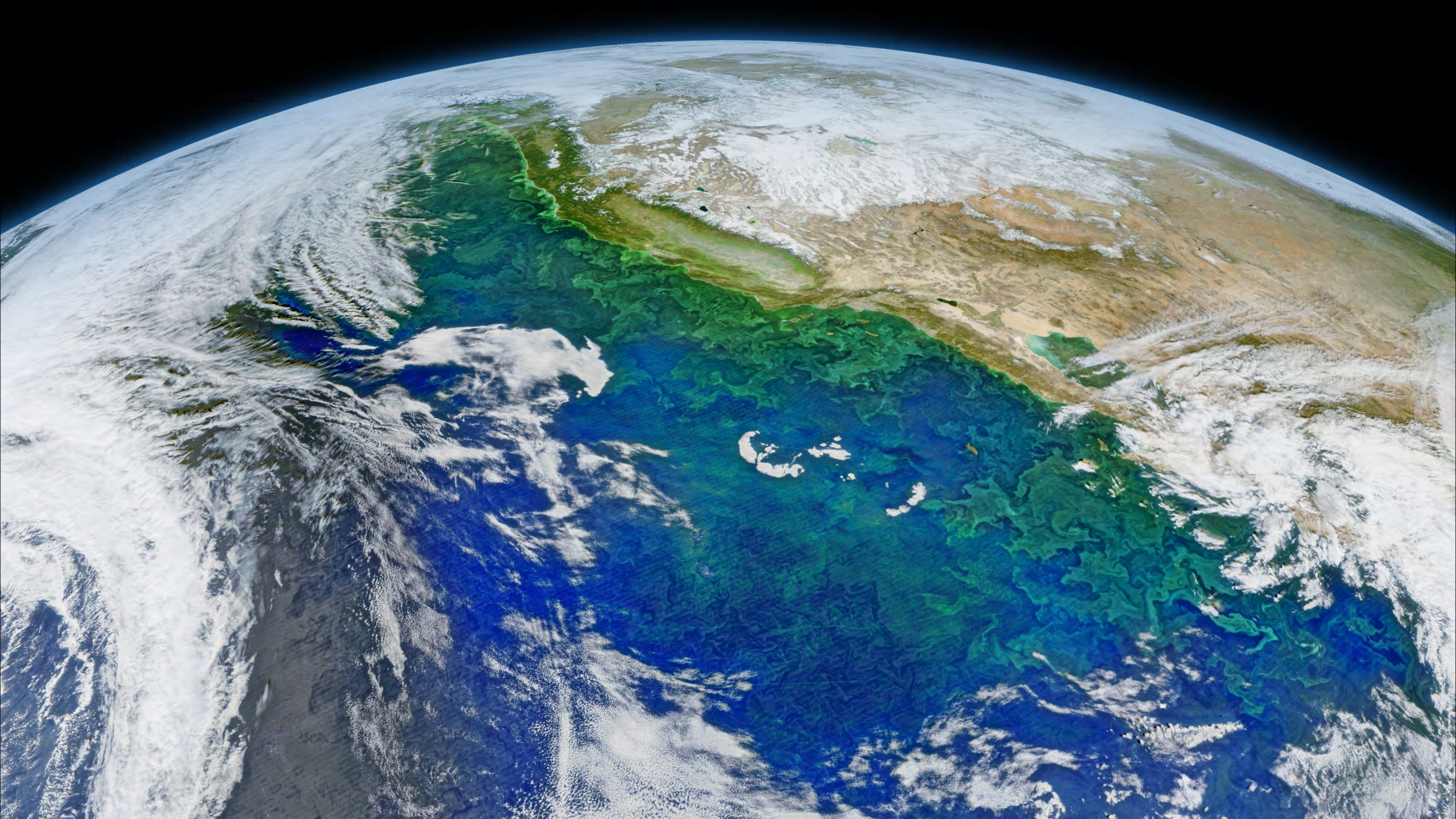
Revisiting Lasker's stable Ocean hypothesis:

The influence of wind events on larval fish mortality in the southern California Current Ecosystem

Brendan Turley
University of South Carolina
bturley@email.sc.edu

Ryan Rykaczewski
NOAA NMFS Pacific Islands
Fisheries Science Center



Paul Nicklen, National Geographic

Biting off more than we can chew…

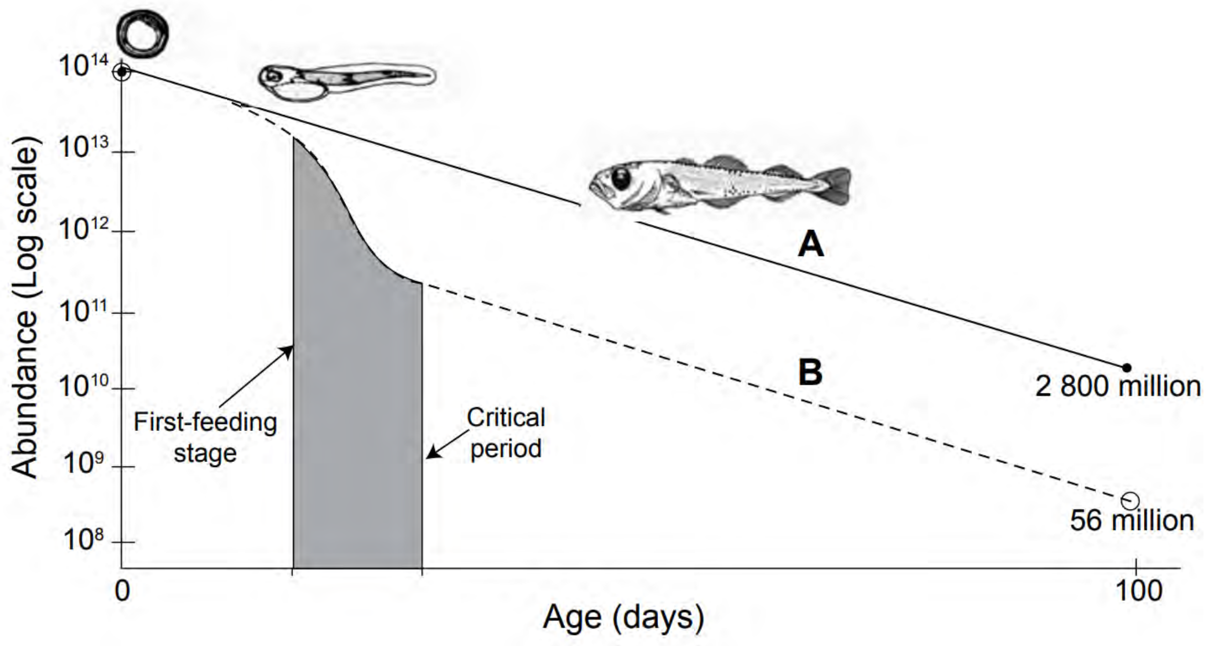
Question: *What drives variability in populations of pelagic fishes?*

Answer (pre Johan Hjort):

A. Fishing effort (via stock-recruitment relationships)
B. Changes in migration patterns

Answer (post Johan Hjort):

A. Fishing effort (via stock-recruitment relationships)
B. Changes in migration patterns
C. Environmental impacts on recruitment with emphasis on the "critical period"…



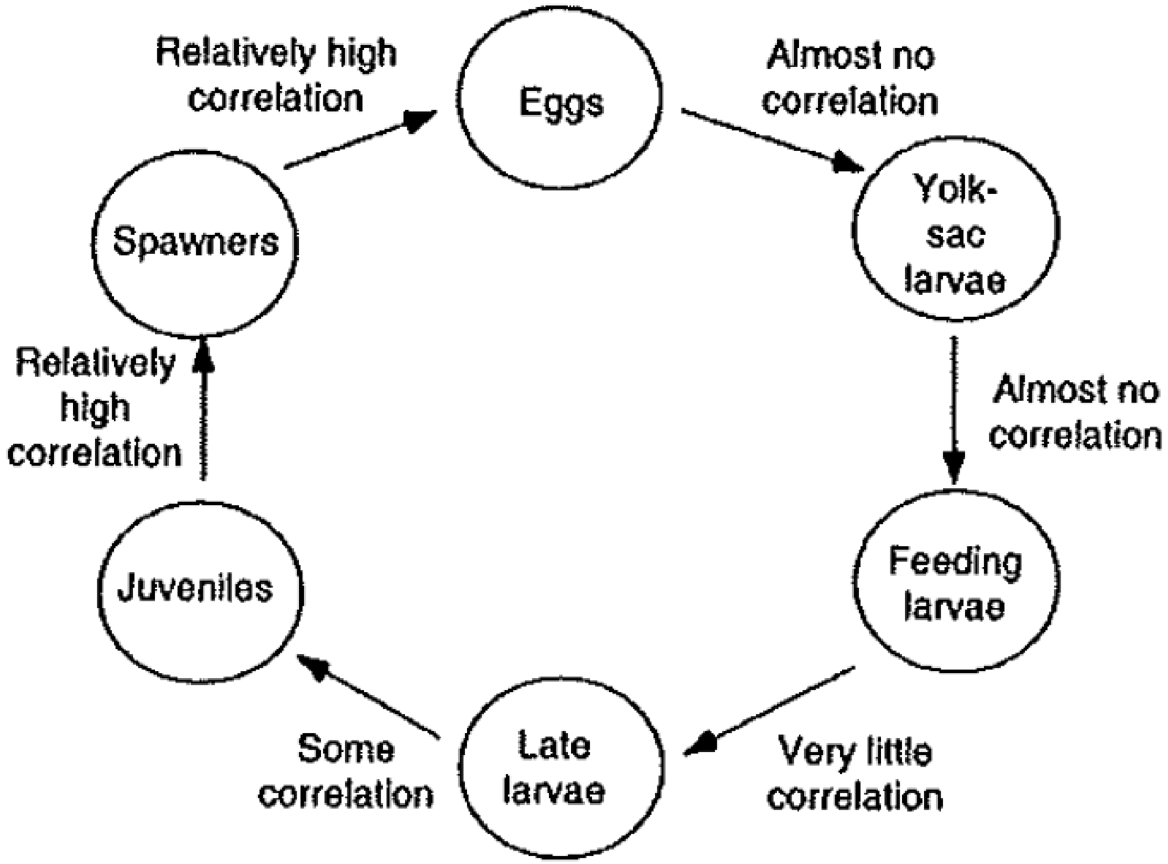
Houde (2008)

Though too narrow in focus, Hjort's "critical period" spawns hypotheses

Hjort's focus on first-feeding larvae was perhaps too narrow in addressing recruitment variability but deserves credit for stimulating broad interest in the trophodynamics of larval fishes.

A whole family of "critical period" hypotheses have been proposed, some of which are specific cases of the original idea:

- David Cushing's "match-mismatch" (1974)
- Ruben Lasker's "stable ocean" (1975)
- Philippe Cury and Claude Roy's "optimal environmental window" (1989)



Cowan & Shaw (2002)

Lasker's observations…

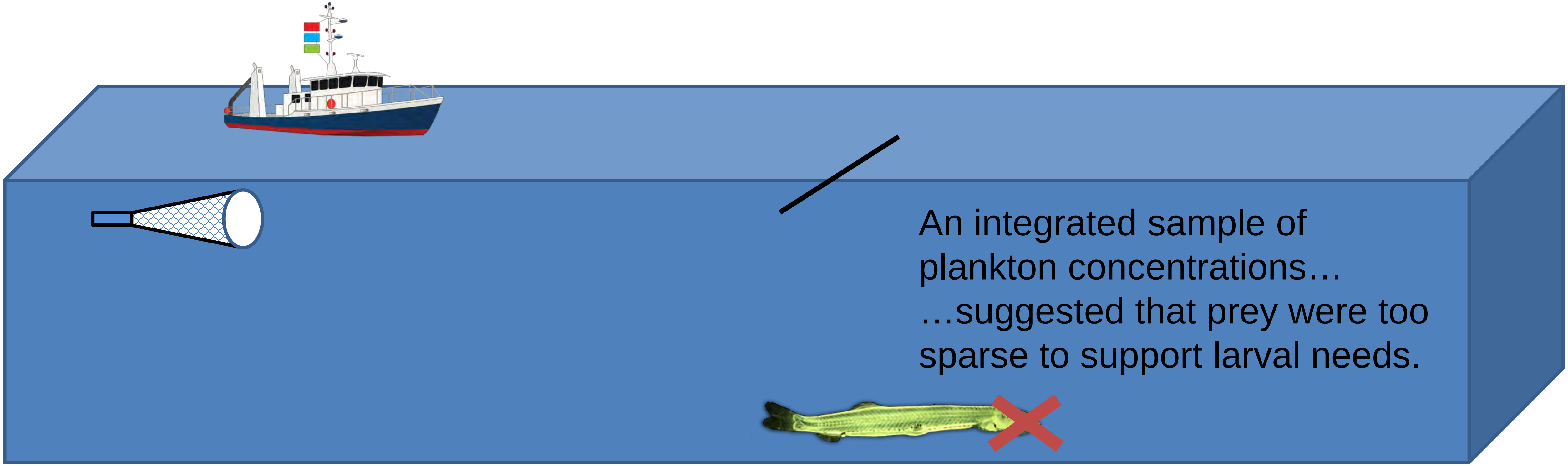
Shipboard incubations allowed an estimate of the plankton concentration required to sustain "first feeding" larvae.

Concentrations of prey from oblique samples of the water column were rarely high enough to stimulate successful feeding and survival by the larvae.

Lasker's observations…

Shipboard incubations allowed an estimate of the plankton concentration required to sustain "first feeding" larvae.

Concentrations of prey from oblique samples of the water column were rarely high enough to stimulate successful feeding and survival by the larvae.



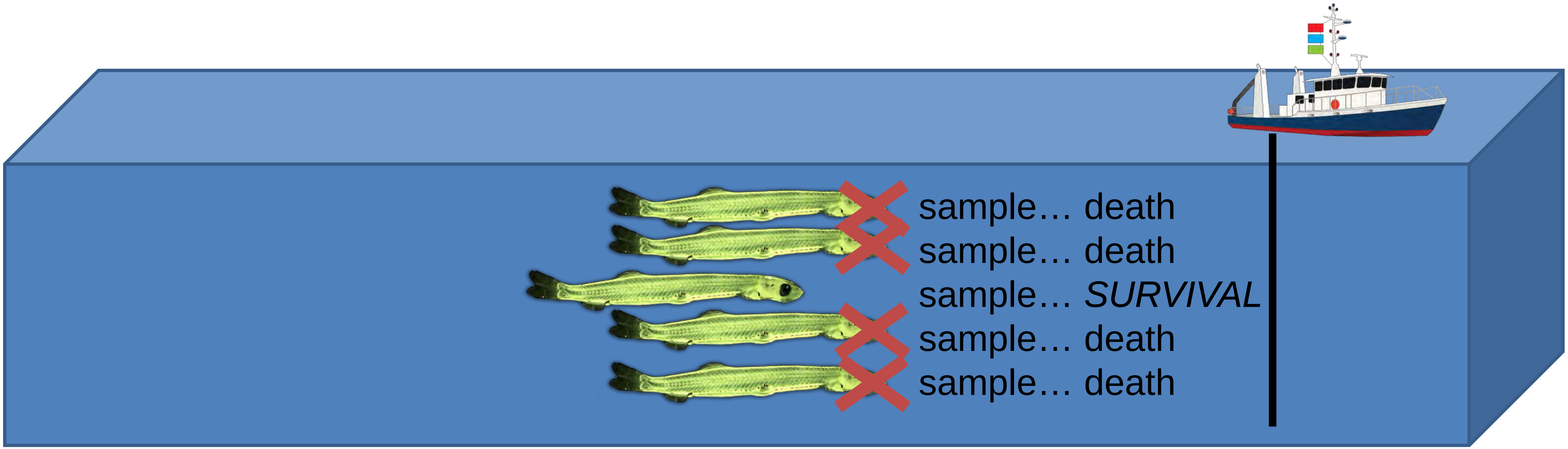
Lasker's observations…

However, depth-resolved estimates of plankton concentrations suggested that prey concentrations in think layers of high plankton density would support feeding.

Lasker's observations…

However, depth-resolved estimates of plankton concentrations suggested that prey concentrations in think layers of high plankton density would support feeding.

"Feeding by larvae in water from the surface was minimal in all experiments, but extensive feeding occurred in water from the chlorophyll maximum layers."



Lasker's stable ocean hypothesis (Lasker 1975 and 1978)

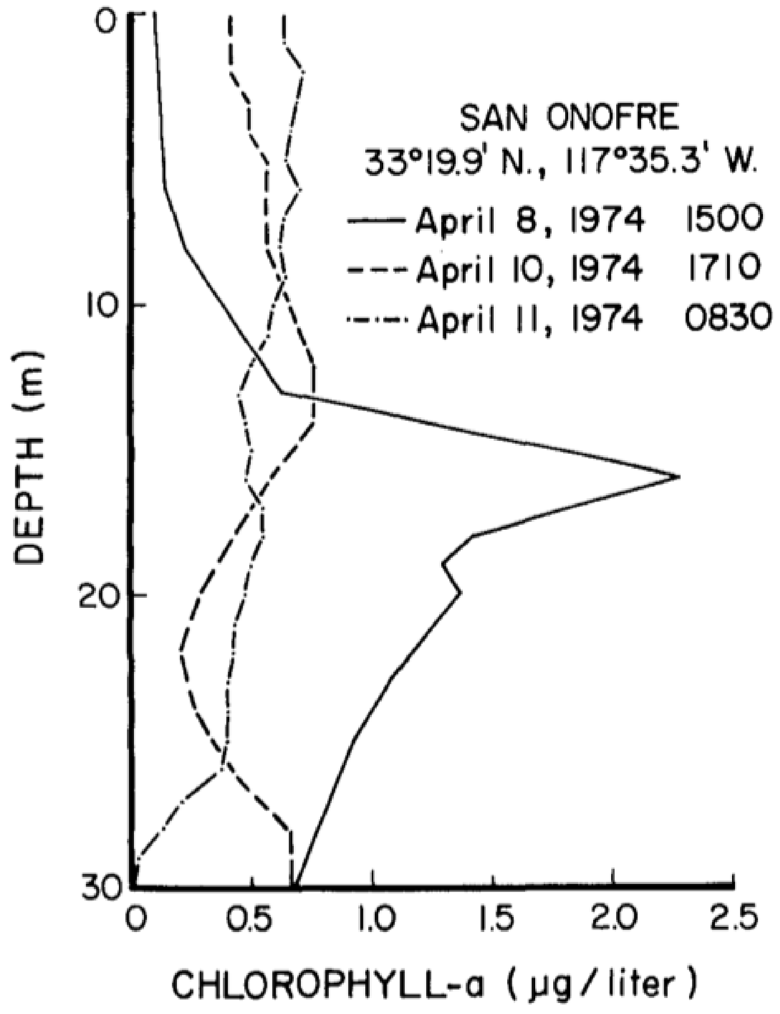
Such subsurface chlorophyll maxima were hypothesized to be common in the region, EXCEPT after the passage of storms.

These observations led Lasker to hypothesize…

High winds associated with storm events act to mix the water column, disaggregating layers of high prey concentration and inhibiting the survival of first-feeding larval fish.

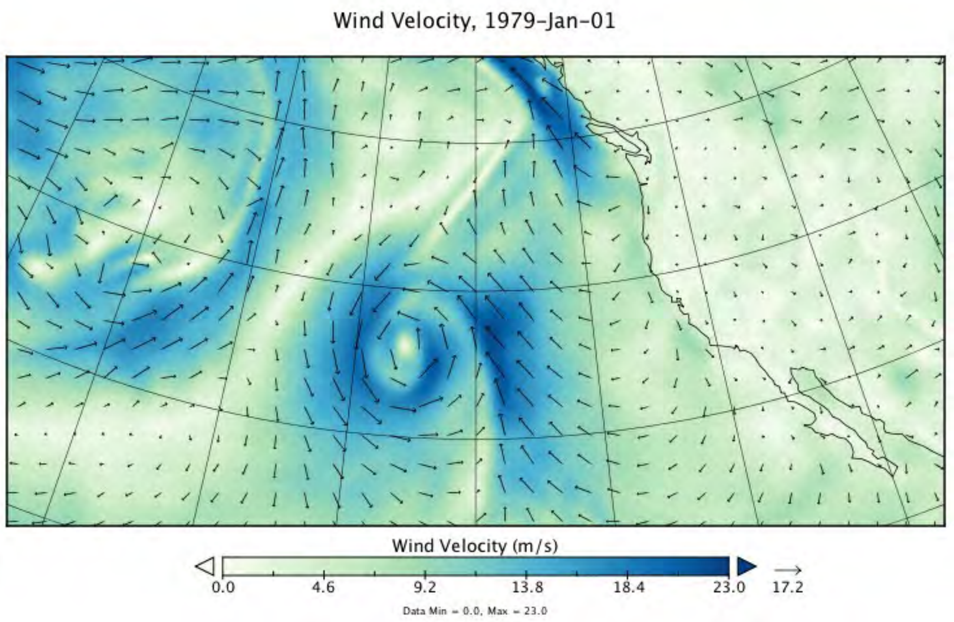
Some tests of the hypothesis over relatively short periods of time produced mixed results…

Peterman and Bradford (1987) for anchovy: *Yes.*
Butler (1991) for sardine: *No.*



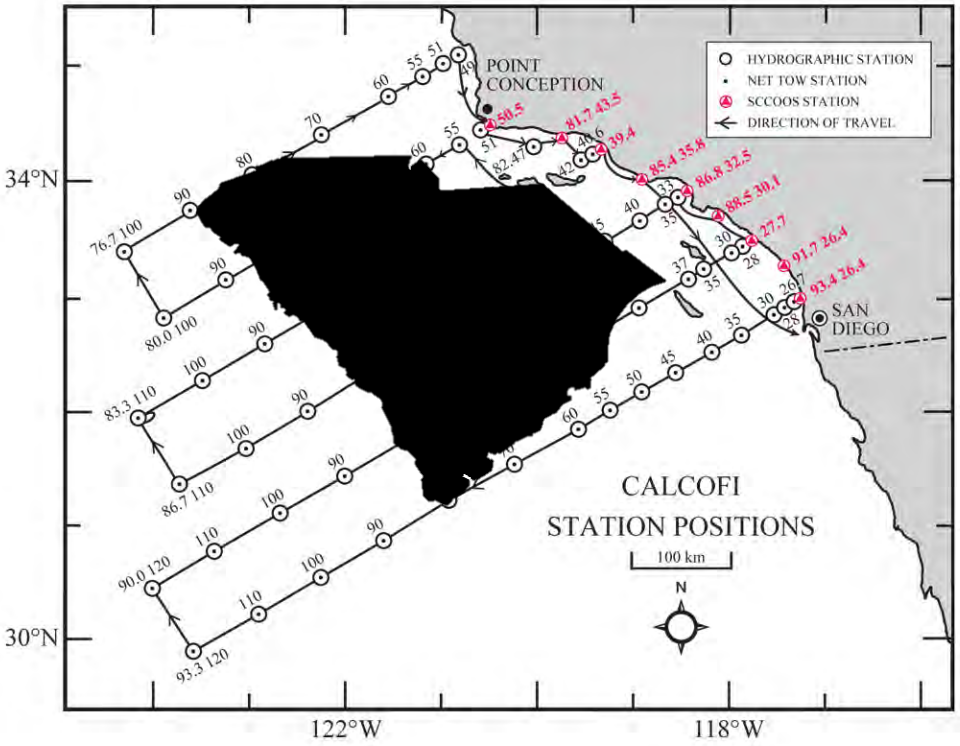
Lasker (1975)

Key datasets: NCEP CFSR and CalCOFI



NOAA-NCEP Climate Forecast System Reanalysis (CFSR) can provides estimates of atmospheric conditions at:

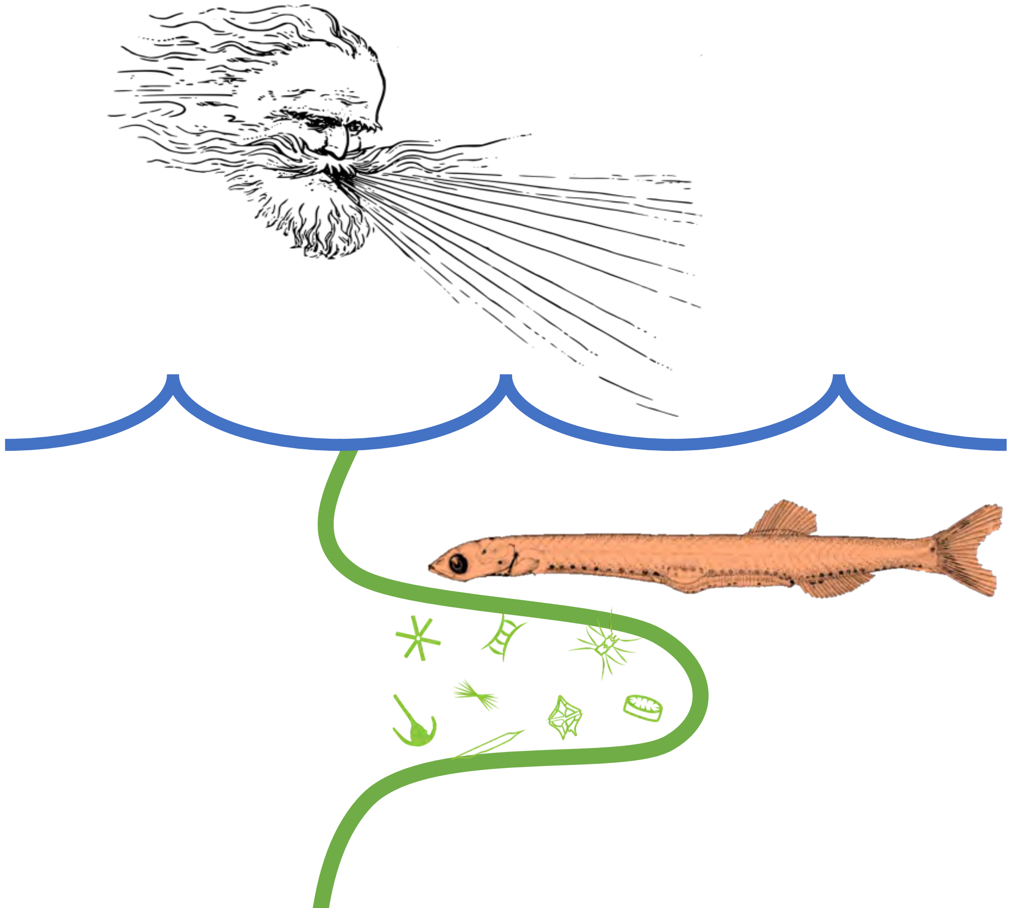
- 6-hourly temporal resolution since 1979
- horizontal resolution of ½ degree



The California Cooperative Oceanic Fisheries Investigations (CalCOFI) Program provides a wealth of observations relevant to the stable ocean hypothesis at approximately seasonal resolution, e.g.:

- depth-resolved CTD data and chlorophyll estimates
- estimates of larval abundance (including species identification and lengths; since 1951)

Can we bring a fresh perspective to this hypothesis with decades of data?



There are three key estimates we need to draw from these datasets…

1. metrics of “wind events” (storms) or calm periods

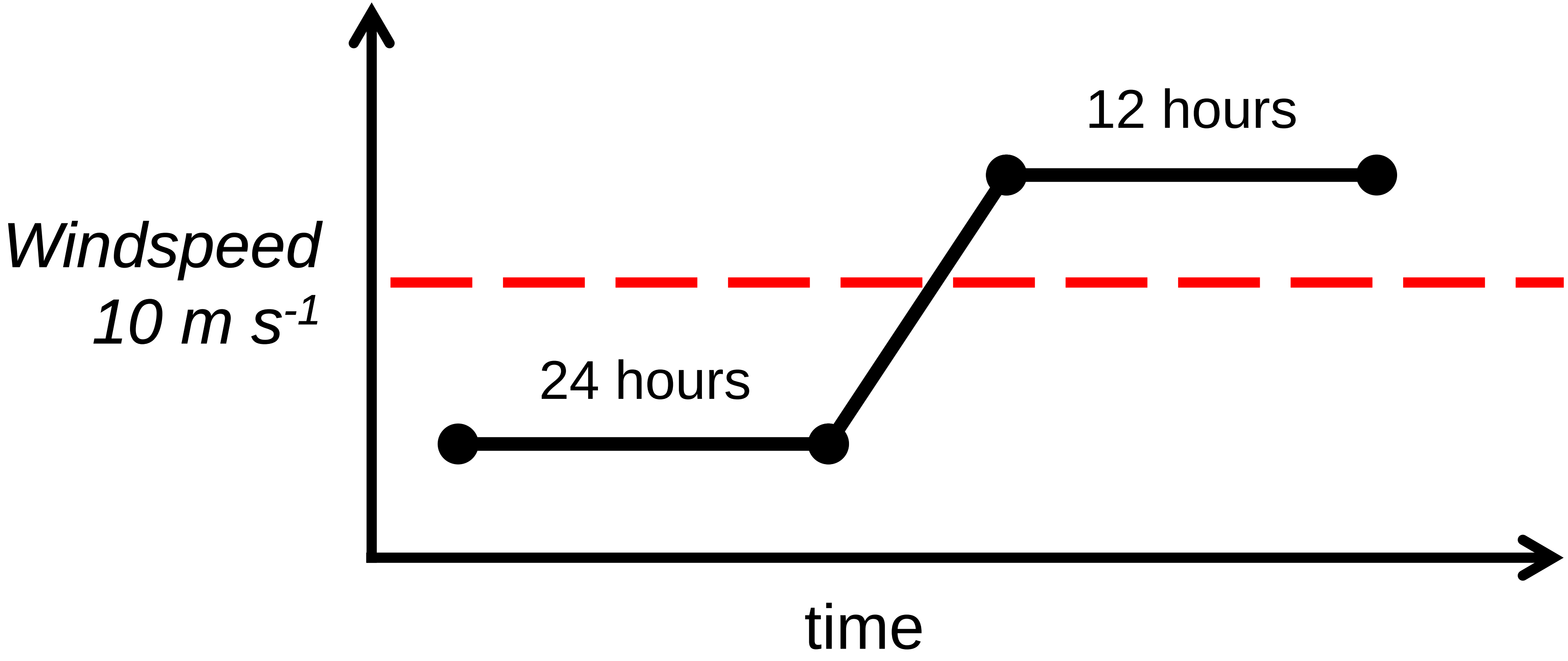
2. rates of larval mortality

3. a description of vertical structure of plankton in the water column

Estimates of winds and larval mortality are required.
Estimate vertical structure would be nice if we want to investigate the mechanism of any identified relationship between winds and mortality.

Metrics of distinct "storms" and distinct "calm" events were derived

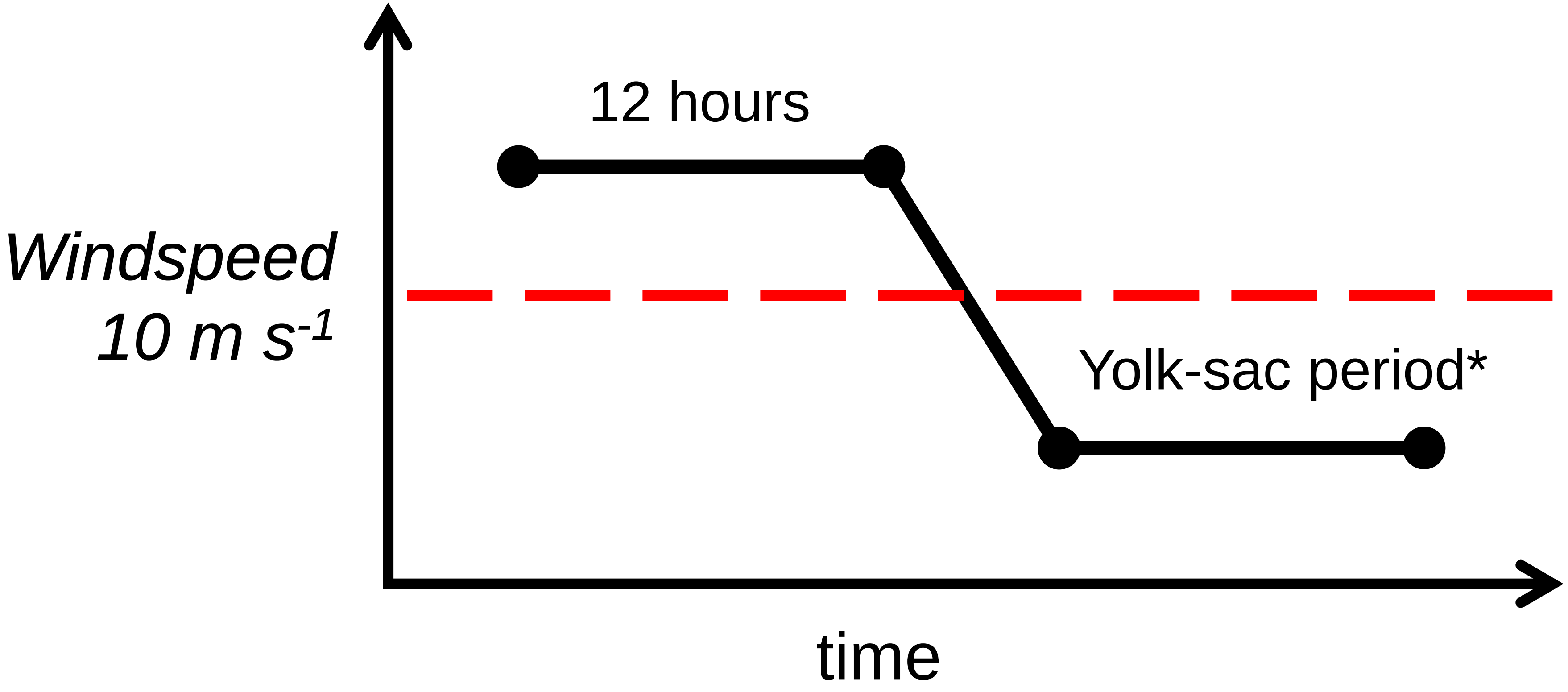
A "storm event" was identified as a period with persistent (at least 12 hours) winds greater than 10 m s^{-1} that followed a calm period of at least 24 hours.



Windspeed threshold based upon speed beyond which turbulence is produced (Simpson and Dickey 1981)

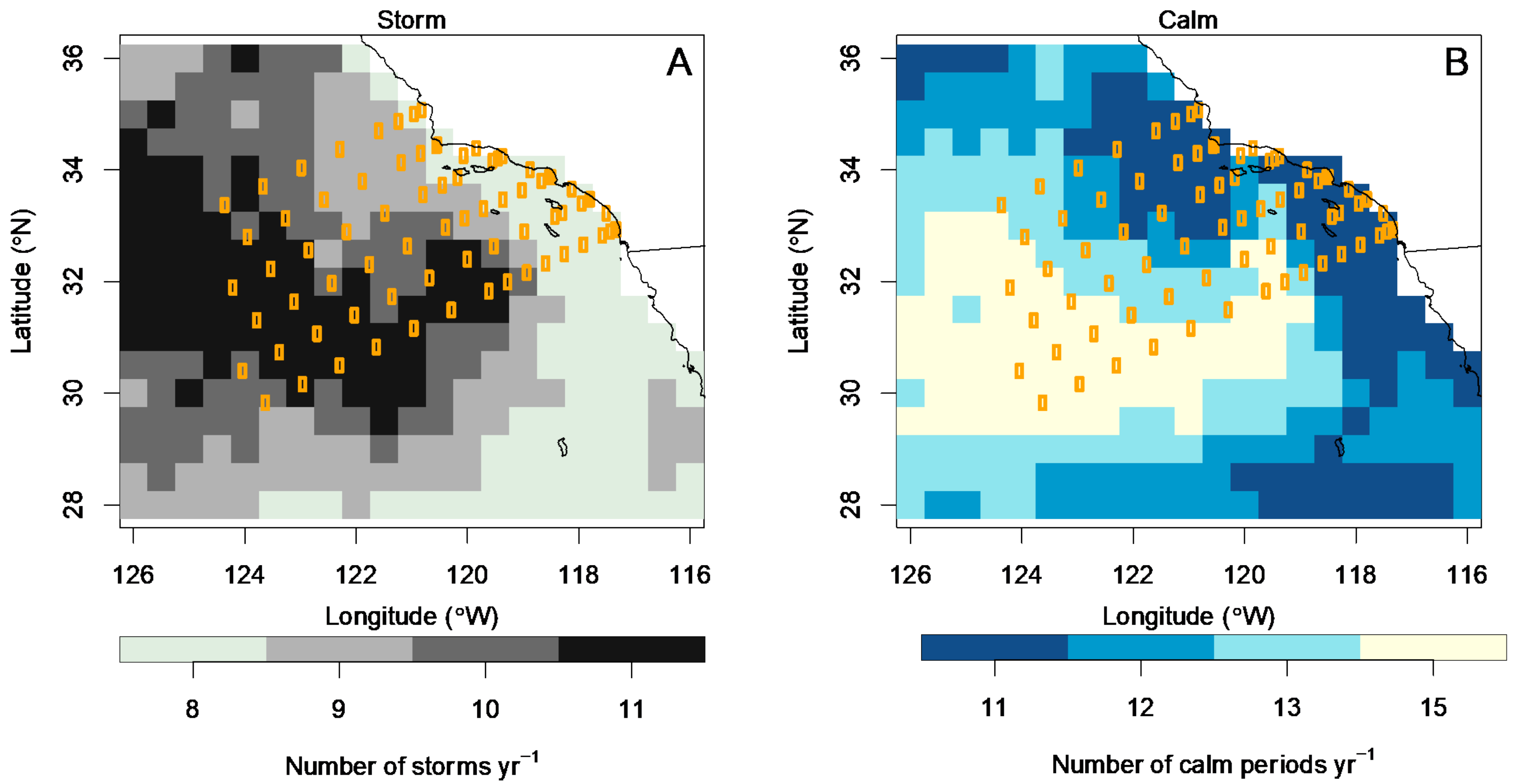
Metrics of distinct "storms" and distinct "calm" events were derived

A "calm period" was identified as periods with persistent (several days; species dependent) winds less than 10 m s^{-1} that followed a windy period of at least 24 hours).



*A calm period was only considered potential influential if it persisted longer than the yolk-sac stage (a duration of about 4-10 days).

Distribution of storm and calm events



Time series of “storm events” and “calm periods” were focused on the CalCOFI cruise periods and tailored to the spawning seasons of each fish species.

Ichthyoplankton collection and analysis is the most unique aspect of the dataset

Bongo and PairoVET nets are used to sample ichthyoplankton.

The species identification and lengths occurs in the lab.

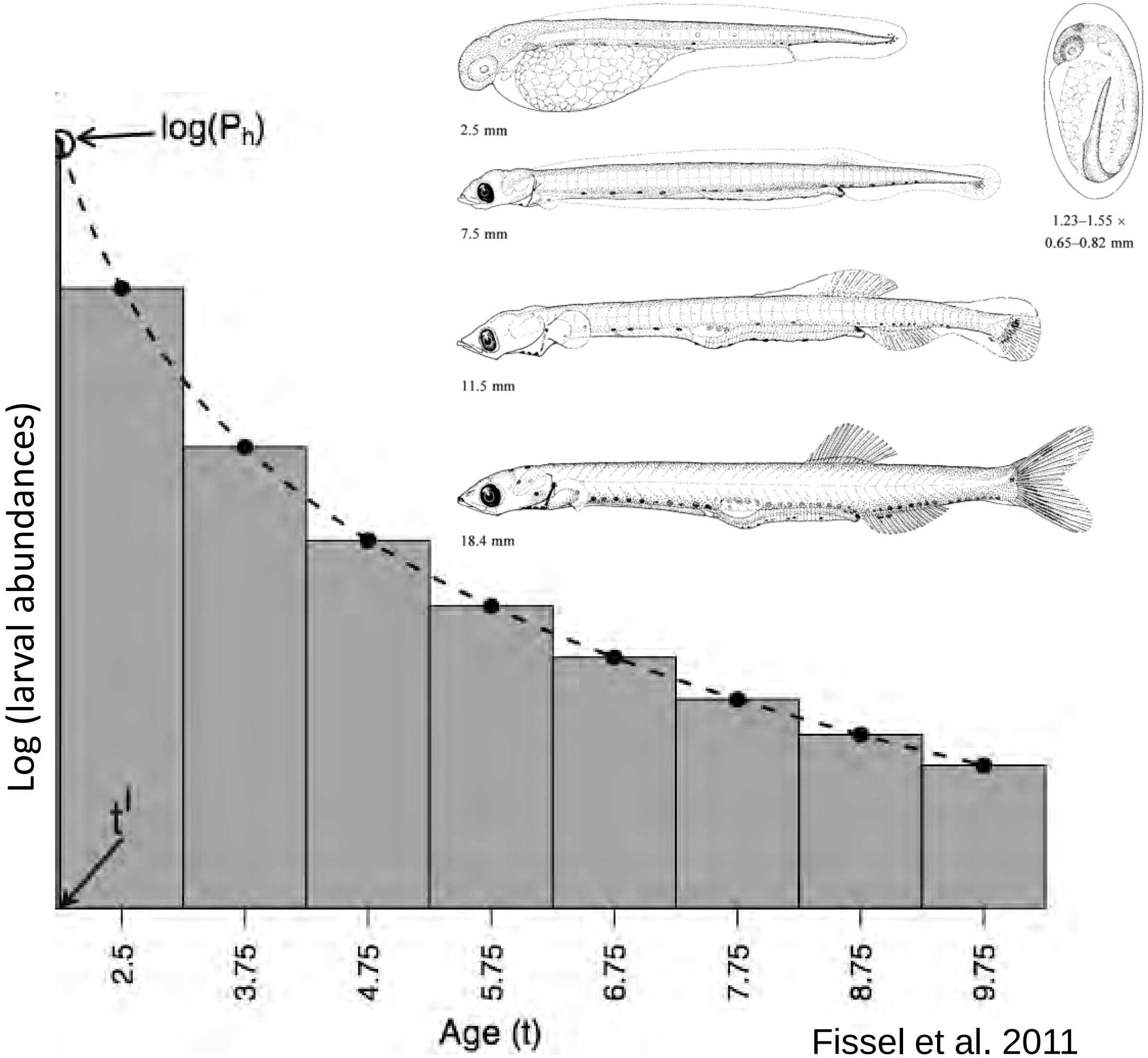
Image credit: Jim Wilkerson

Larval mortality is approximated by analysis of length distributions

Mortality can be approximated by examining the relative distributions of larvae across size bins after making some assumptions for growth rate.

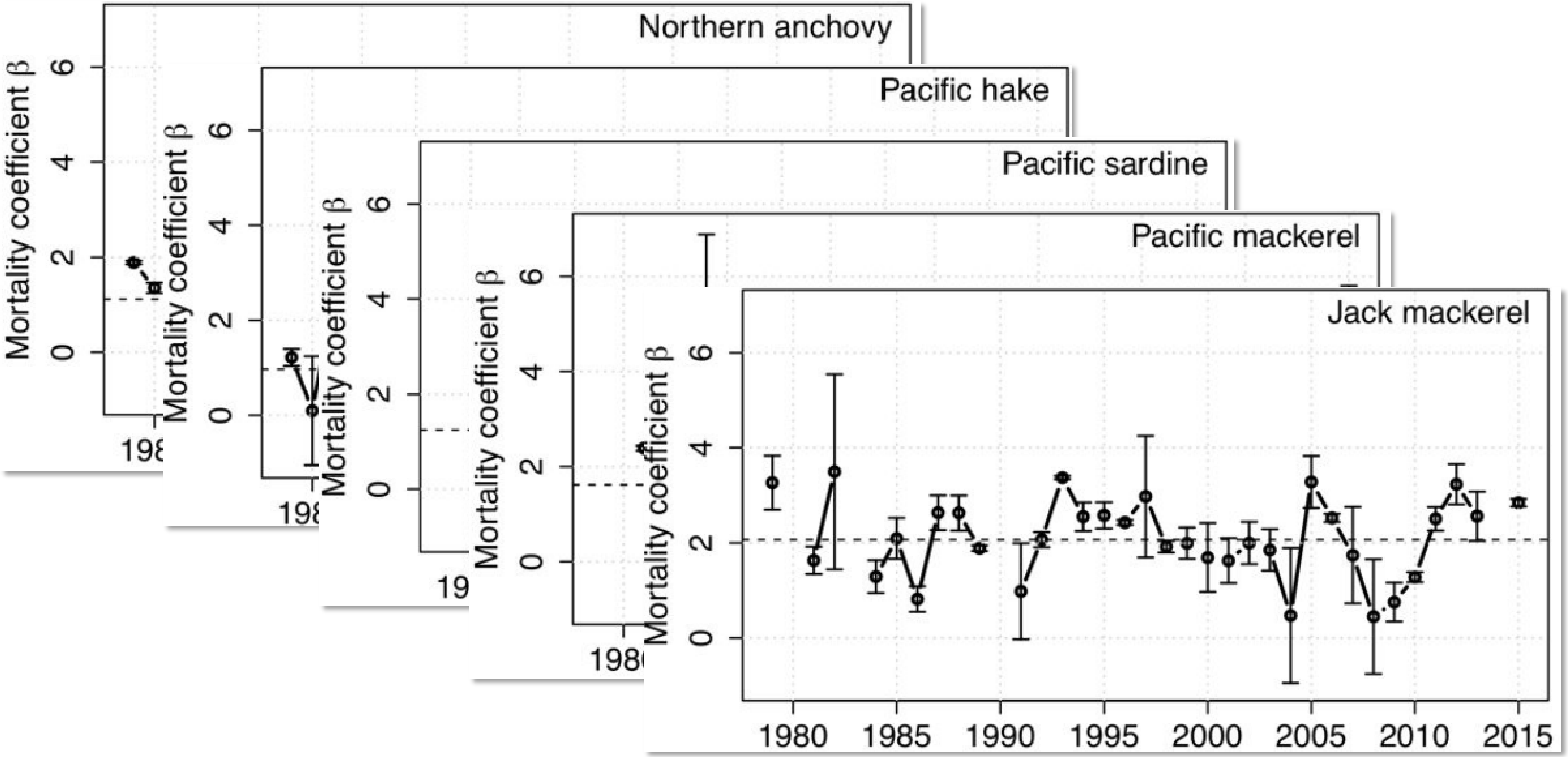
Here, the temperature-dependent Gompertz growth curve was used to estimate size at age, and a negative exponential model was fitted to the resulting distribution to estimate mortality rates of the following species:

northern anchovy (*Engraulis mordax*)
Pacific sardine (*Sardinops sagax*)
Pacific hake (*Merluccius productus*)
Pacific mackerel (*Scomber japonicus*)
jack mackerel (*Trachurus symmetricus*)

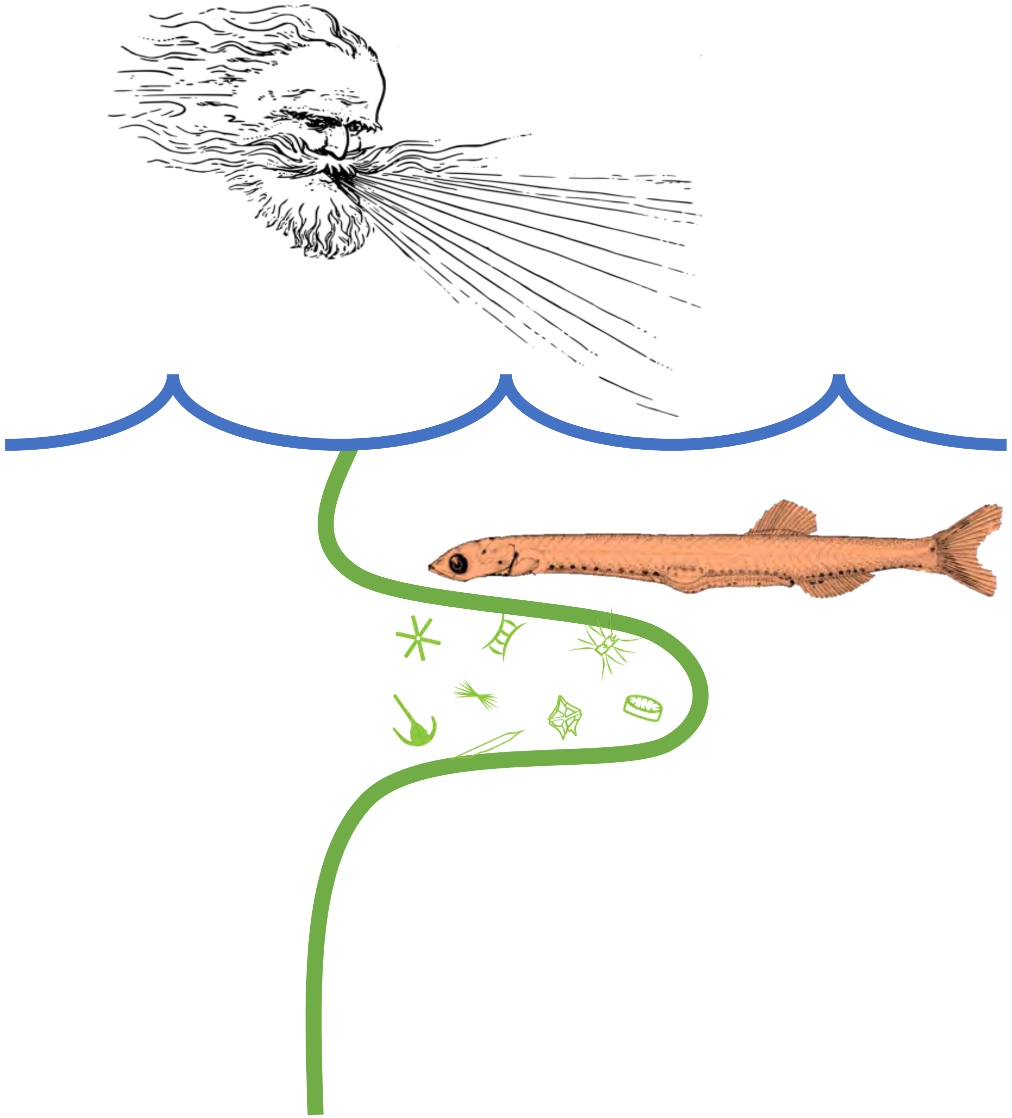


Fissel et al. 2011

Confidence is highly dependent on larval abundances and size distributions

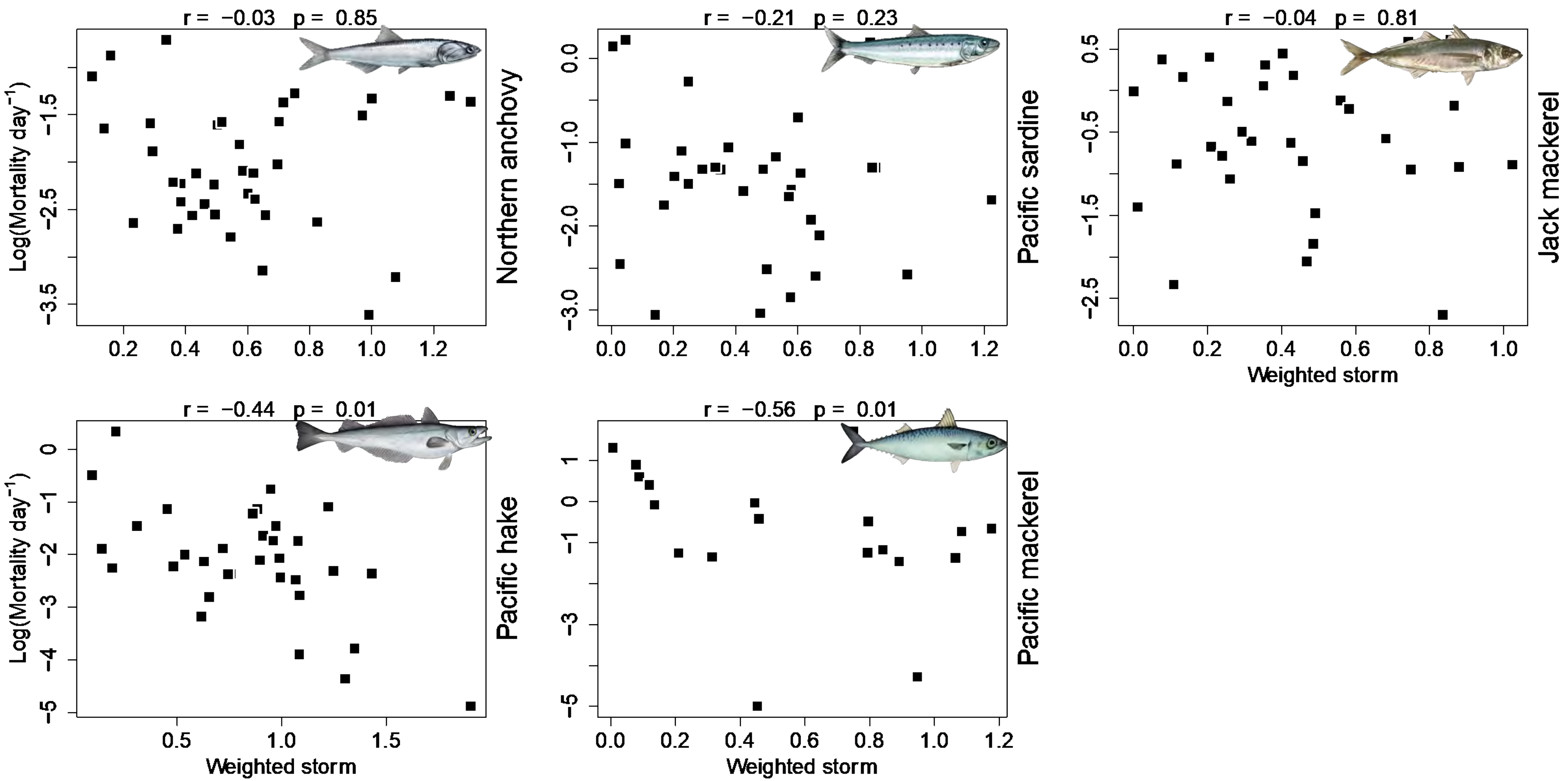


Results regarding larval mortality and wind events



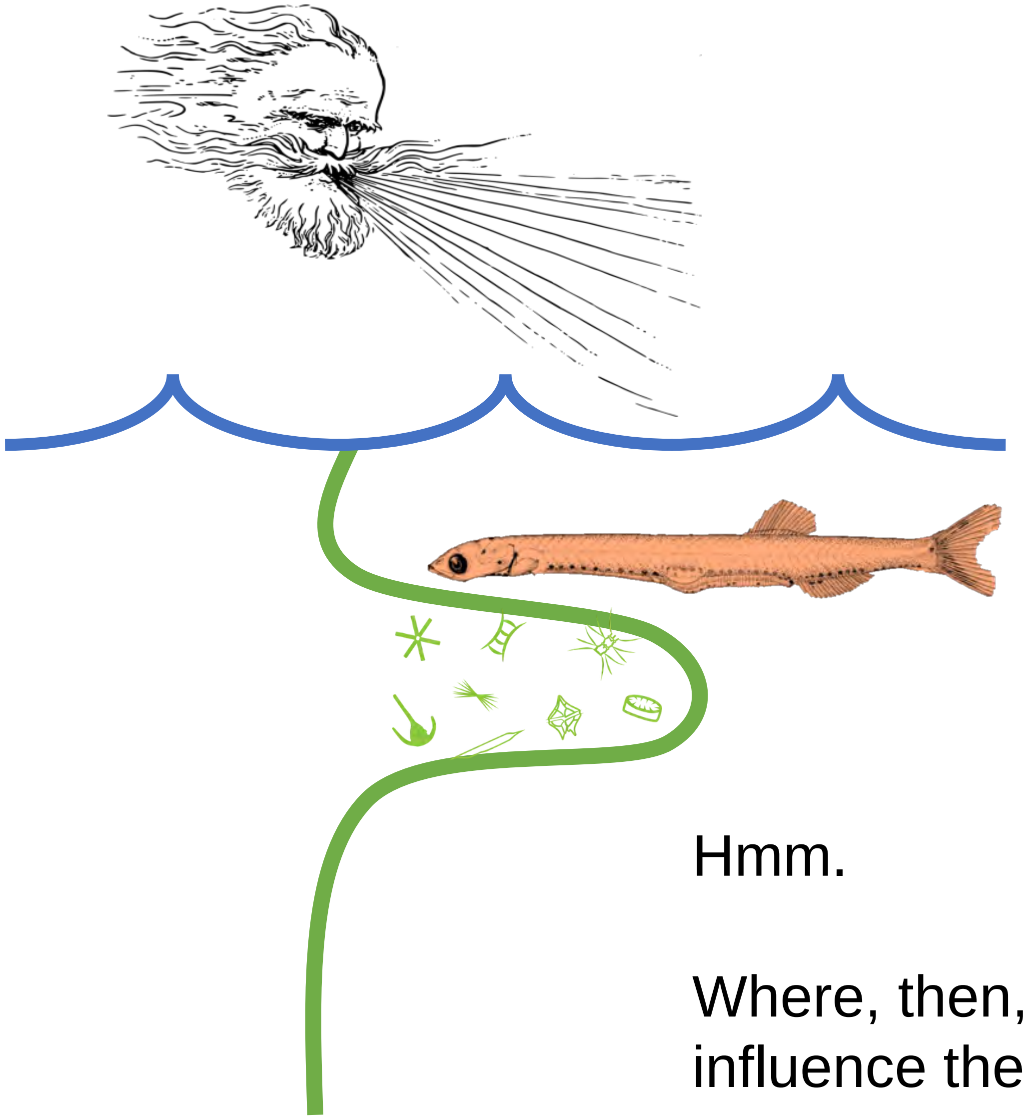
With these estimates of wind events and mortality rates, we can perform a basic test of the stable ocean hypothesis…

Q: Does larval mortality *increase* as the number of wind events increases?



r = −0.03 p = 0.85
Northern anchovy
r = −0.21 p = 0.23
Pacific sardine
r = −0.04 p = 0.81
Jack mackerel
r = −0.44 p = 0.01
Pacific hake
r = −0.56 p = 0.01
Pacific mackerel
Log(Mortality day−1)
Weighted storm

Results regarding larval mortality and wind events



With these estimates of wind events and mortality rates, we can perform a basic test of the stable ocean hypothesis…

Q: Does larval mortality increase as the number of wind events increases?

A: No. In fact, mortality appears to decrease for two of these species (hake and Pacific mackerel).

Hmm.

Where, then, does the story fall apart? Do winds indeed influence the vertical structure of plankton in the water column?

Ichthyoplankton collection and analysis is the most unique aspect of the dataset

The fluorometer casts deployed with the CTD allow opportunities to explore vertical structure in chlorophyll profiles.

Both vertical structure (i.e., a subsurface chlorophyll maximum) and a concentration threshold were explored.

Image credit: Jim Wilkerson

Responses of the chlorophyll vertical structure to wind events

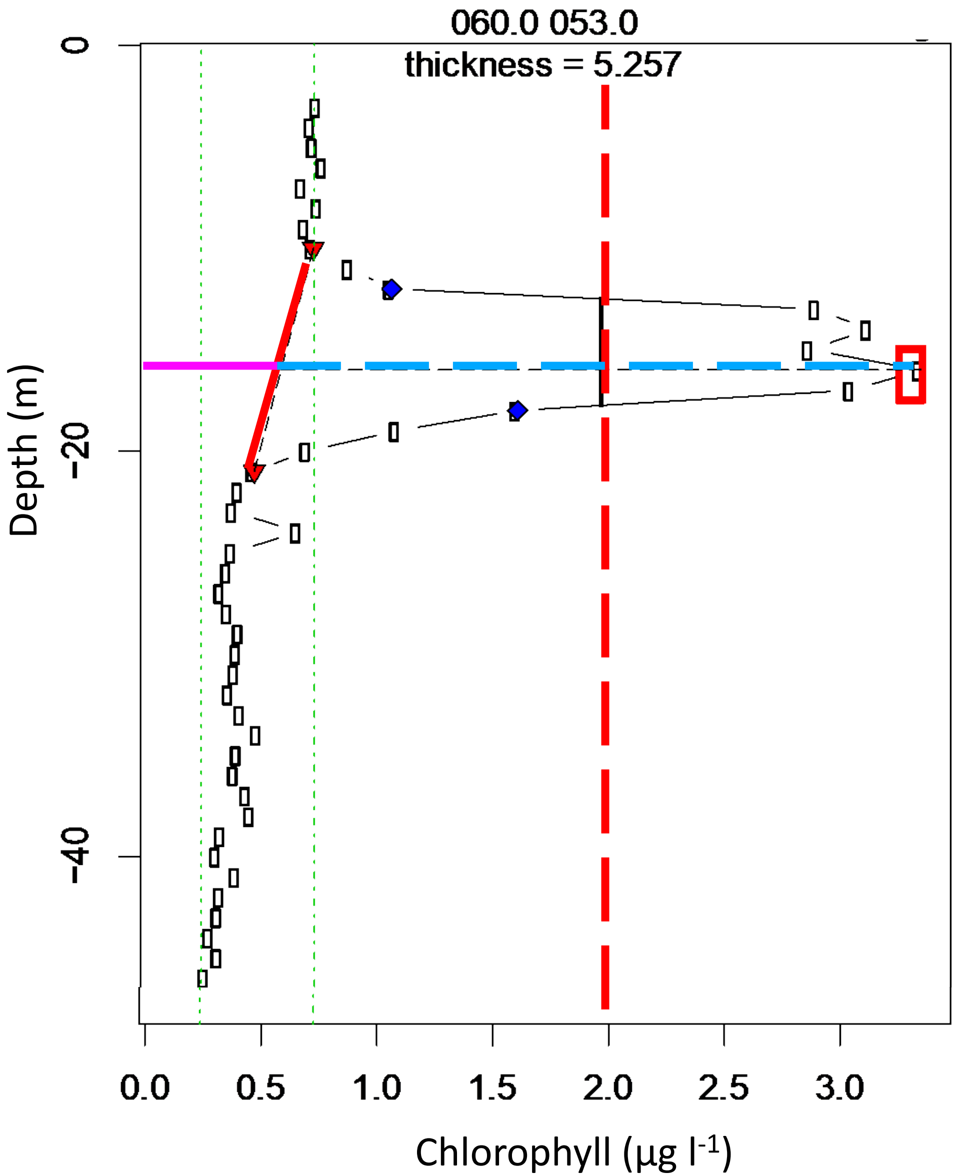
Peaks in the chlorophyll profile that were shallower that the wintertime mixed-layer depth were identified.

Two criteria were used to categorize these subsurface chlorophyll maxima as the "vertical chlorophyll structure" (VCS) relevant to the stable ocean hypothesis:

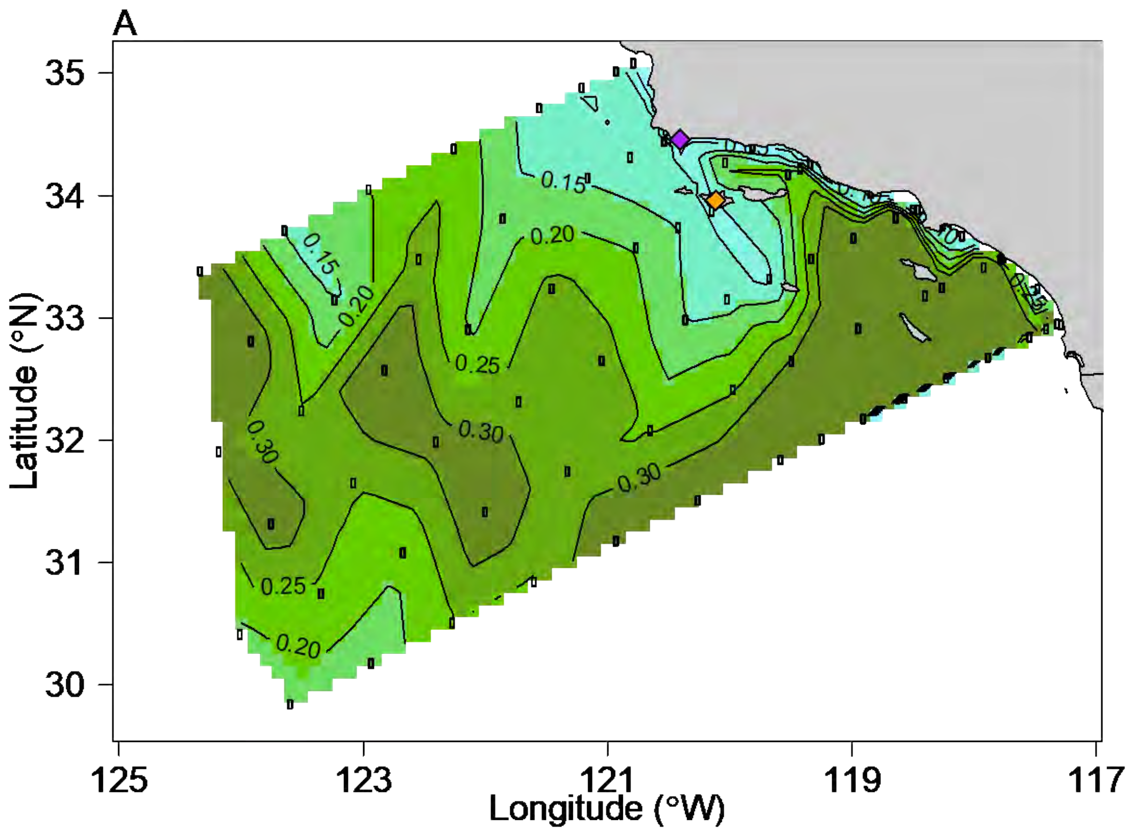
1. Peak chl magnitudes ≥ 3 times the background chl, and additionally…

2. Peak chl magnitudes ≥ 2 μg chl l^{-1}.

There were 3,443 fluorometer casts use in the analysis.

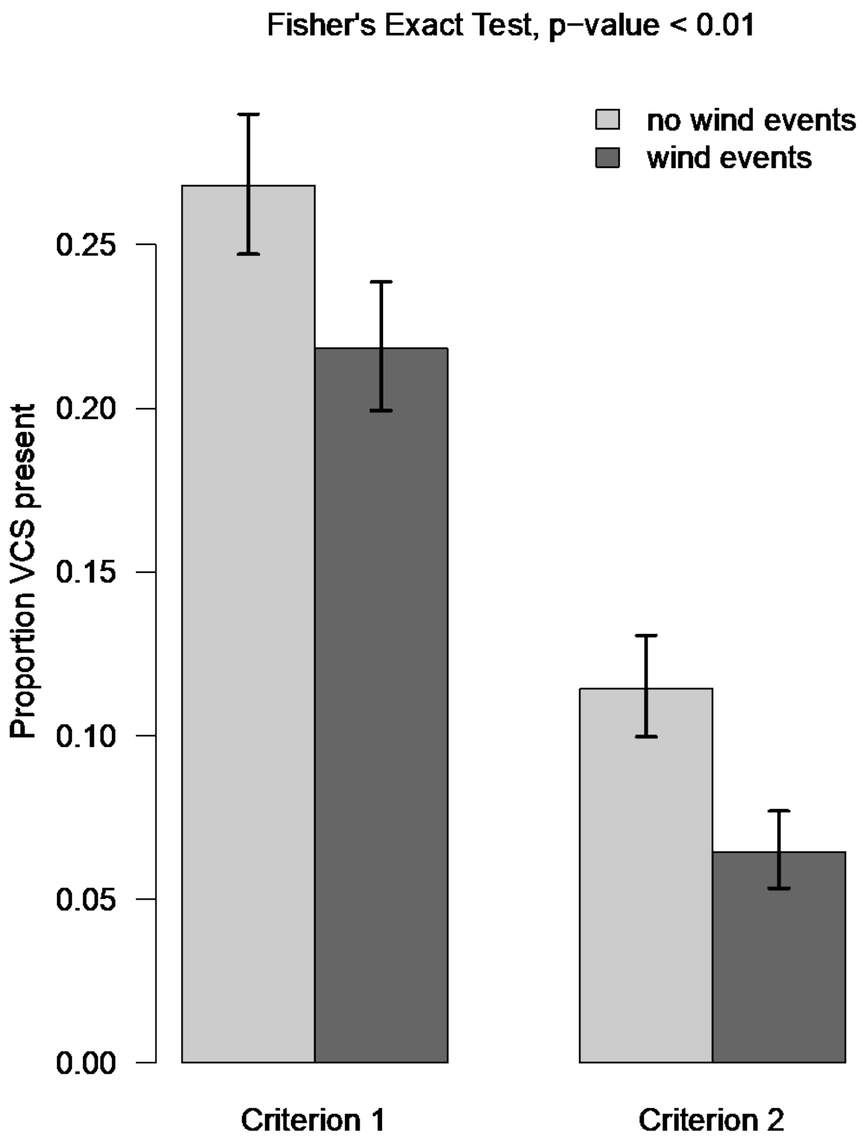


Results – Spatial distribution of "vertical chlorophyll structure" (VCS)



Criterion 1
Relative intensity ≥ 3

Results on "vertical chlorophyll structure" (VCS)



Q: Is the passage of wind events associated with reduced vertical structure of chlorophyll in the water column?

Results were examined three ways…

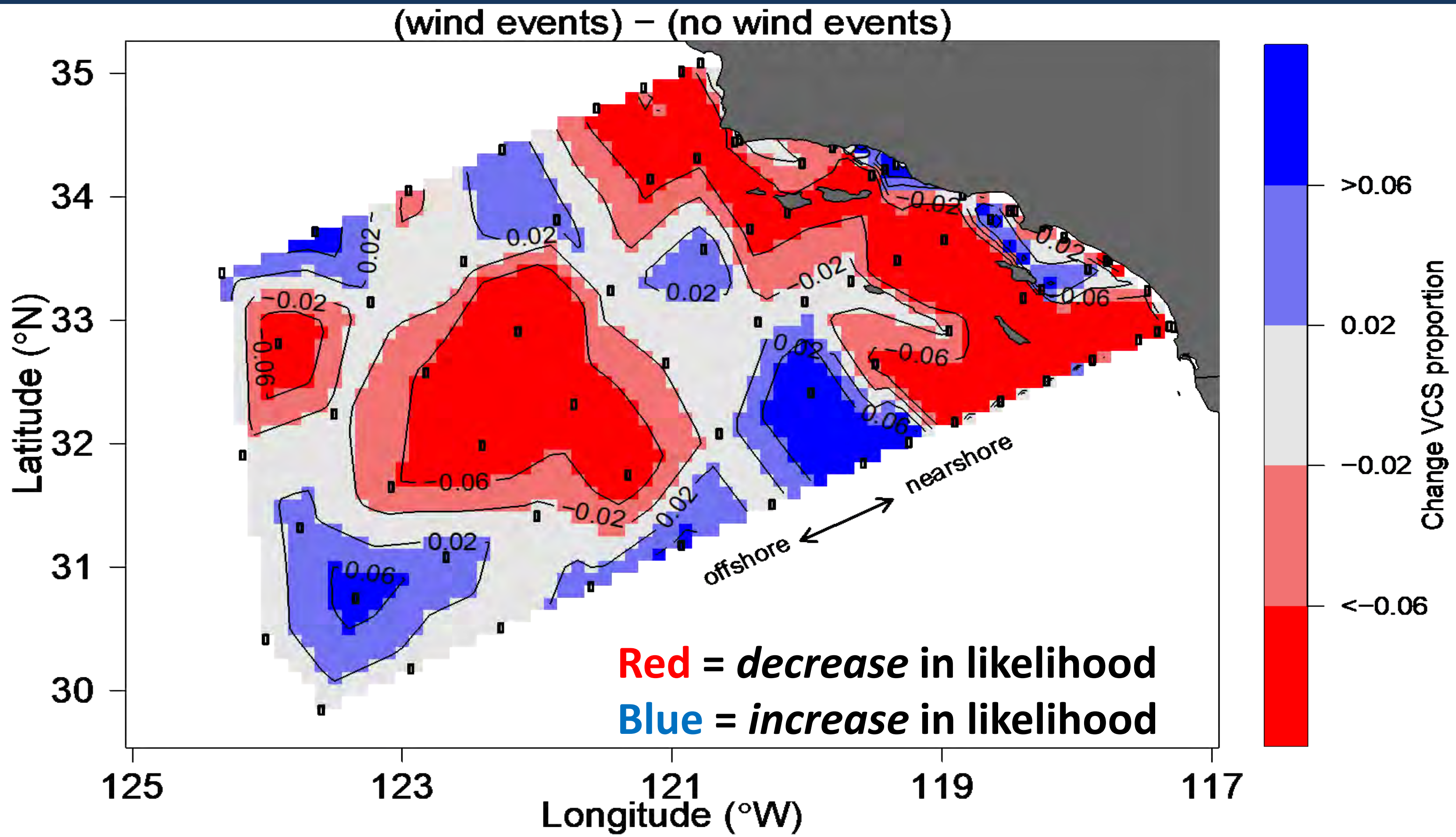
#1: In bulk, yes, the water column is less likely to exhibit VCS after a wind event.

Results – Spatial distribution of "vertical chlorophyll structure" (VCS)

Q: Is the passage of wind events associated with reduced vertical structure of chlorophyll in the water column?

Results were examined three ways…

#2: Yes, this appears when the spatial variability is considered as well.



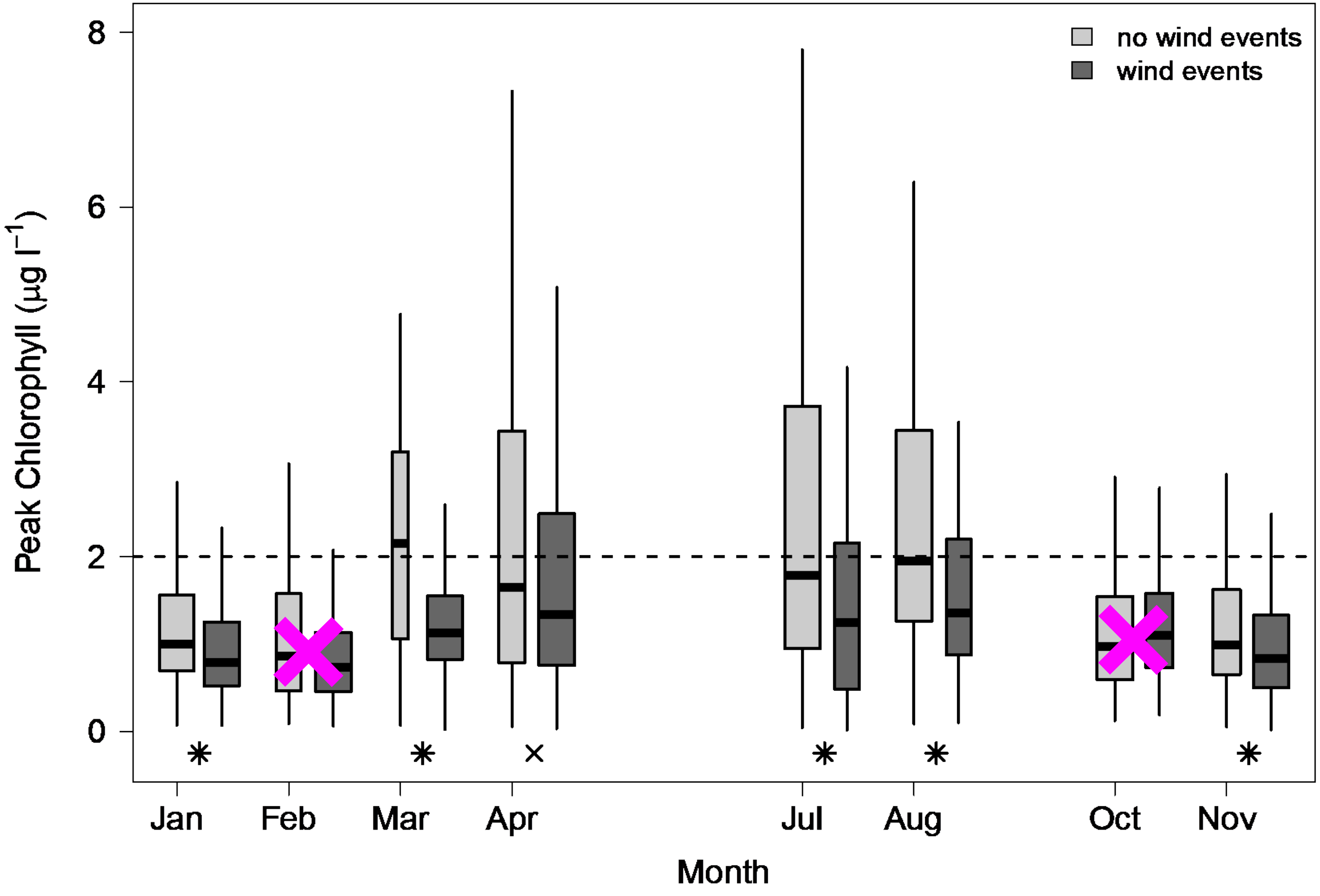
The decrease in the likelihood of observing VCS is 62% in the nearshore area, and the decrease is 37% in the offshore area.

Results on seasonal "vertical chlorophyll structure" (VCS)

Q: Is the passage of wind events associated with reduced vertical structure of chlorophyll in the water column?

Results were examined three ways…

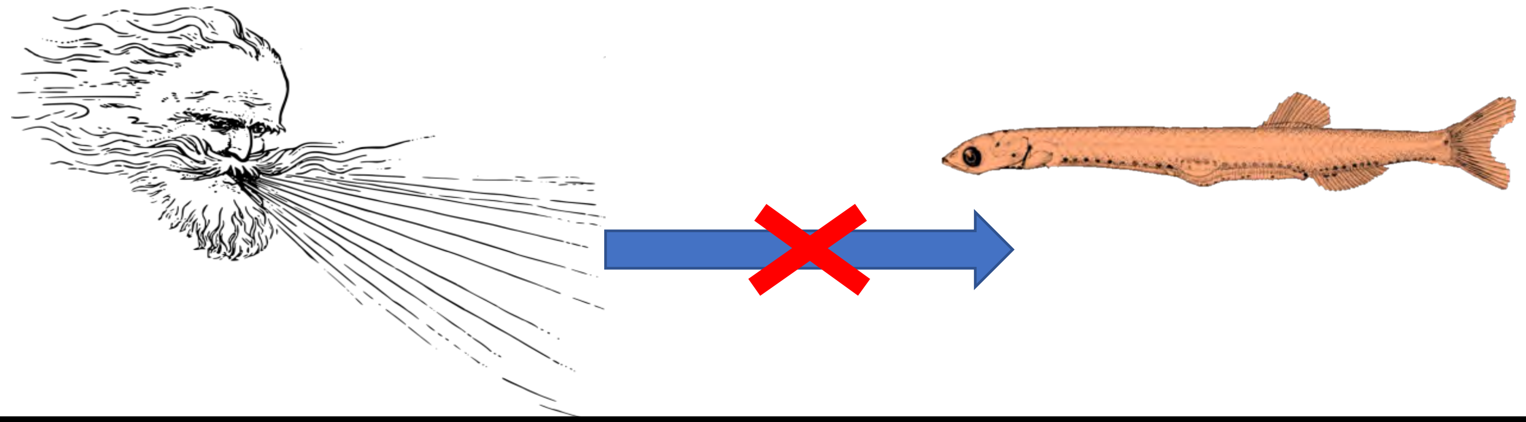
#3: Yes, wind events led to a decrease in the peak chlorophyll concentrations in all months sampled except February and October.



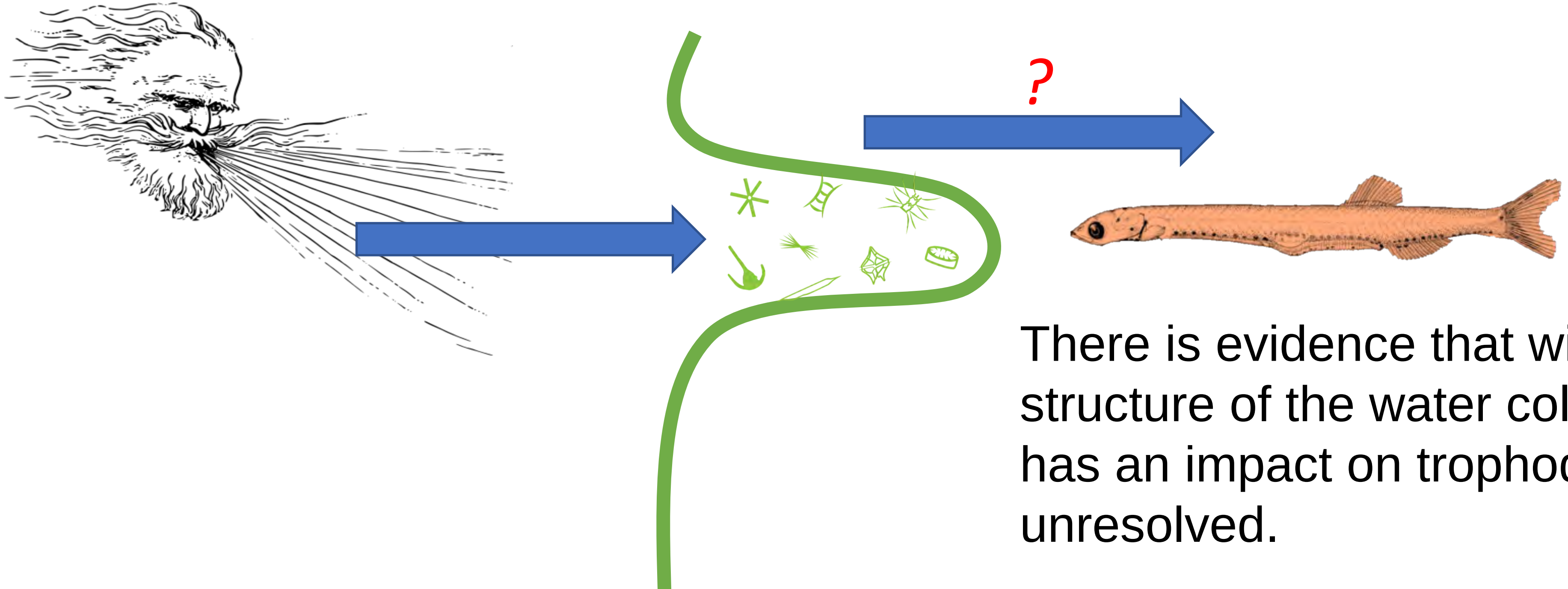
* Significant pairwise Wilcoxon Sum Rank ($p < 0.01$)

x Significant pairwise Wilcoxon Sum Rank ($p < 0.05$)

Summary



There was no clear negative impact of wind events on larval survival (in fact, the opposite for some offshore species).



There is evidence that wind events disturb the structure of the water column. Whether this has an impact on trophodynamics is yet unresolved.

Hindsight

What might we have done differently?

- more effort in developing metrics of “storm” and “calm” periods that might include a duration factor.

- explore data from earlier in the CalCOFI record.

- attempt to more closely reproduce the study of Peterman and Bradford (1987).

Continued work:

- exploration of the difference in plankton composition across VCS in the region.

Acknowledgements and support

Brendan's family: Kat and Zora (who could not wait)

Past and present members of the Ecosystem Oceanography Lab

Carl van der Lingen, Bill Sydeman, Steven Bograd, Bryan Black, Marisol Garcia-Reyes, Tarron Lamont

CalCOFI scientists, vessel crew, technicians, and volunteers

Committee:
~~Ryan Rykaczewski, advisor~~
Tammi Richardson
Matt Kimball
George Voulgaris

Thanks for your attention!