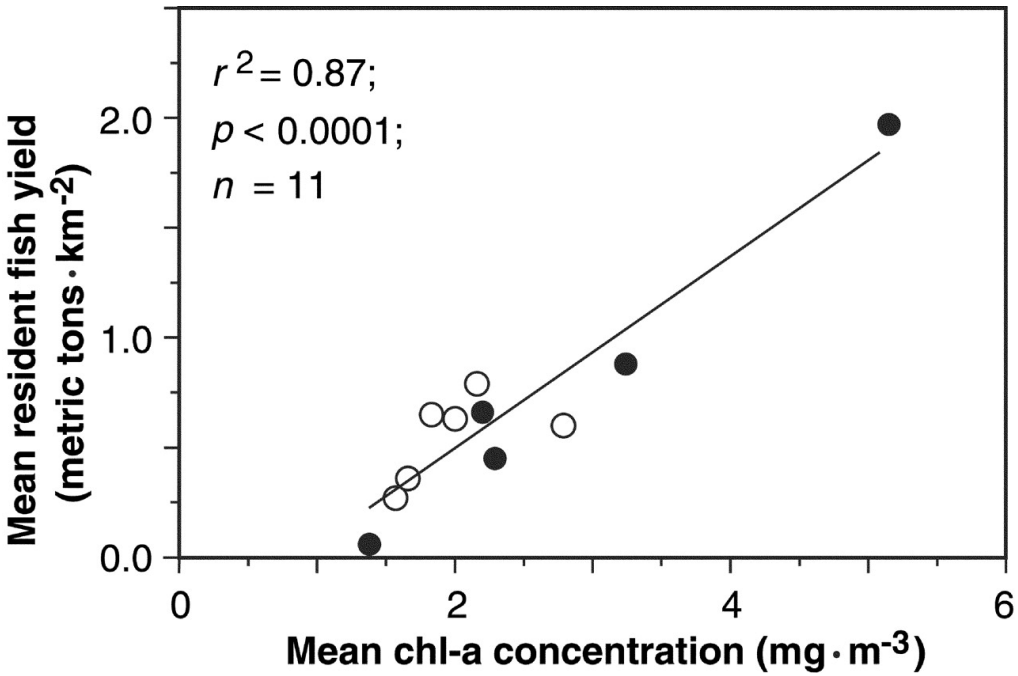


Ware and Thomson 2005

Bottom-Up Ecosystem Trophic Dynamics Determine Fish Production in the Northeast Pacific

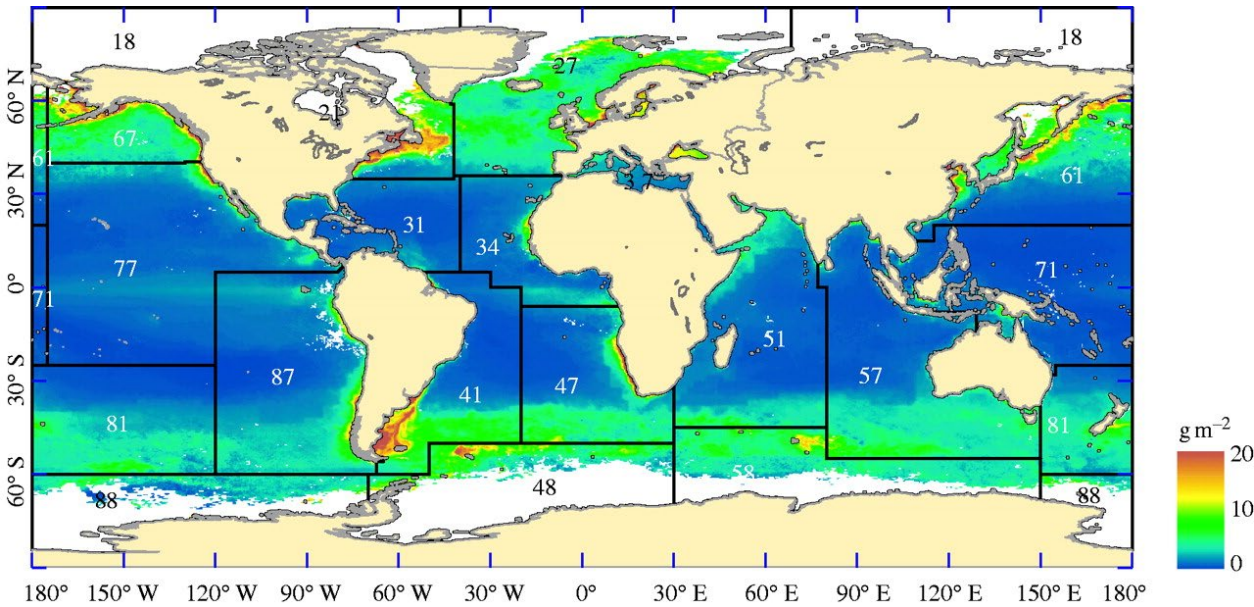
Large-scale trophic linkage between the annual mean chl-a concentration and the long-term annual yield of resident fish for each of the 11 NPAFC regions.

Solid circles = upwelling regimes
Open circles = downwelling regimes.

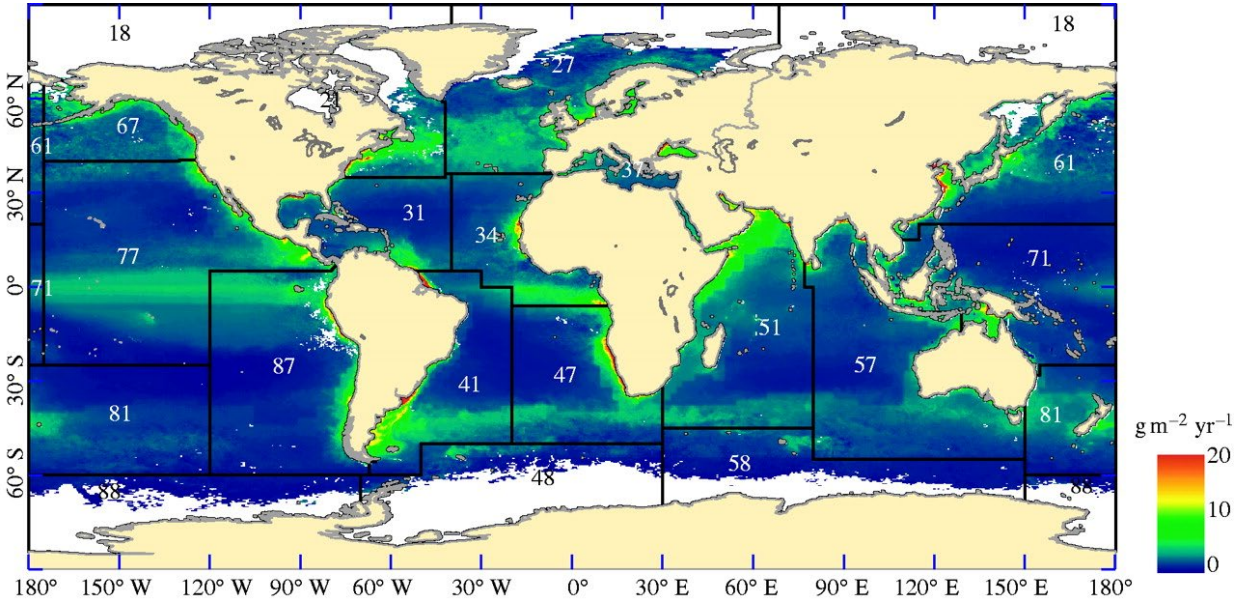


Ware and Thomson 2005

Global fish biomass



Global fish production



Estimated from remotely sensed SST and primary production

Jennings et al. 2008

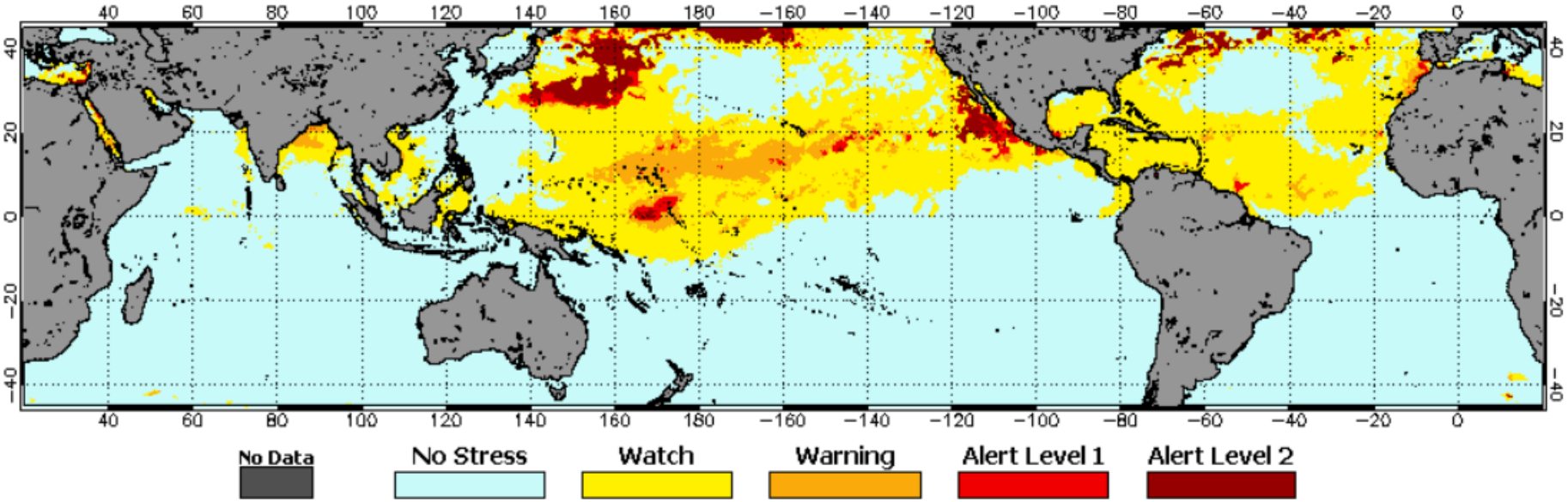
Ecological Indicators

- Coral reef bleaching
- Biome Dynamics
- Spring Bloom Statistics (date, duration, max biomass, total biomass)
- Phytoplankton functional groups and/or size structure

Platt and Sathyendranath. 2008

Coral Reef Watch

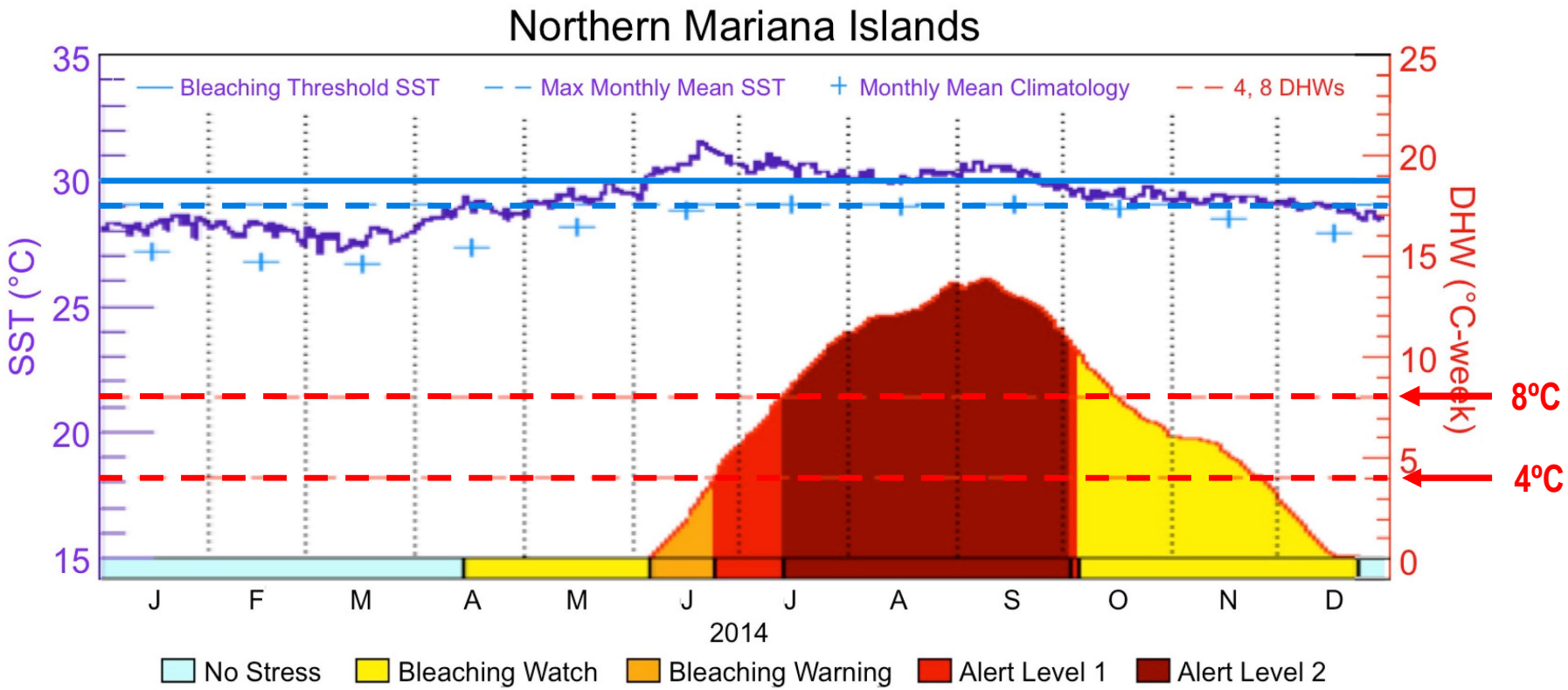
7-day maximum Bleaching Alert – 10/03/2018



This map shows the maximum stress level experienced during the most recent seven (7) consecutive days.

https://coralreefwatch.noaa.gov/satellite/index.php

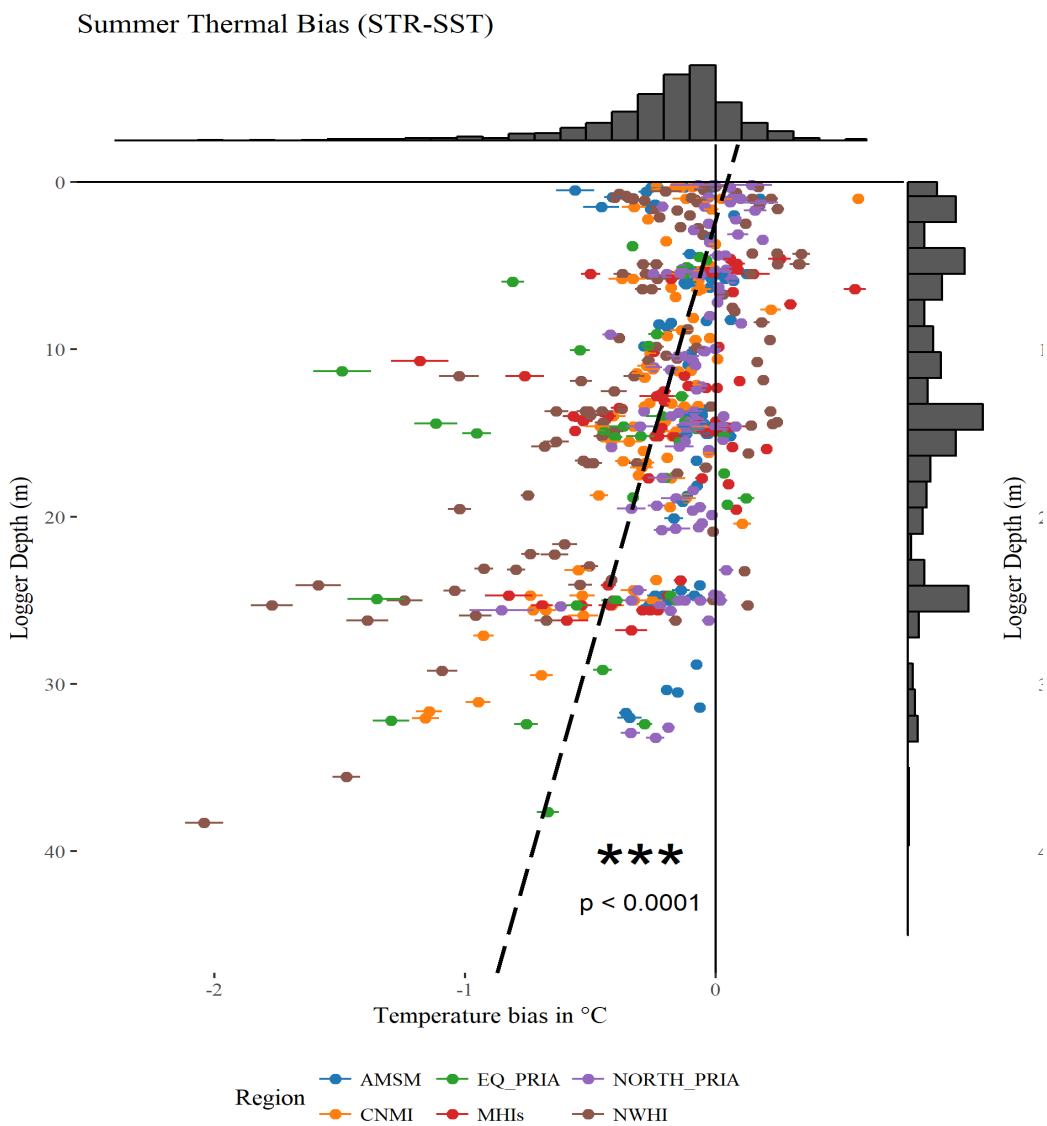
Coral Reef Watch



Degree Heating Week (DHW) accumulates when the SST value exceeds the maximum (blue dashed) of the monthly mean climatology values (blue plus) by at least 1 °C (blue solid: Bleaching Threshold). DHW thresholds of 4 and 8 °C-weeks (red dashed) have been associated with significant coral bleaching, and widespread bleaching and significant mortality, respectively.

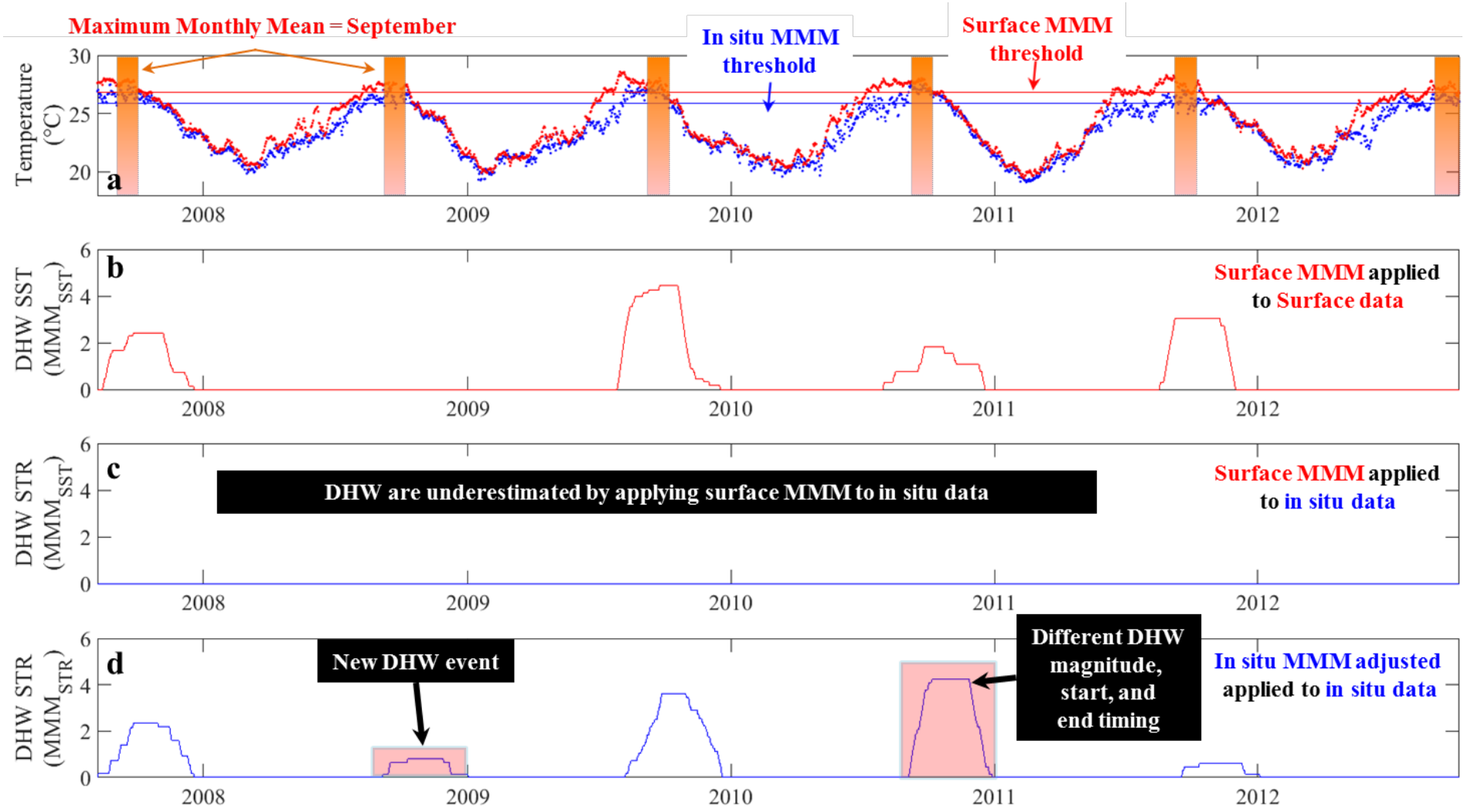
Heron et al. 2016

Correcting Thermal Stress for Depth



- Water tends to cool with depth.
- We rely on satellite <u>surface</u> data for both:
  - Our thresholds for what temperatures are 'normal'
  - Our record of what temperatures occurred during an event.
- We can instead use *in situ* data to adjust thresholds and calculate stress metrics

Correcting Thresholds for Bleaching Stress



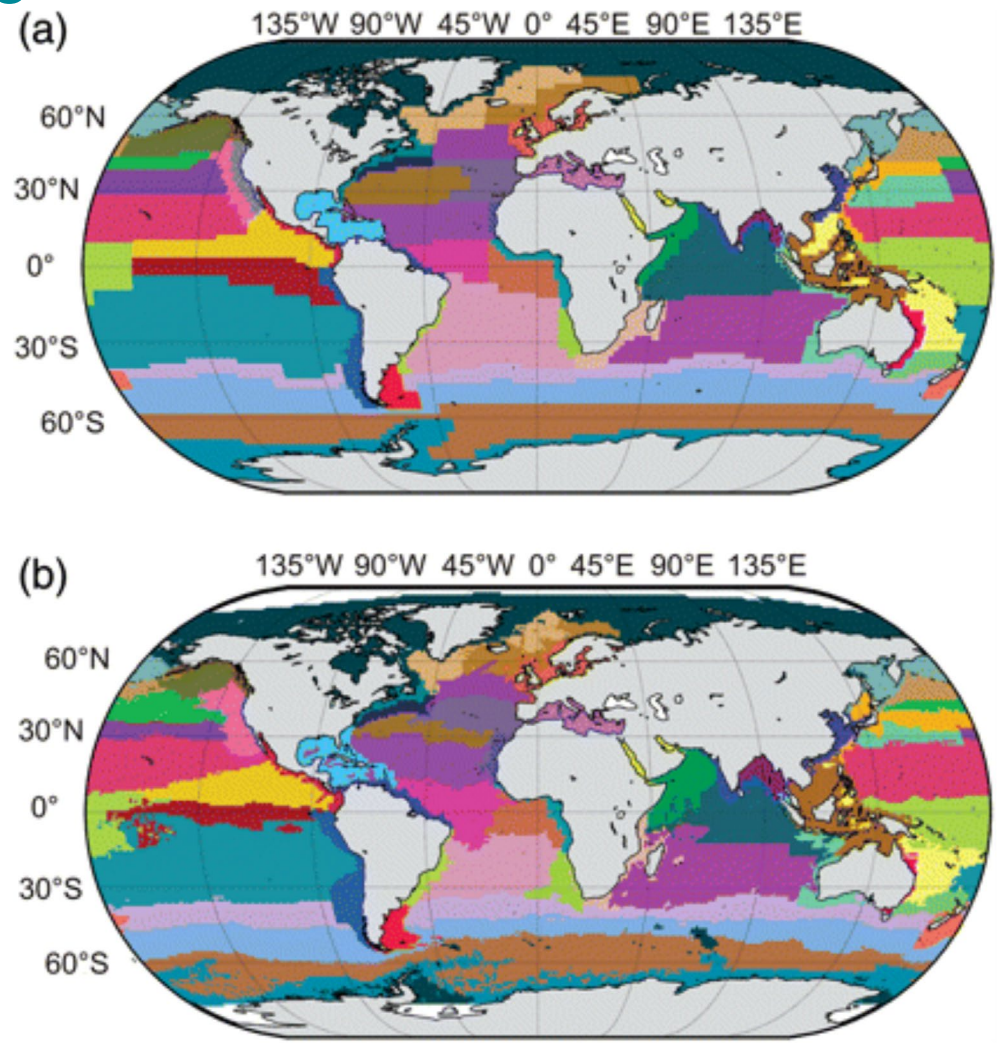
BioGeoChemical Provinces

(a) Map of Longhurst (2007) BGCP
(b) Map of the dynamic BGCP for 2005

Dynamic BGCP were derived from:

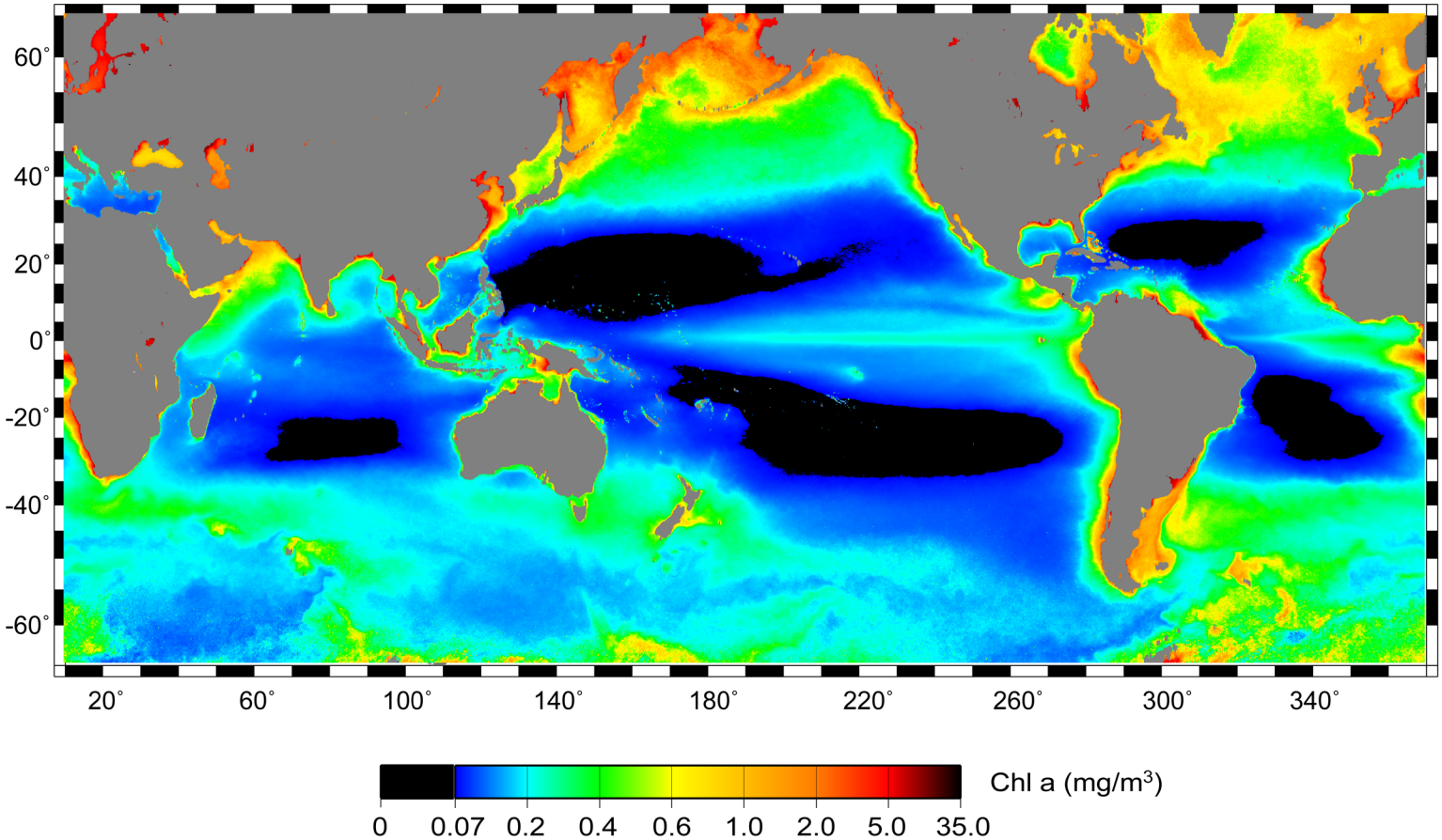
- SST based on the AVHRR series
- SeaWiFS Chl a
- salinity (World Ocean database)
- bathymetry (GEBCO)

(G. Reygondeau, pers. comm.)



Chassot et al. 2011

Least productive waters are expanding

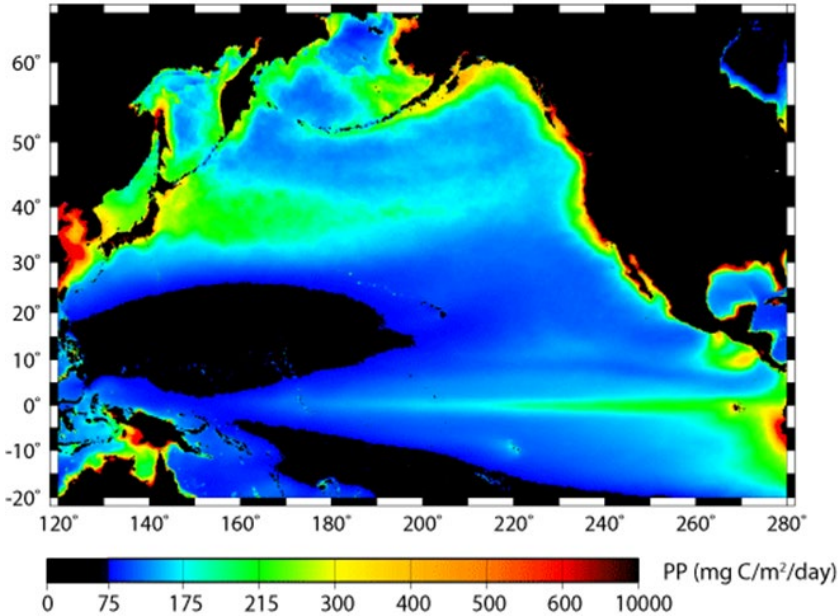


SeawiFS surface chlorophyll climatology with oligotrophic gyres in black

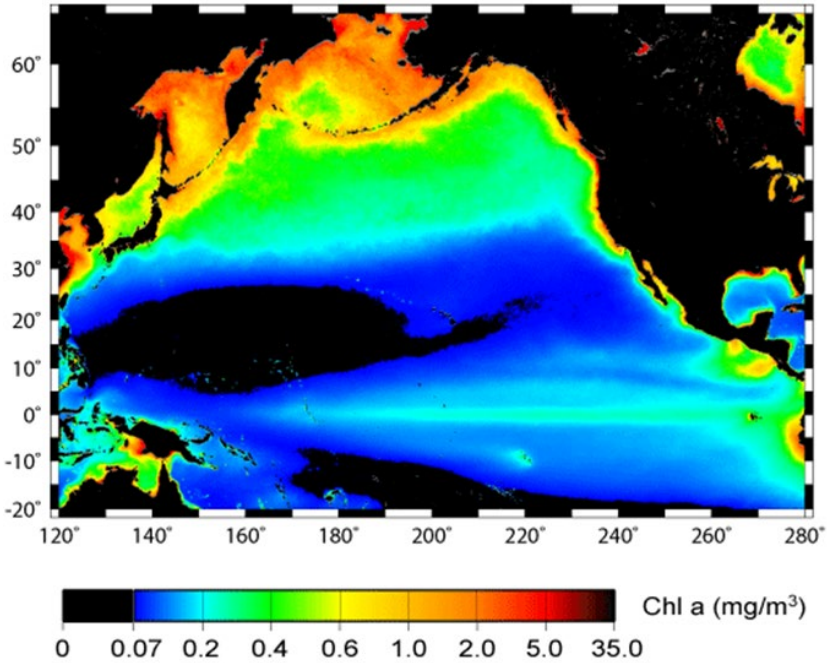
Polovina et al. 2008

Annual mean depth integrated net primary productivity

(data from Behrenfeld 2007)

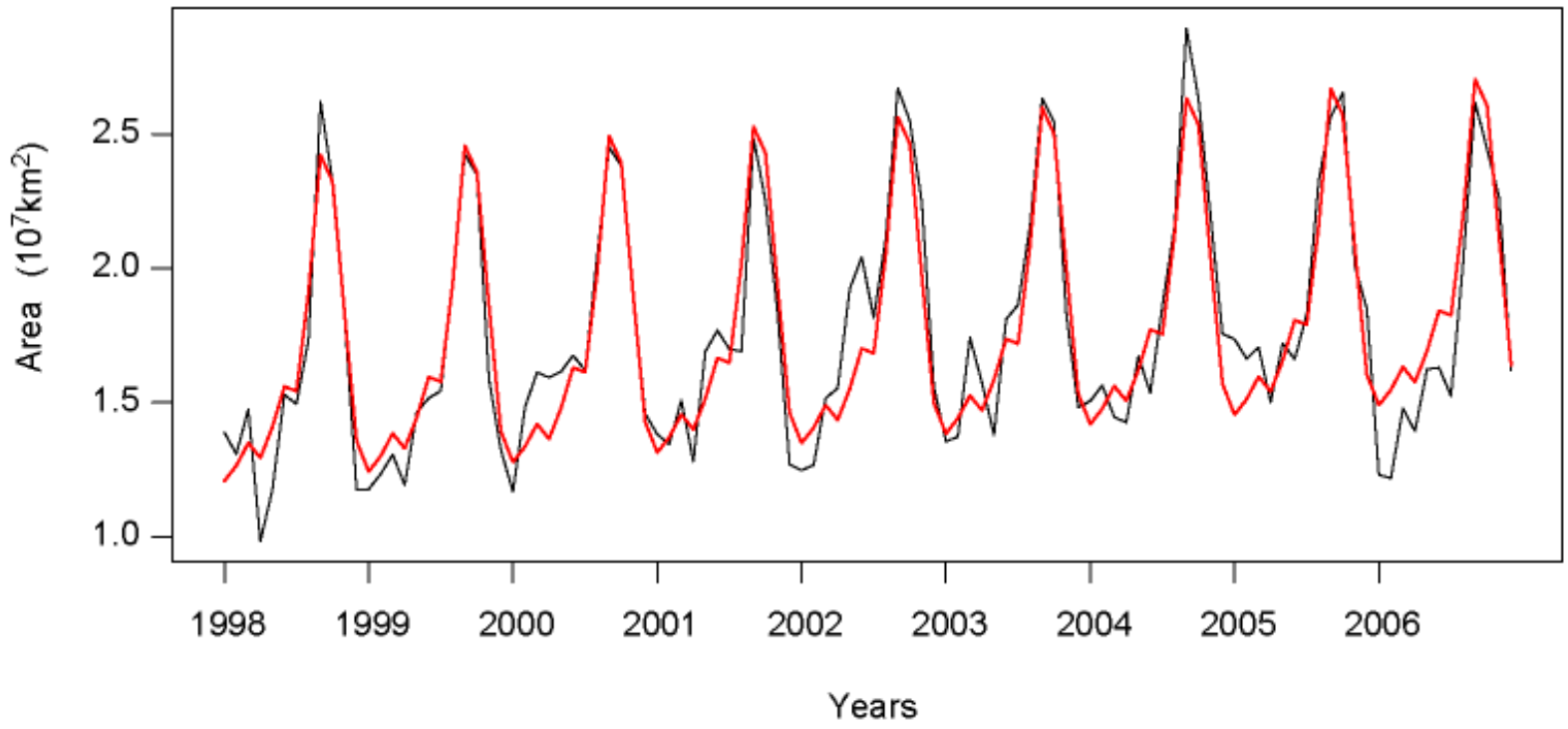


Annual mean surface chlorophyll from SeaWiFS

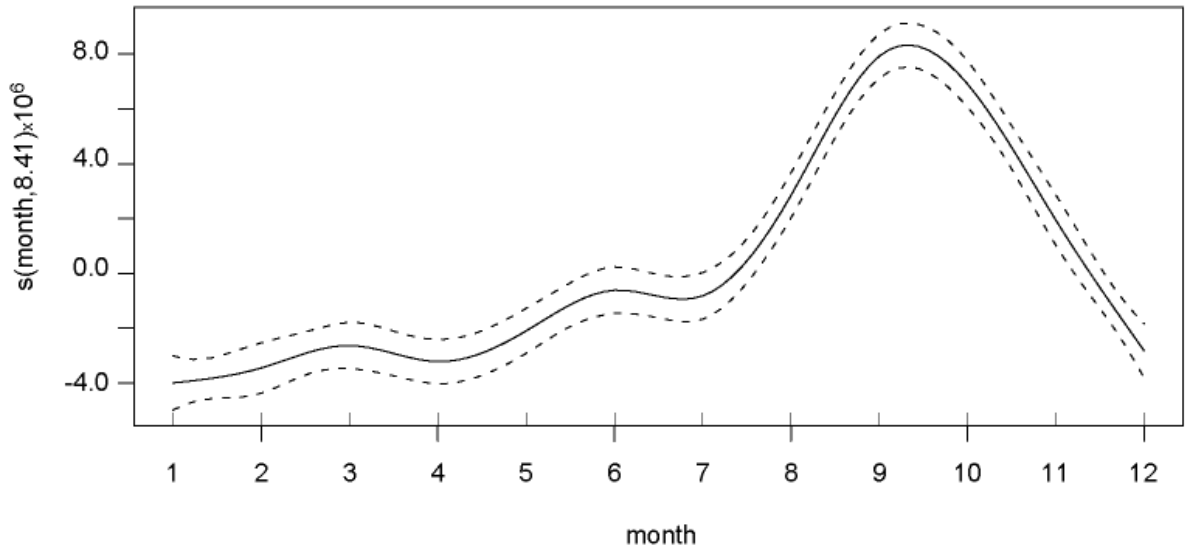


Area of oligotrophic waters in the N. Pacific

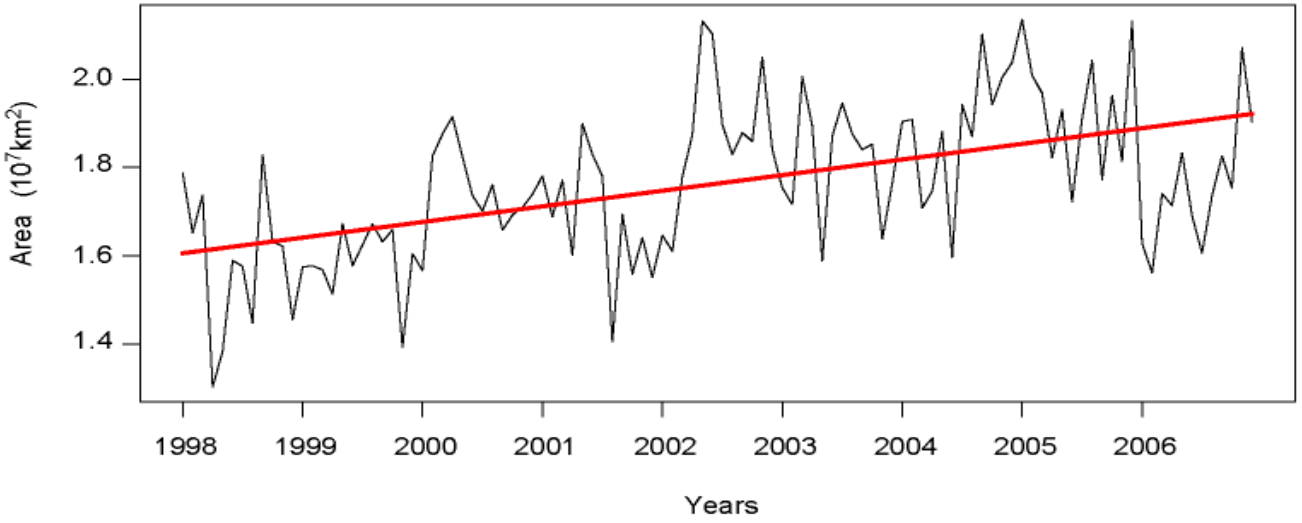
Monthly area of waters with surface chlorophyll< =0.07 mg C/m^3 (black line)
GAM fit : Monthly Area = A + B*time + S(Month) + error (red line)



Area of oligotrophic waters in the N. Pacific



GAM seasonal term

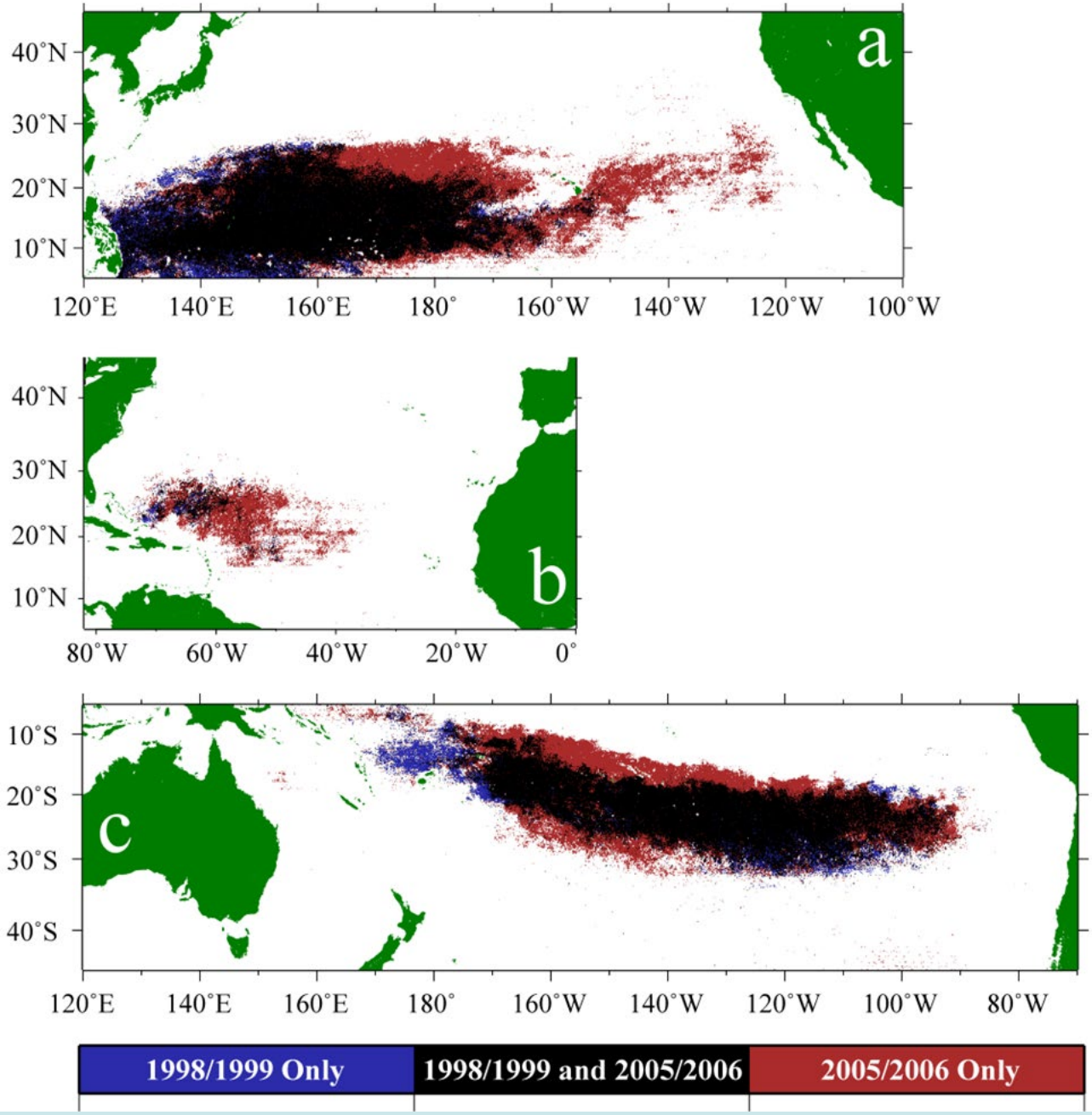


seasonally adjusted area

Changes in oligotrophic areas

Between 1998-1999 and 2005-2006

- in December:
  - a) North Pacific,
  - b) North Atlantic,
- August:
  - c) South Pacific



Phytoplankton Cell Size

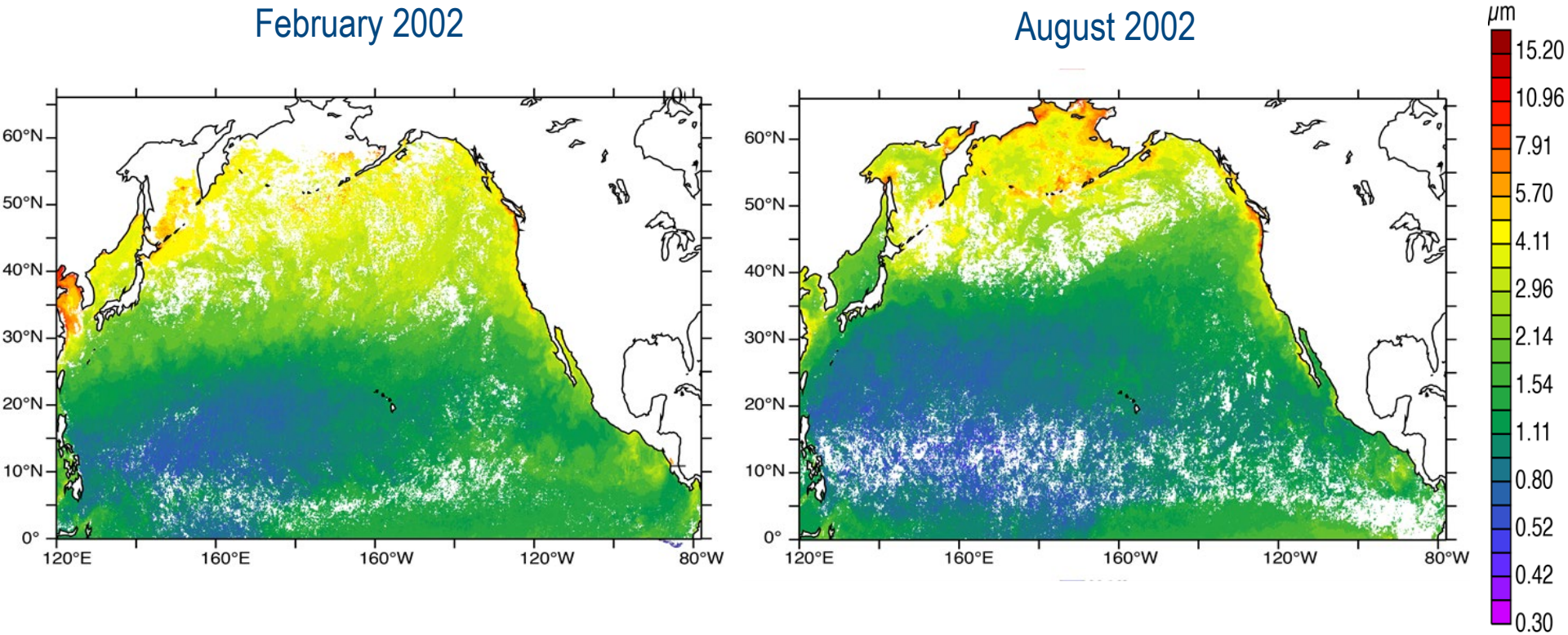
$$\log_{10}(\text{median cell wt}) = 1.340 - 0.043(\text{SST}) + 0.929(\log_{10}(\text{Chl}))$$

$$M_{D50} = 2.14*(\text{median cell wt})^{0.35}$$

Where M_{D50} is the cell diameter for the median cell wt

Barnes, C., Irigoien, X., De Oliveira, J.A.A., Maxwell, D., Jennings, S., 2011. Predicting marine phytoplankton community size structure from empirical relationships with remotely sensed variables. J. Plankton Res. 33 (1), 13–24

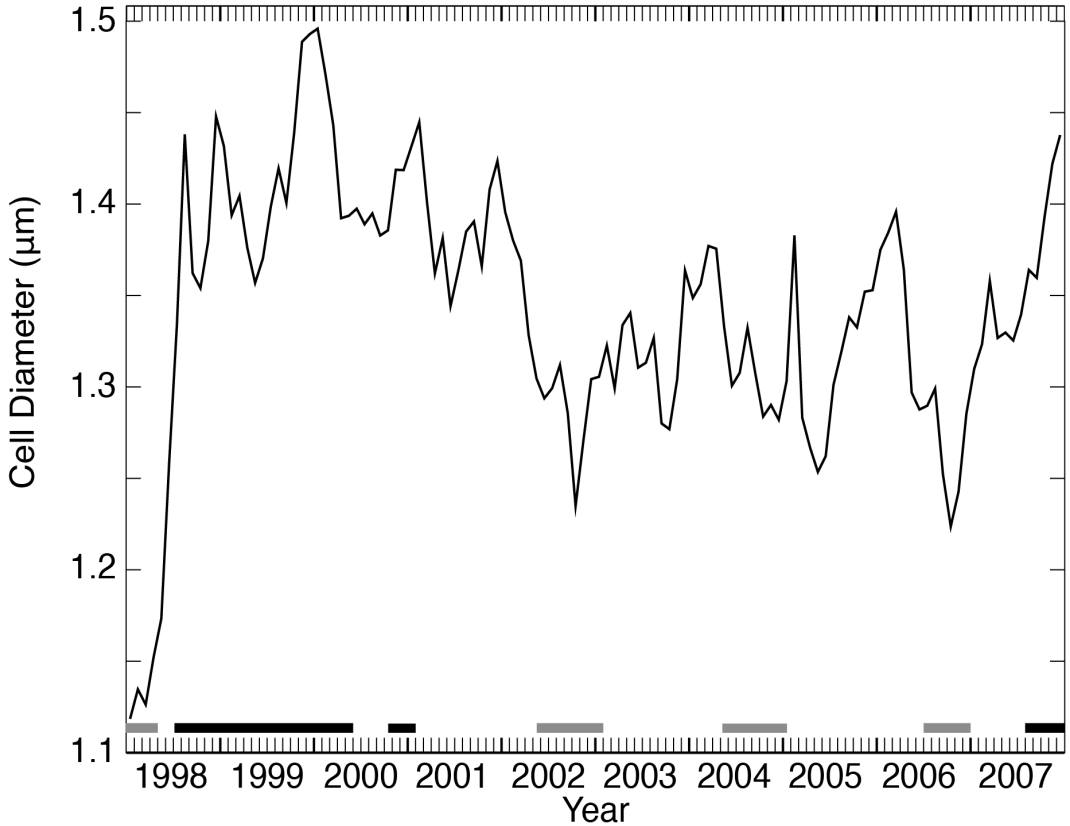
Phytoplankton Cell Size



Distribution of phytoplankton median cell diameter estimated using remotely sensed variables over the North Pacific.

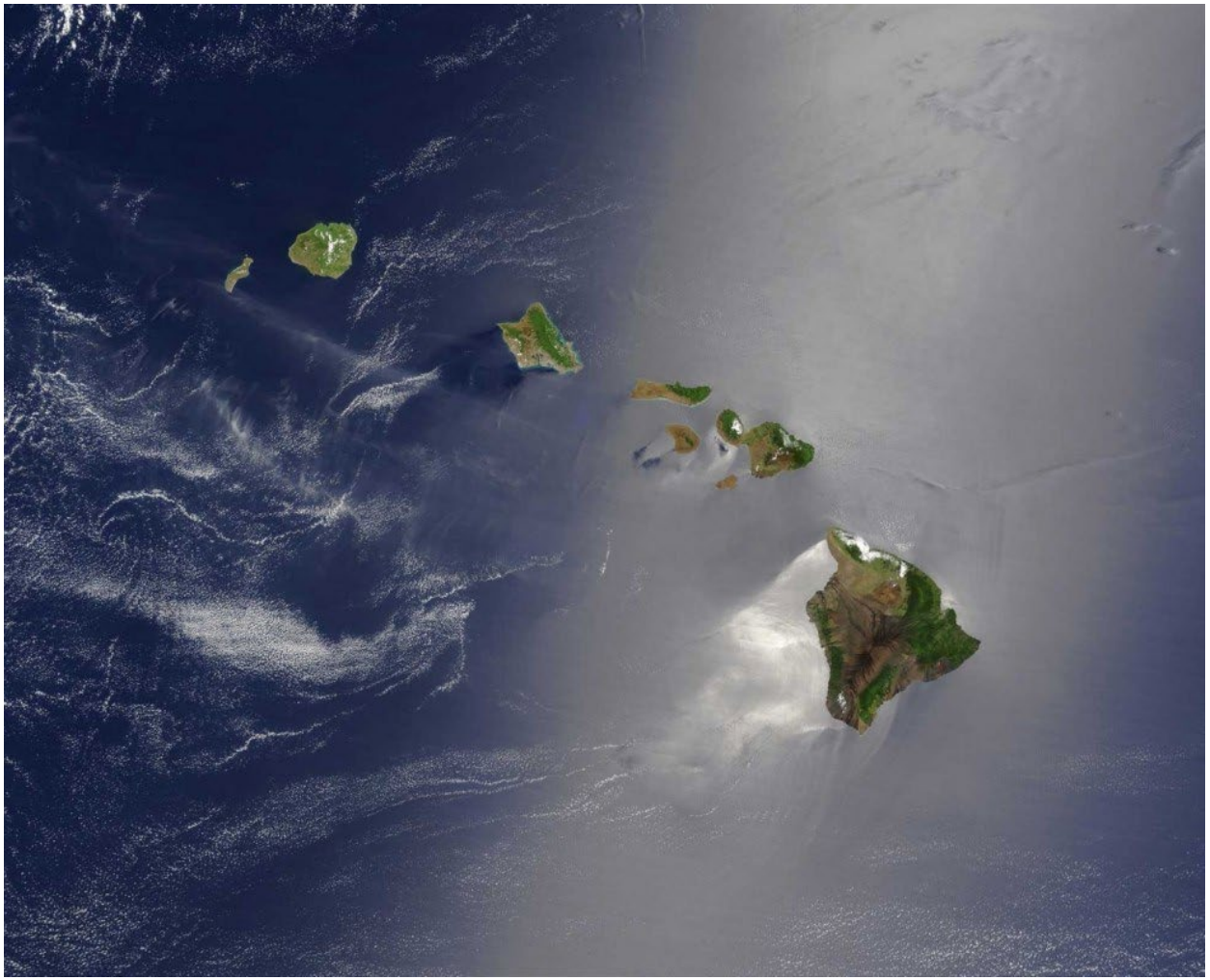
Polovina and Woodworth 2012

Equatorial Phytoplankton size variation



Monthly mean cell diameter estimated using remotely-sensed variables averaged over the Pacific equatorial upwelling region, 10°S – 10°N, east of 180°.

Gray and black lines above the date axis indicate El Niño and La Niña periods respectively.

Polovina and Woodworth 2012

Questions?