PICES
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College of Earth, Ocean, and Atmospheric Sciences

Coastal retention in upwelling currents: Mechanisms and sensitivity to wind forcing

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The Setting:
Eastern Boundary Currents (EBCs)

Coastal Upwelling

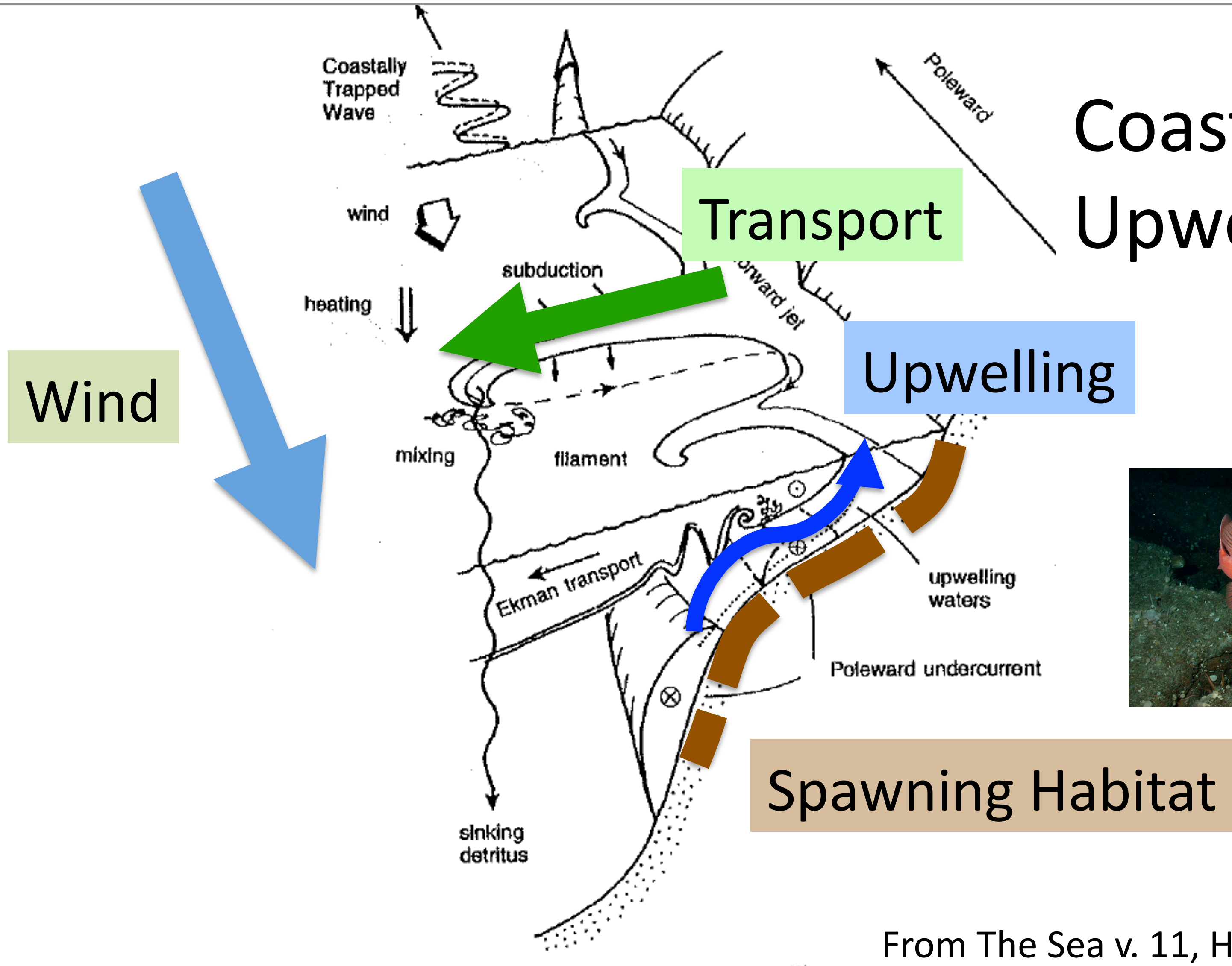
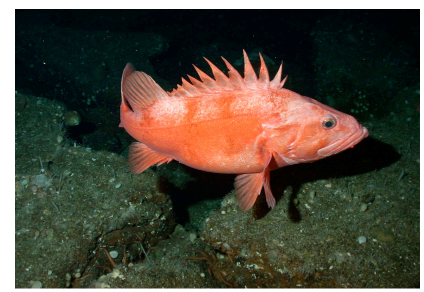
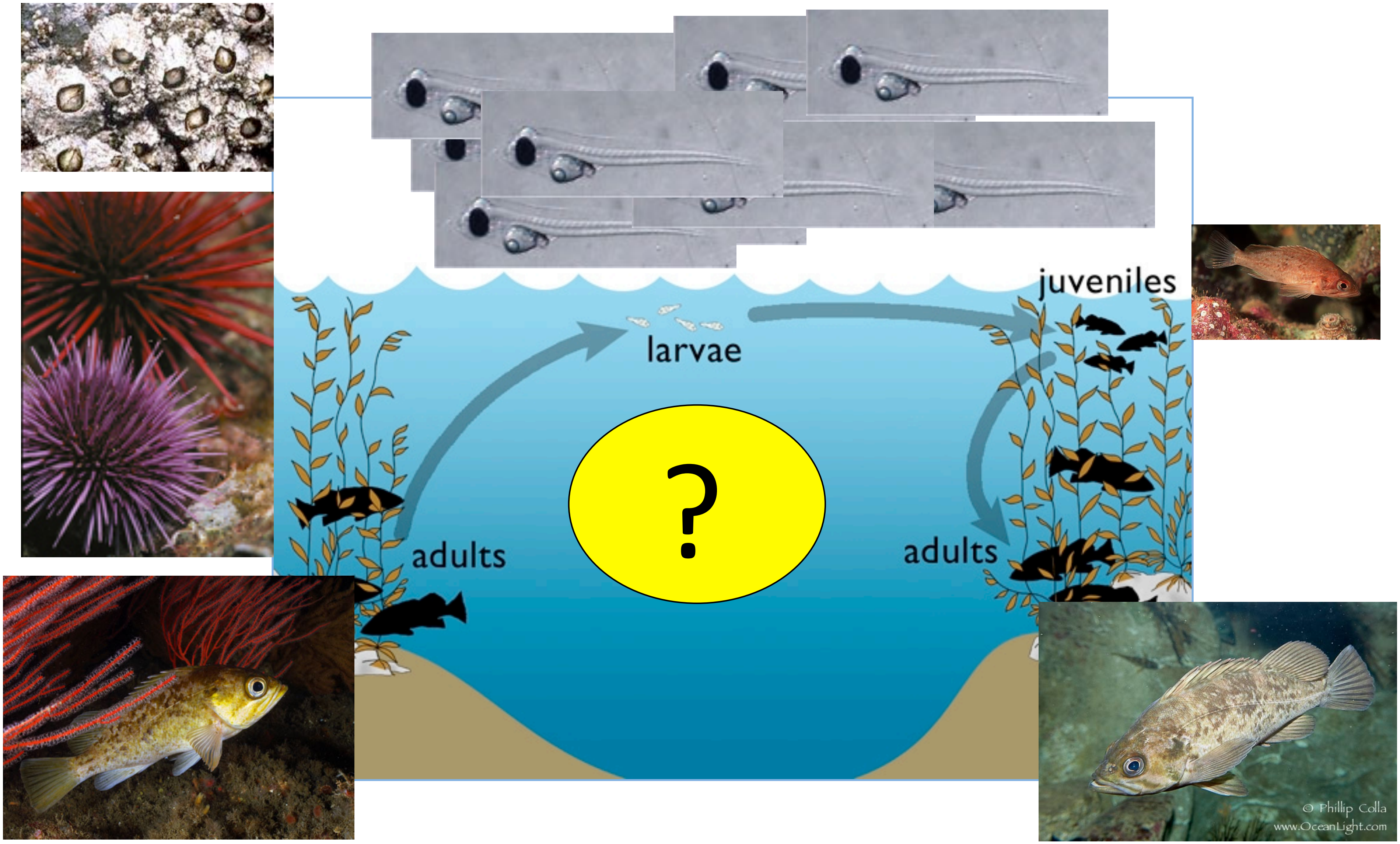


Fig. 2.4. Schematic of an upwelling system.



From The Sea v. 11, Hill et al. 1998

Motivation: Benthic Larval Transport



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Larval Transport Paradigms in Eastern Boundary Currents

Older:
- The well-mixed larval pool
- Upwelling relaxation => high settlement

The Tattered Curtain

Roughgarden 1988

Newer:
- Linear, diffusive, alongshore advective transport
- Gaussian dispersion kernel

Largier 2003

Newest:
- Eddy-driven intermittent dynamics
- Stochastic/packet model
- Lagrangian coherent structures map transport pathways

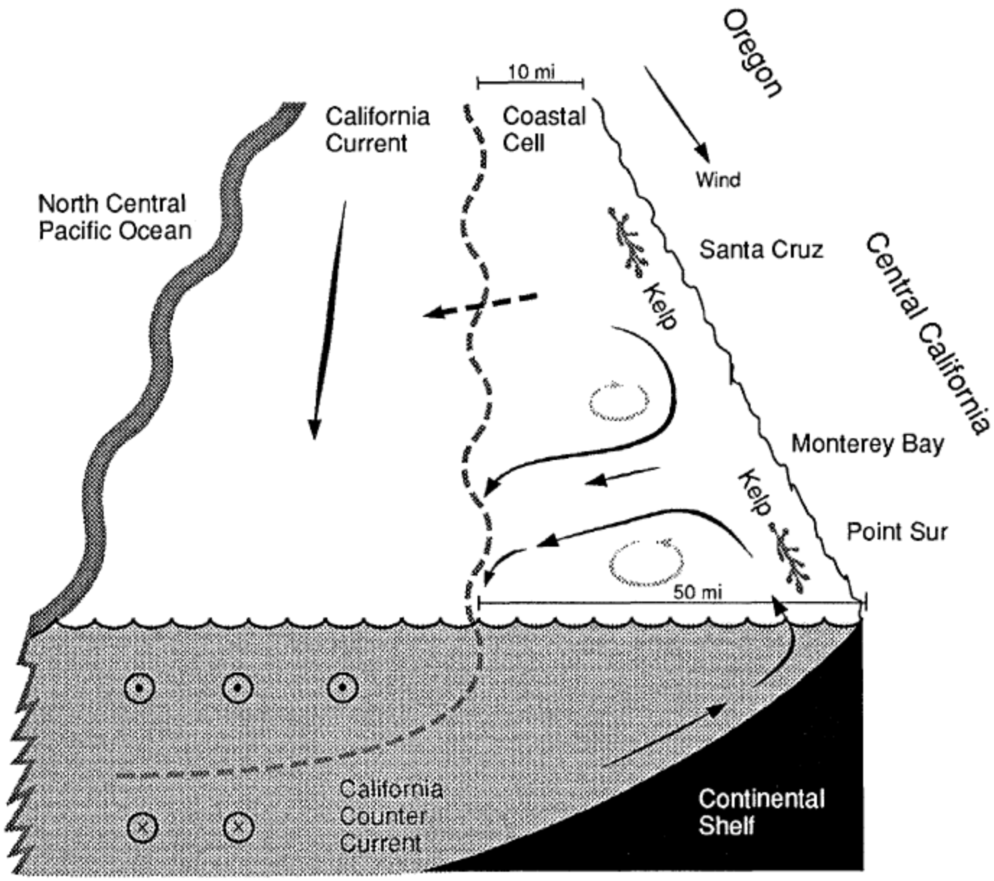
Siegel et al. 2008

Harrison et al. MEPS 2013

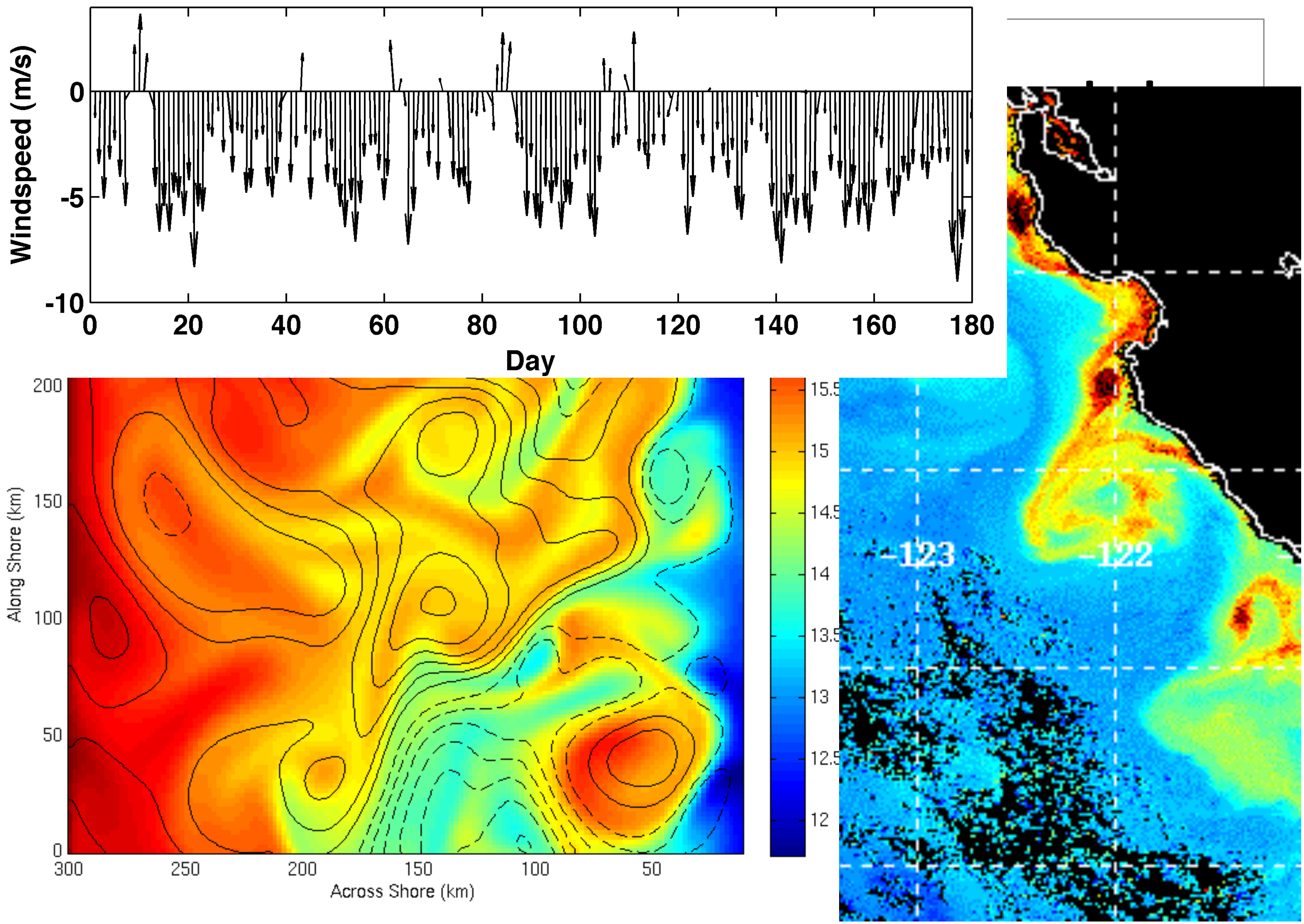
The Tattered Curtain Hypothesis

Physical Hypothesis:

Roughgarden et al. 1988, 1991

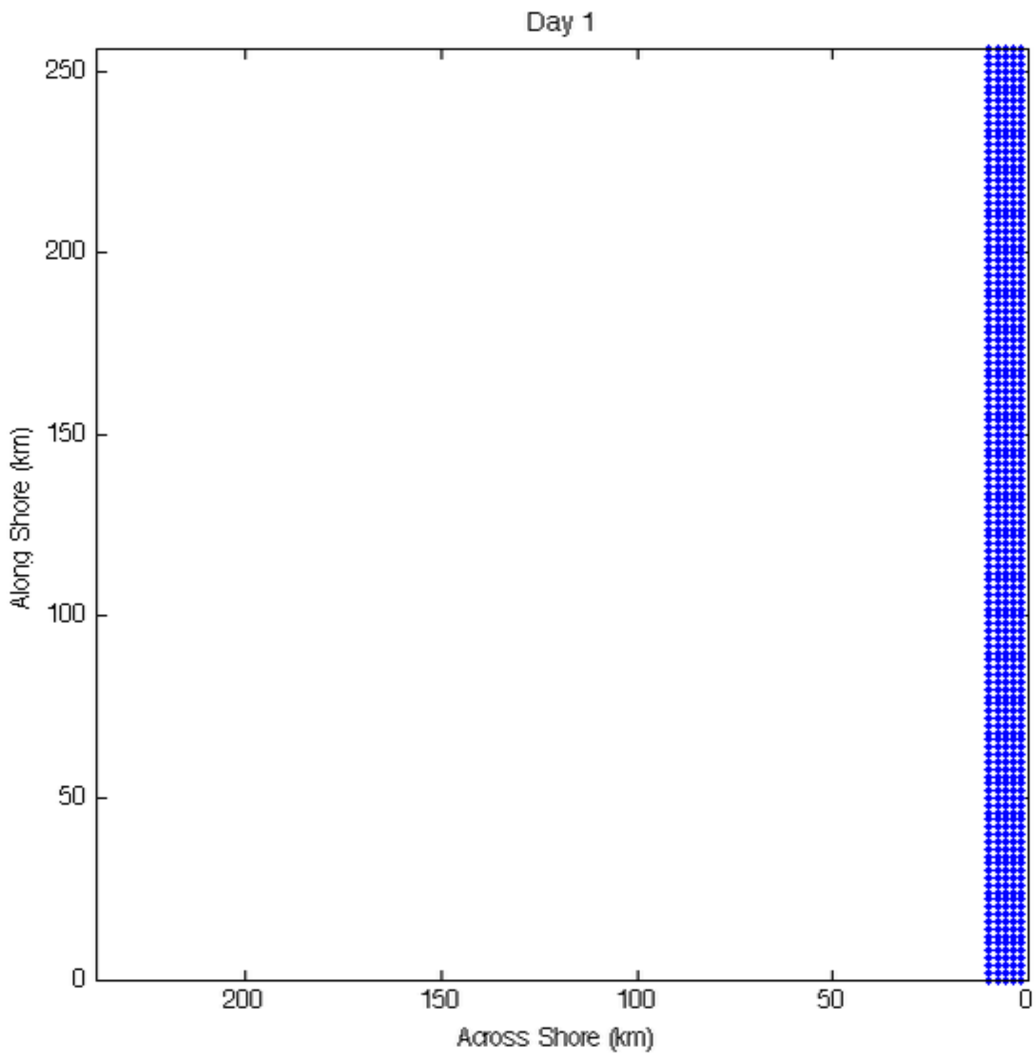


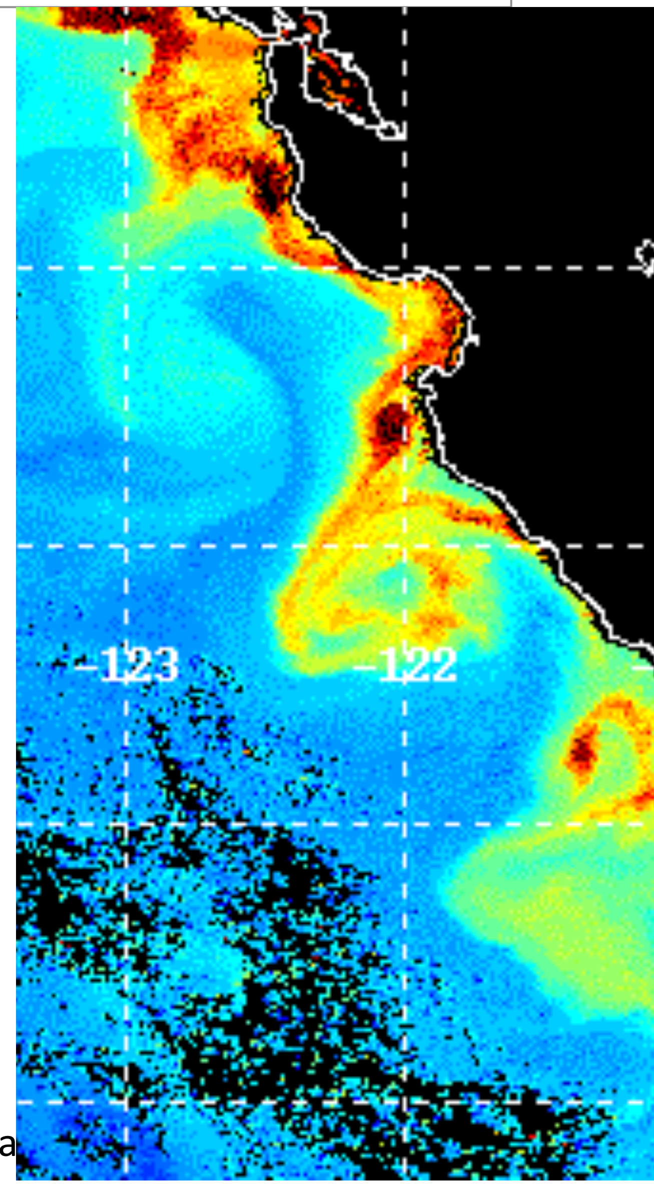
- Curtain is the upwelling front billowing in the wind, interacting with eddies
- Tattered by eddies and filaments, esp. at headlands
- Convergence at front
- During relaxation front collides with coast



Harrison et al. MEPS 2013, Mitarai et al. 2008, Siegel et al. 2008

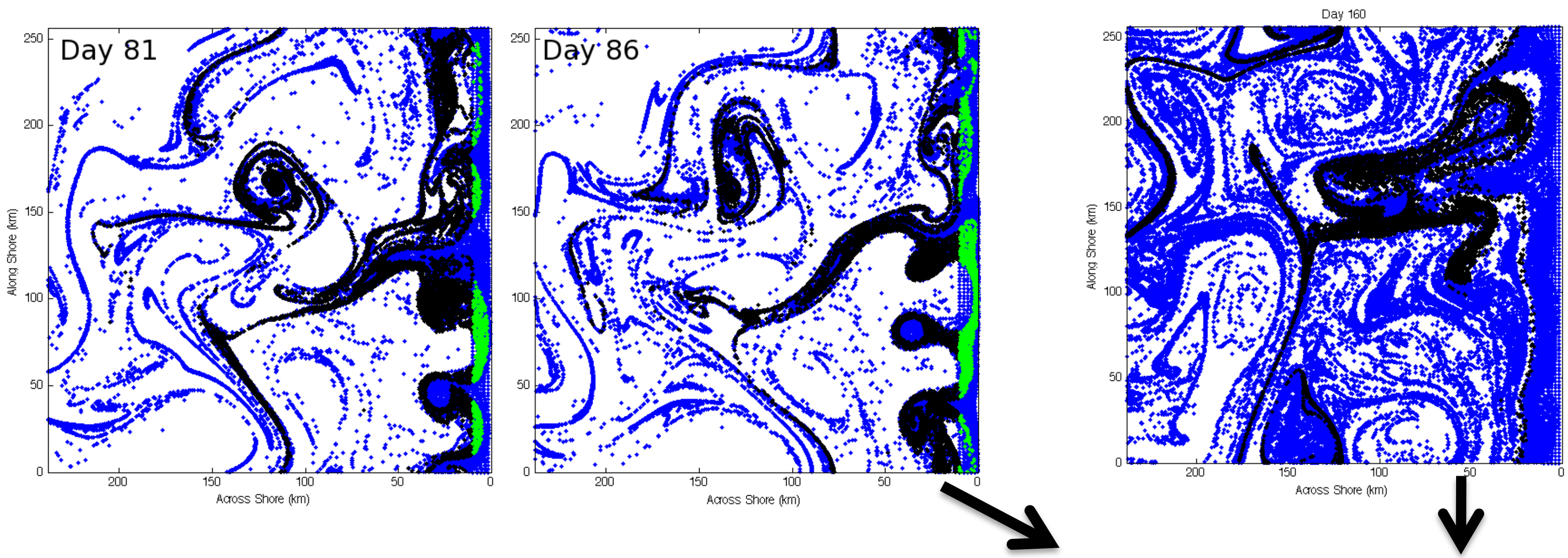
Particle "Larvae" Model



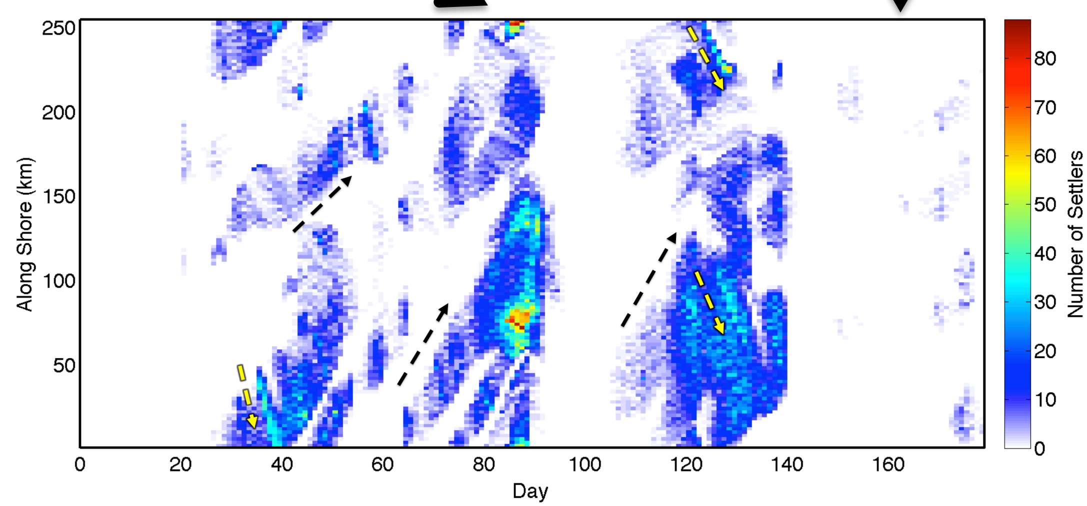


Harrison et al. MEPS 2013, Mitarai et al. 2008, Siegel et al. 2008, Ha

Coastal jets: A mechanism for retention

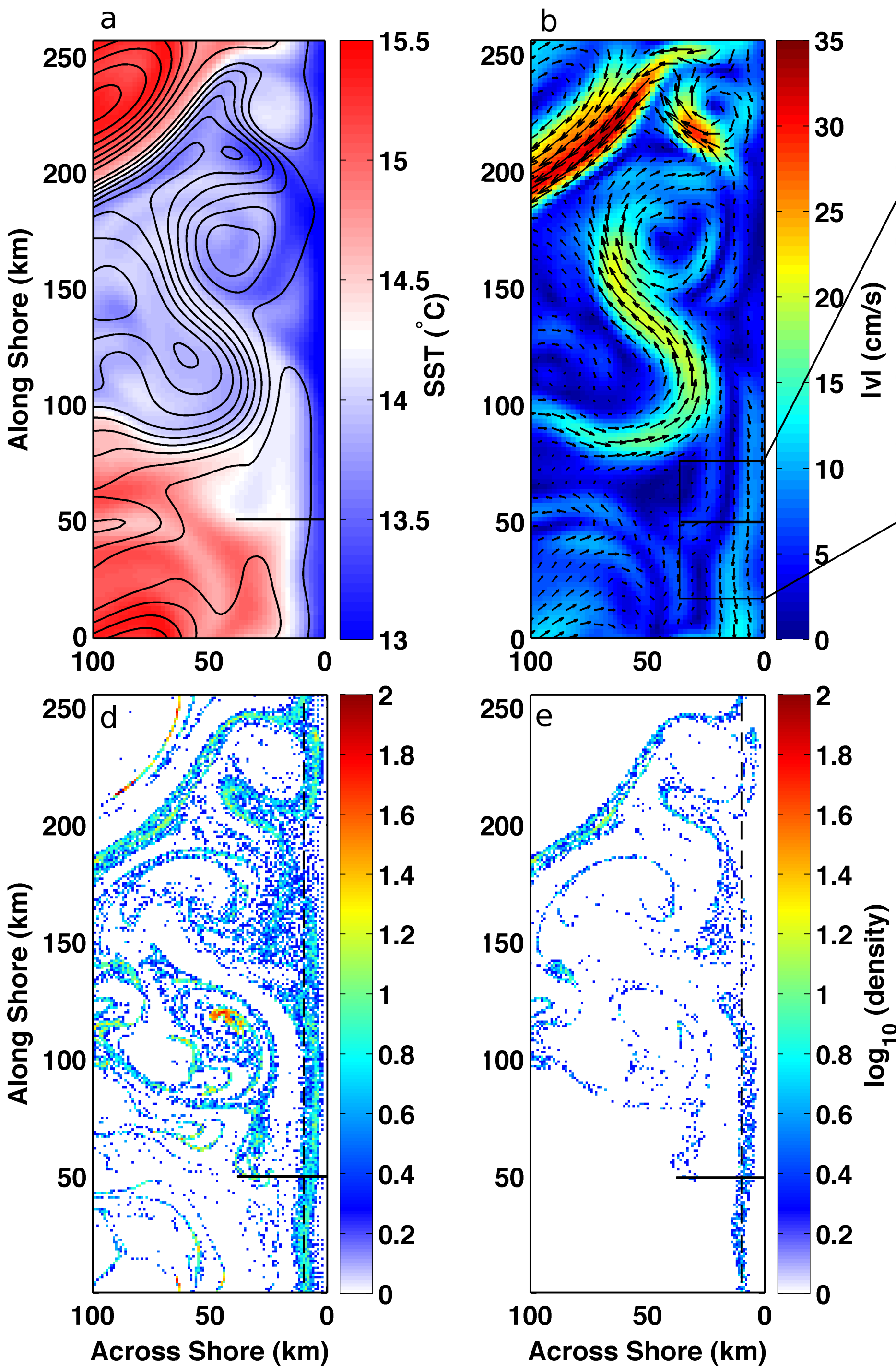


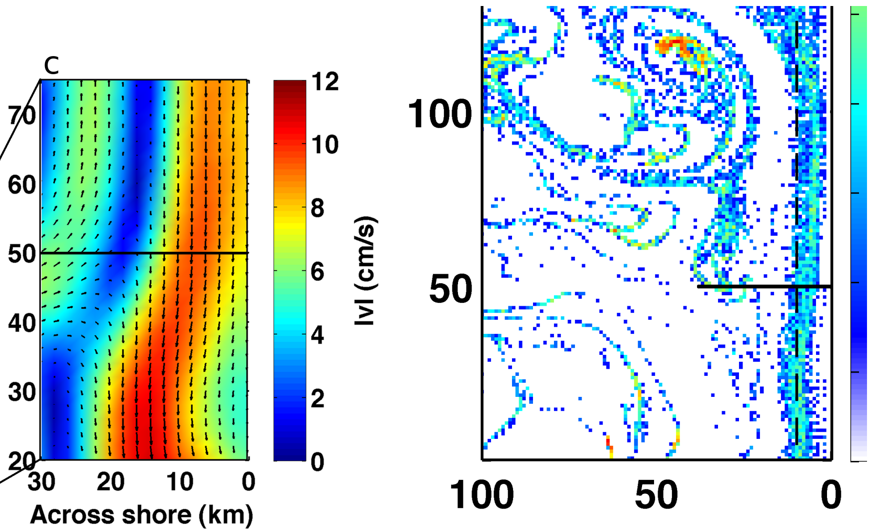
Retention/settlement tends to be semi-coherent along the coast, moderated by a tattered upwelling jet



Settlement Diagram: alongshore settlement through time

Run 111



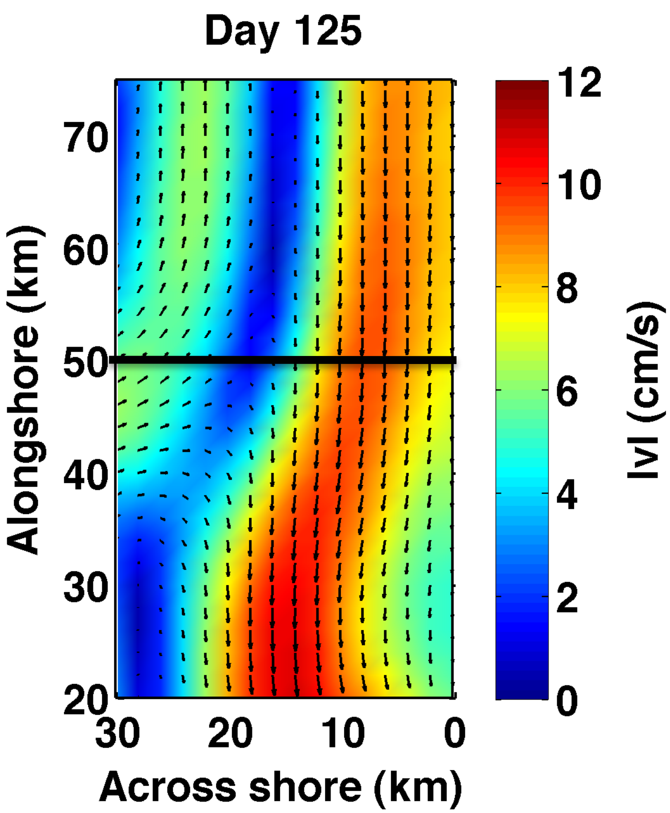


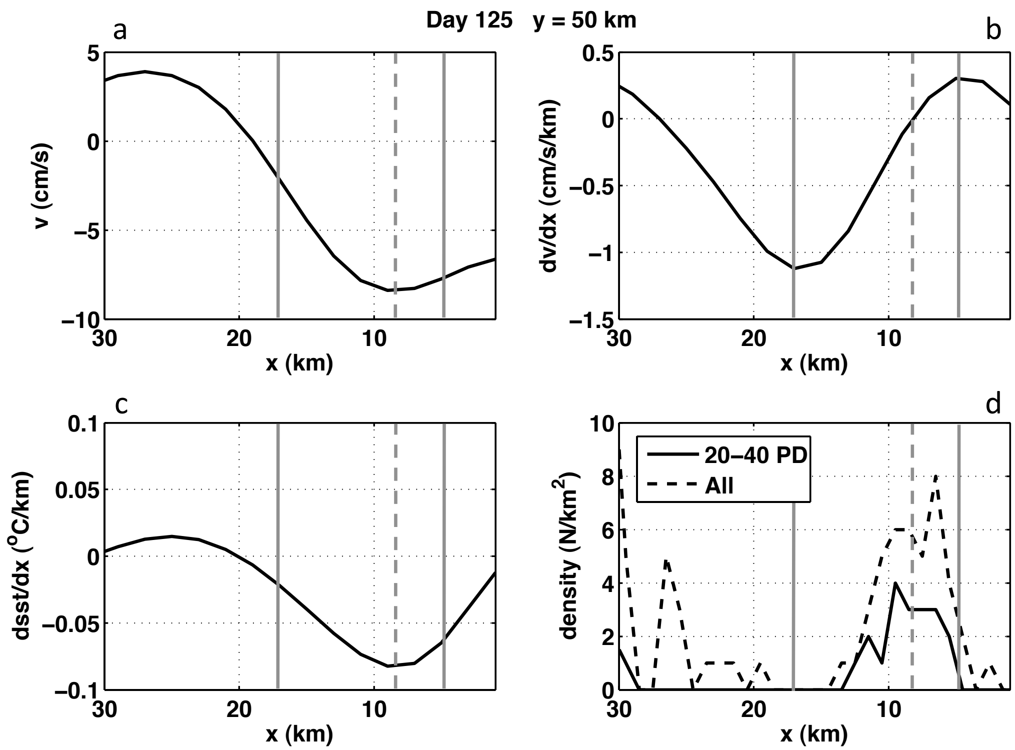
A quasi-retentive upwelling jet

- Material in interior of jet
- Jet controls retention and settlement patterns
- Some jet segments linear and coherent
- Some tattered by filaments

Jet Transects

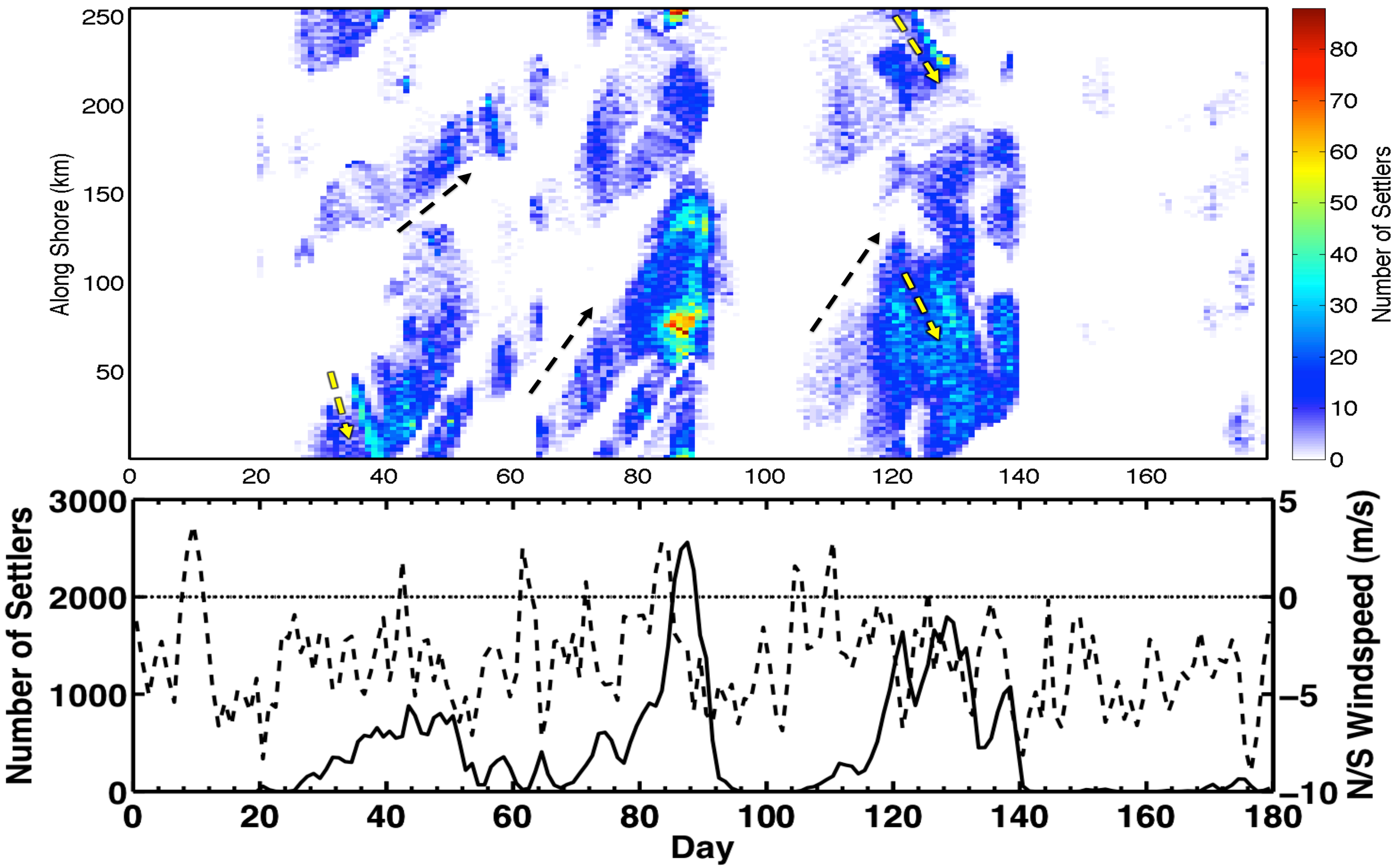
- Material concentrated within high shear zones
- Near the core of the jet
- On either side of the upwelling front





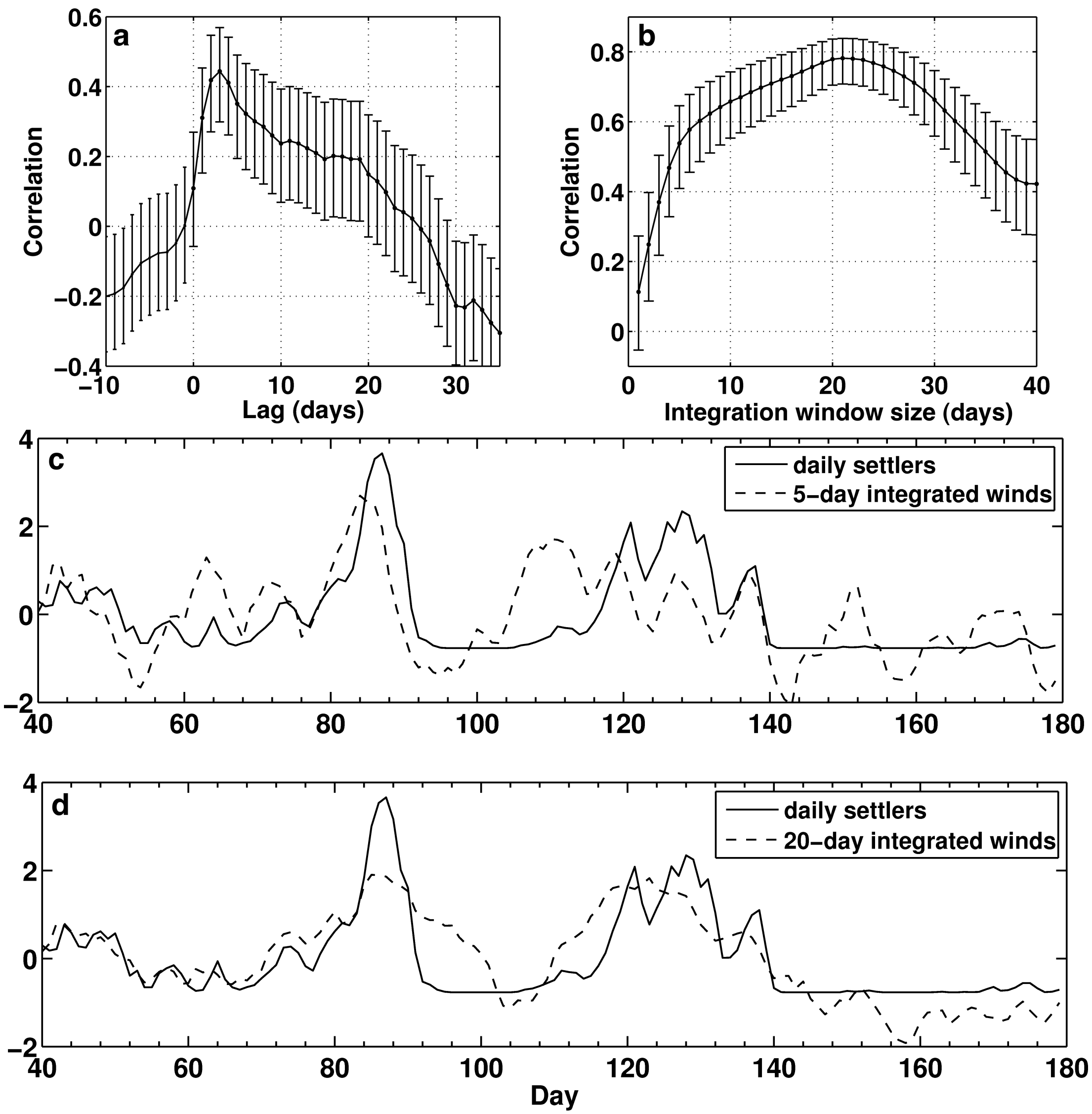
Retention (settlement) and Wind

"Settlers" = 20-40 days old and < 10km offshore



Run 111

Wind & Settlement Statistics
(single run)



Note: wind and settlement normalized

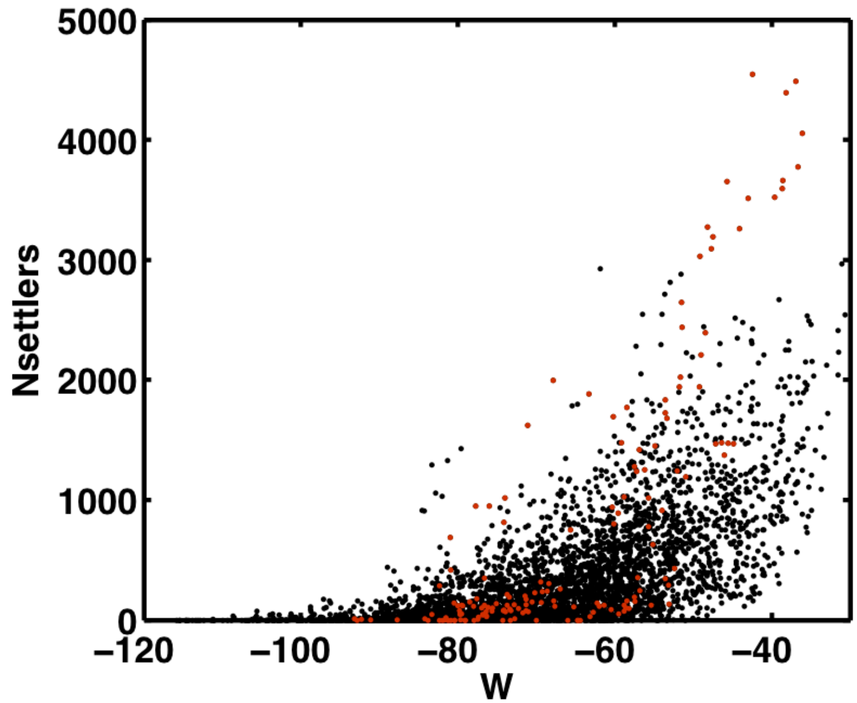
- Settlement shows a strong correlation (r = 0.75) with a 20-day integrated wind product
- Some settlement patterns better predicted by 2-5 day wind product
- Lack of settlement more predicted by long bouts of upwelling favorable winds, “tattering” the upwelling jet

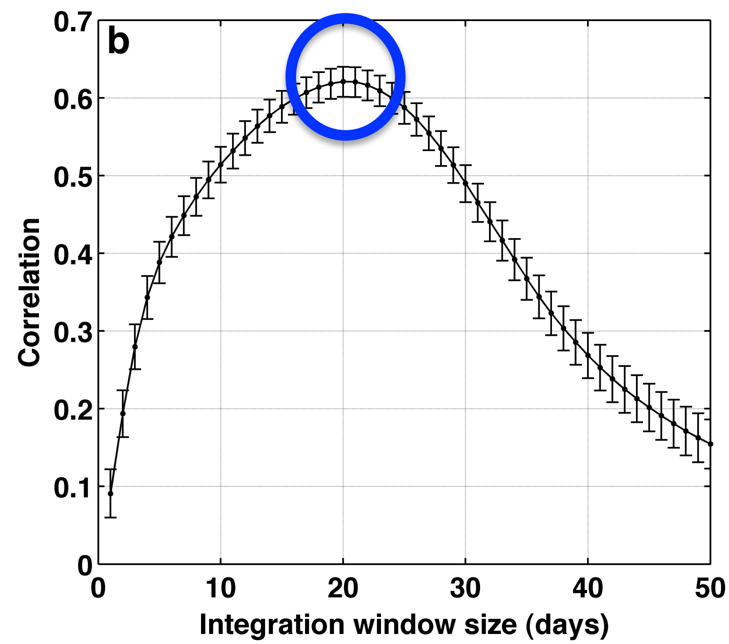
Run 111

Wind & Settlement Statistics (Ensemble Results)

• In the CCS-box model, extended, strong upwelling completely tatters the upwelling jet and moves potential settlers far offshore.

• There is a positive correlation between 20-40 PLD settlement and the integrated alongshore wind, peaking at r = 0.63 for a 20-day integrated wind (W).



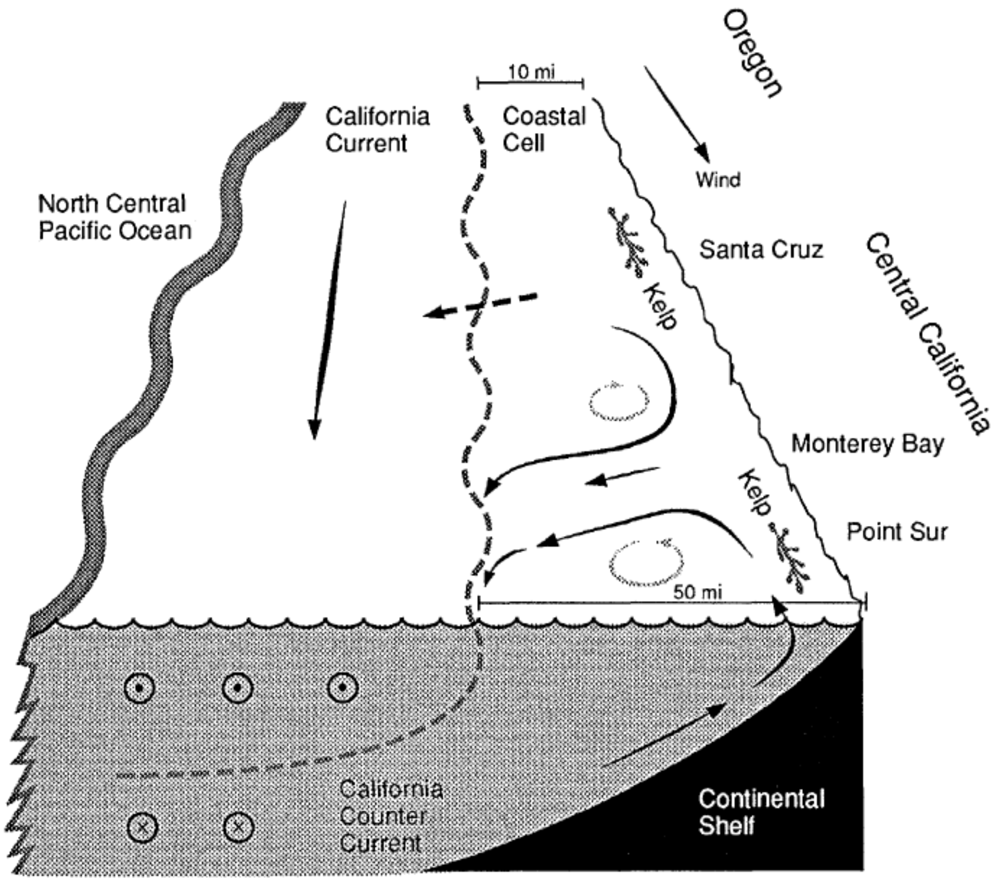


Correlation of lagged wind (left) and integrated wind (right) and settlement as a function of window size for the 28 run ensemble.

The Tattered Curtain Hypothesis Revisited

Harrison and Siegel, submitted to LO:FE

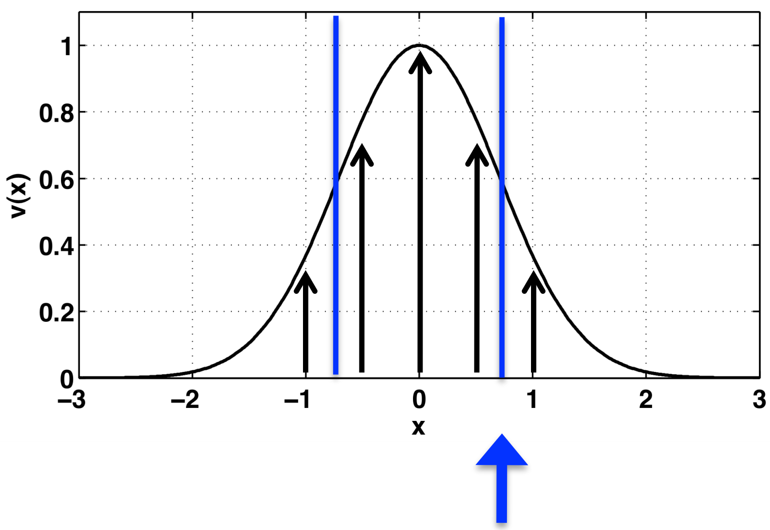
Physical Hypothesis:



- Curtain is the upwelling ~~front~~ jet billowing in the wind, interacting with eddies
- Jet is tattered by eddies and filaments~~, esp. at headlands~~
- ~~Convergence at front~~ Retention in jet core
- ~~During relaxation front collides with coast~~ Moderate upwelling keeps jet at coast regionally

Moving beyond the Bakun upwelling index

- The tattered upwelling jet is an emergent feature in upwelling systems
- There is LOCAL reduction of upwelling by coastal velocity shear:



Shear ($\delta v_G/\delta x$) is high

Bakun: $fu_E = T_y/\rho$

+ jet

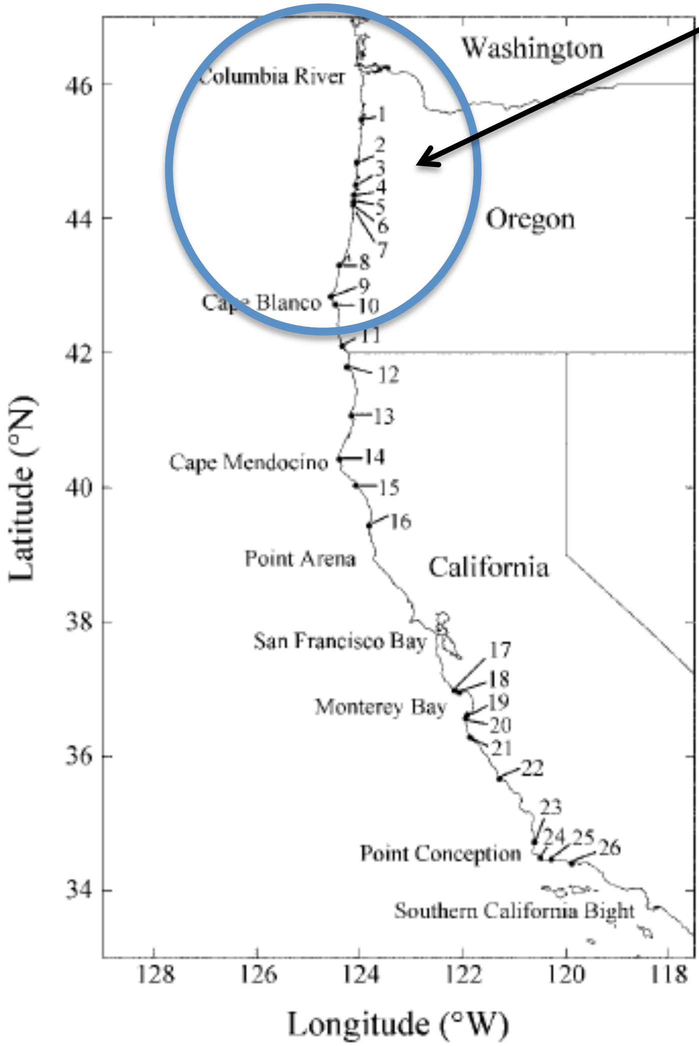
$u_E \, \delta v_G/\delta x + fu_E = T_y/\rho$

$u_E = T_y/\rho(f + \delta v_G/\delta x)$

= reduction of Ekman transport

Brink 1987, Woodson et al. 2013

Land of the upwelling jet



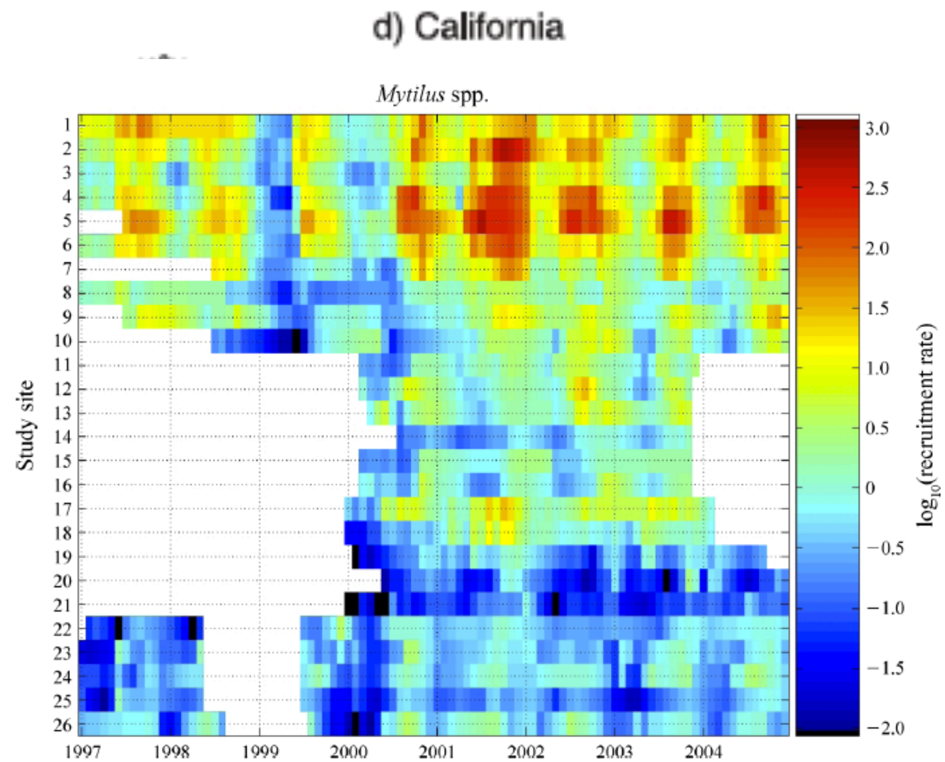
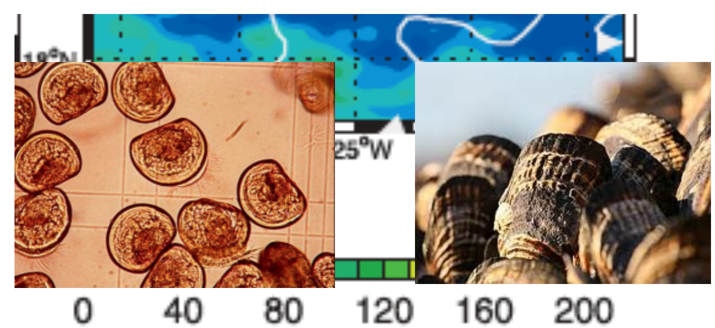
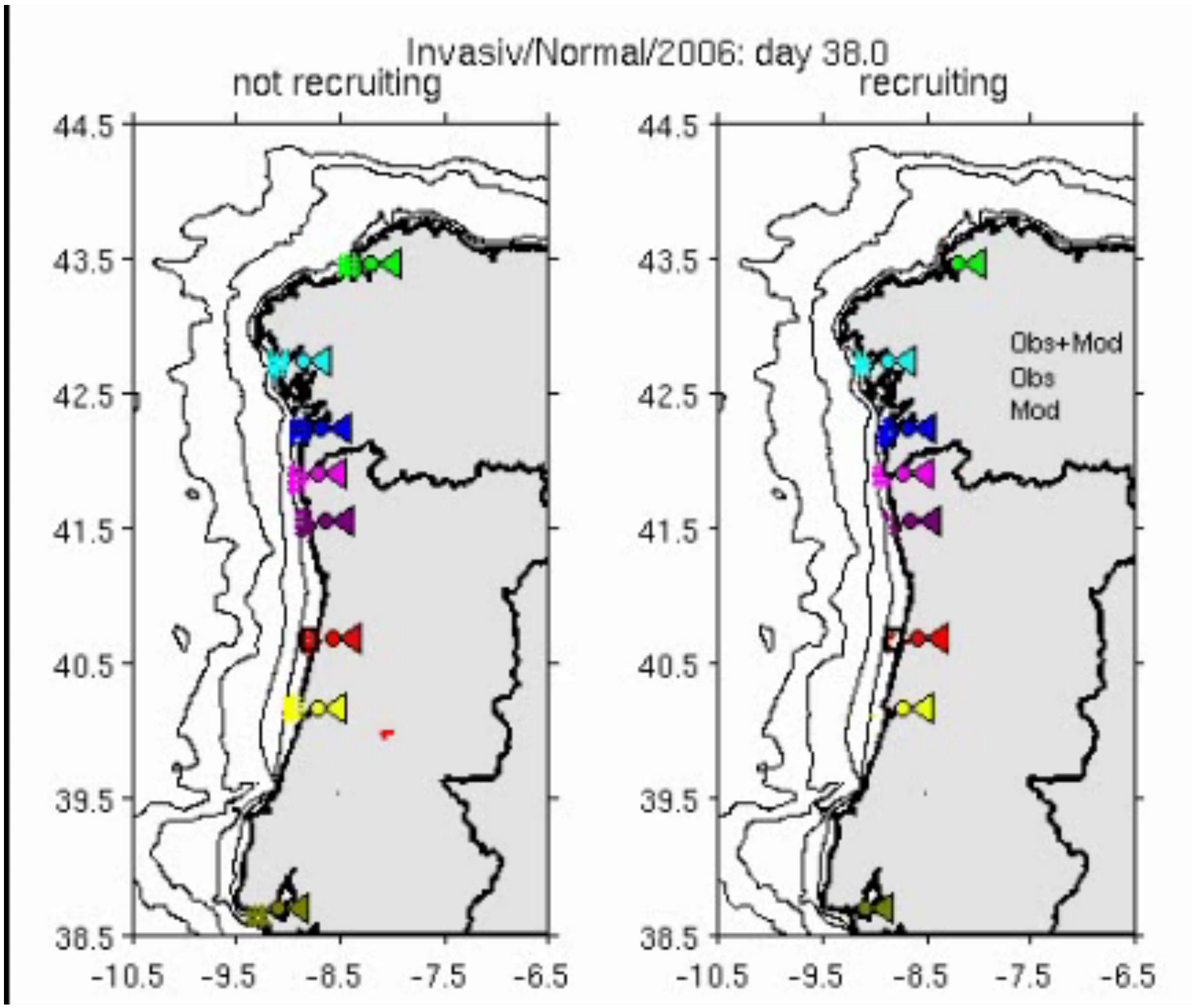


FIG. 2. Monthly larval recruitment rate time series from January 1997 to December 2004 for *Mytilus* spp. at the 26 study sites. Recruitment rate was measured as the number of recruits $\cdot d^{-1} \cdot$ (larval collector)$^{-1}$ and was transformed prior to analyses. Note the marked annual cycles across the region and the abrupt decline in larval recruitment rates south of Cape Arago (site 8). Black indicates zero recruitment, and white indicates no data.



Broitman et al., 2008, Ecol. Mono

Coastal Retention in Iberian EBC



Crab larvae

Domingues et al. 2012 PloS ONE

Conclusions

- The upwelling jet partially retains material released over the shelf, broken up by filaments
- Strong upwelling winds tatter this jet, moving material offshore in complex patters
- The response of the jet to wind is nonlinear, making predictability limited in this high energy region

“The Tattered Curtain Hypothesis Revisited”
Harrison and Siegel, submitted to LOFE

Thank you

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