Vertical distribution, transport, and delivery of barnacle larvae in the nearshore environment

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Oregon State University

PISC
Partnership for Interdisciplinary Studies of Coastal Oceans

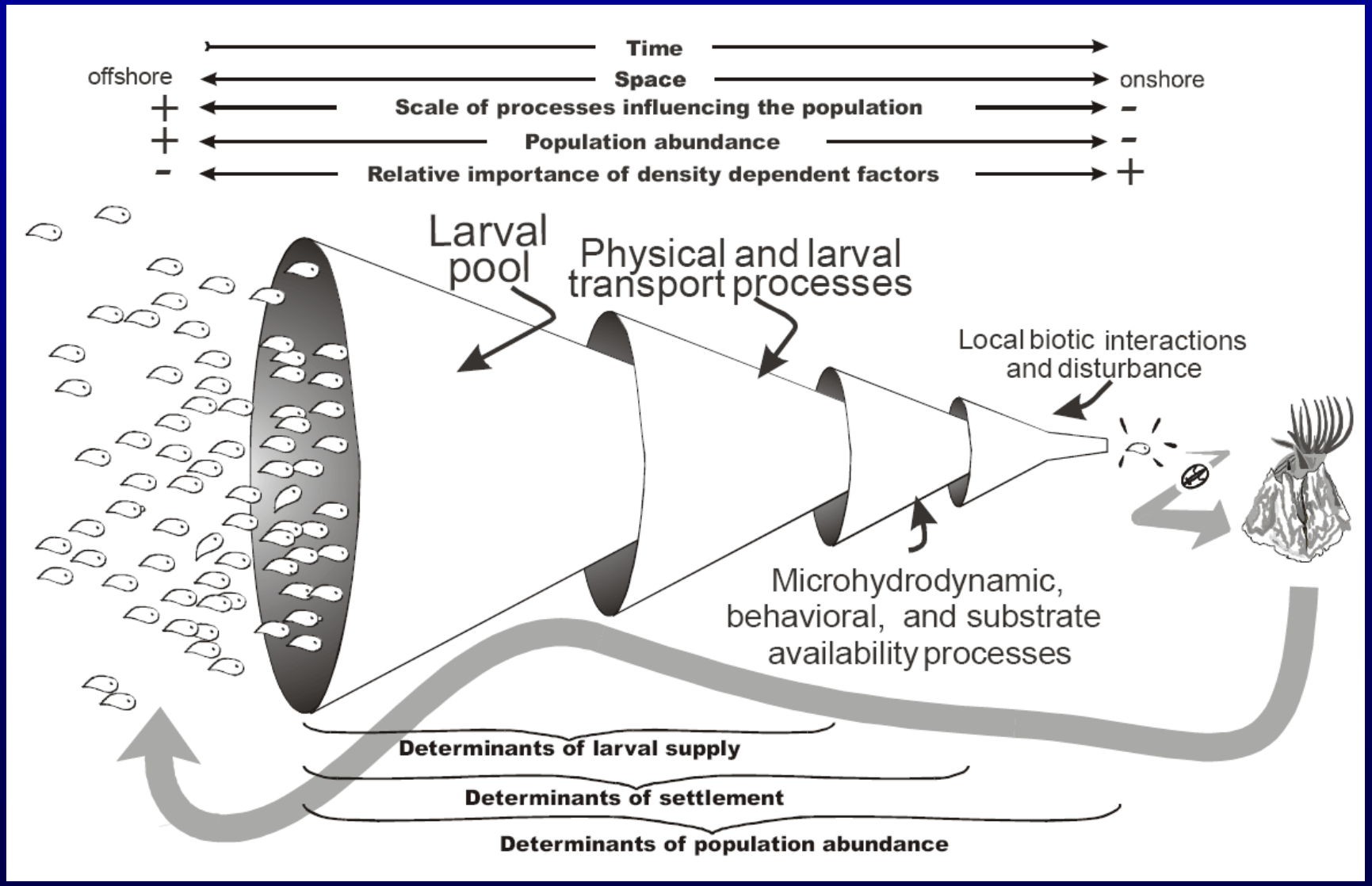
Why larvae matter

- Most marine organisms have:
  - a bipartite life-cycle
  - a dispersive larval stage
  - demographically “open” local populations

- The fate of larvae may determine patterns of adult abundance and species interaction strength

- Understanding of recruitment dynamics and population connectivity is essential for management and conservation

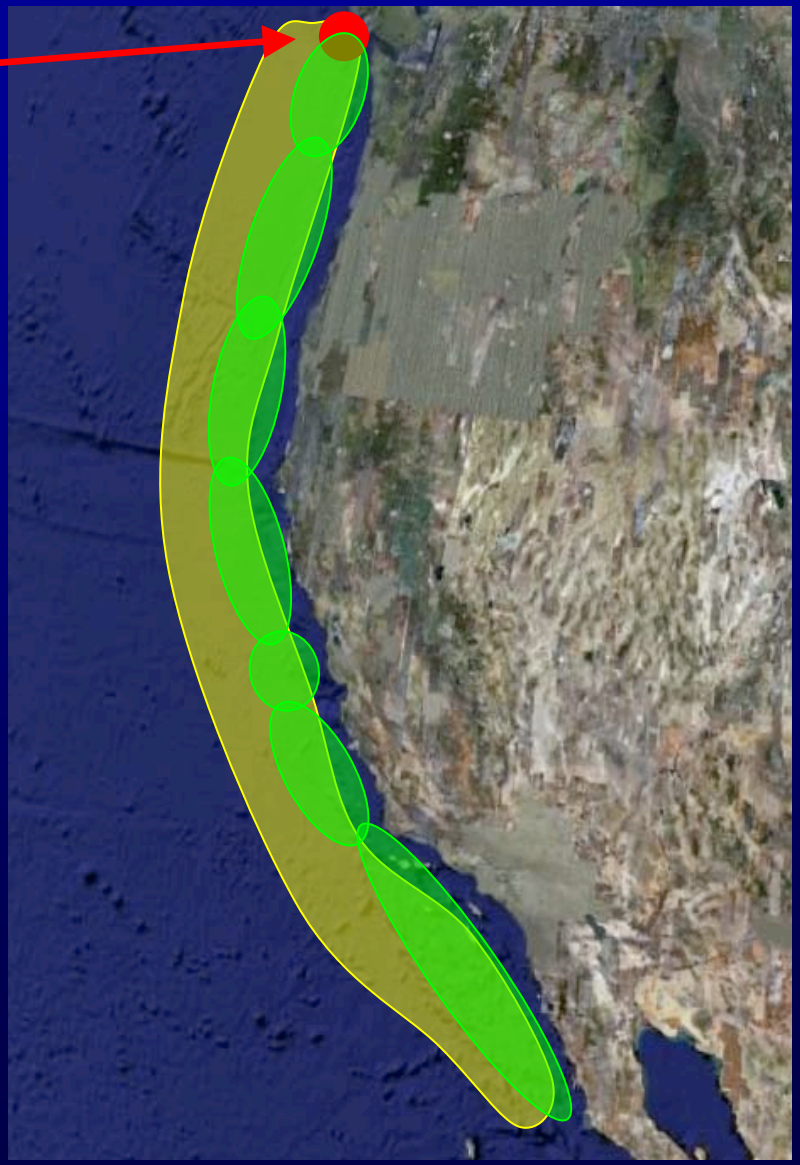
Larval pool, transport, & recruitment



(Pineda 2000)

Evolution of the larval pool concept

- Paine, Connell – species interactions (closed populations)
- Roughgarden – larval pool (completely open populations)
- Cowen, Sponaugle, Kinlan, Gaines, Sotka – limited dispersal, connectivity (metapopulation network)

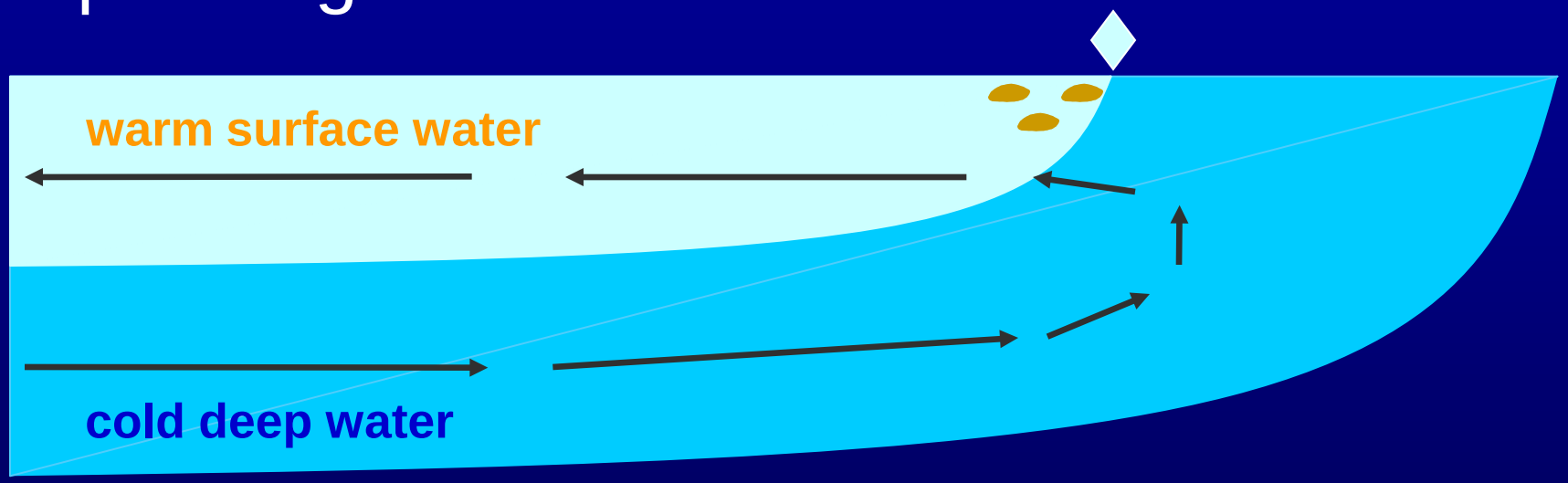


Why oceanography matters

- Most invertebrate larvae cannot effectively swim against horizontal currents.
- The water column is often stratified and has cross-shore and alongshore velocities that vary with depth.
- Vertical position relative to layers with different horizontal velocities is likely very important for larval transport and delivery.

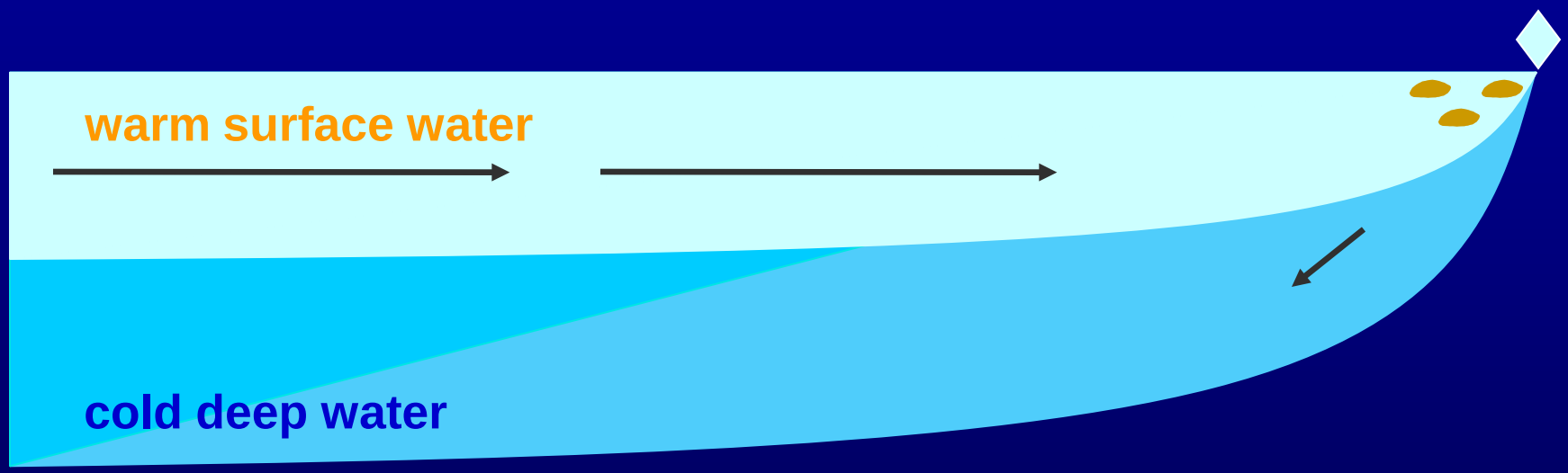
Stratified flow and larval delivery

Upwelling



Stratified flow and larval delivery

Relaxation



Hypothesis: pulses of settlement should occur during relaxation.

(Roughgarden et al. 1988, Farrell et al. 1991, Grantham *unpub.*, Dudas et al. 2009)

Project goals

- Determine larval distributions relative to transient oceanographic features (discrete sampling).
- Identify oceanographic processes and larval distributions associated with onshore delivery & settlement (temporally integrated sampling).
- Create a simple model of nearshore larval transport using data on currents & larval distributions.

Approach

- Collaborative PISCO study using collective resources, personnel, and instruments.

- Focus on physically isolated, well-studied area – northern Monterey Bay.

- Barnacles: a good model organism
  - bipartite lifecycle common to most marine species
  - abundant onshore and in the plankton
  - settlement easily quantified

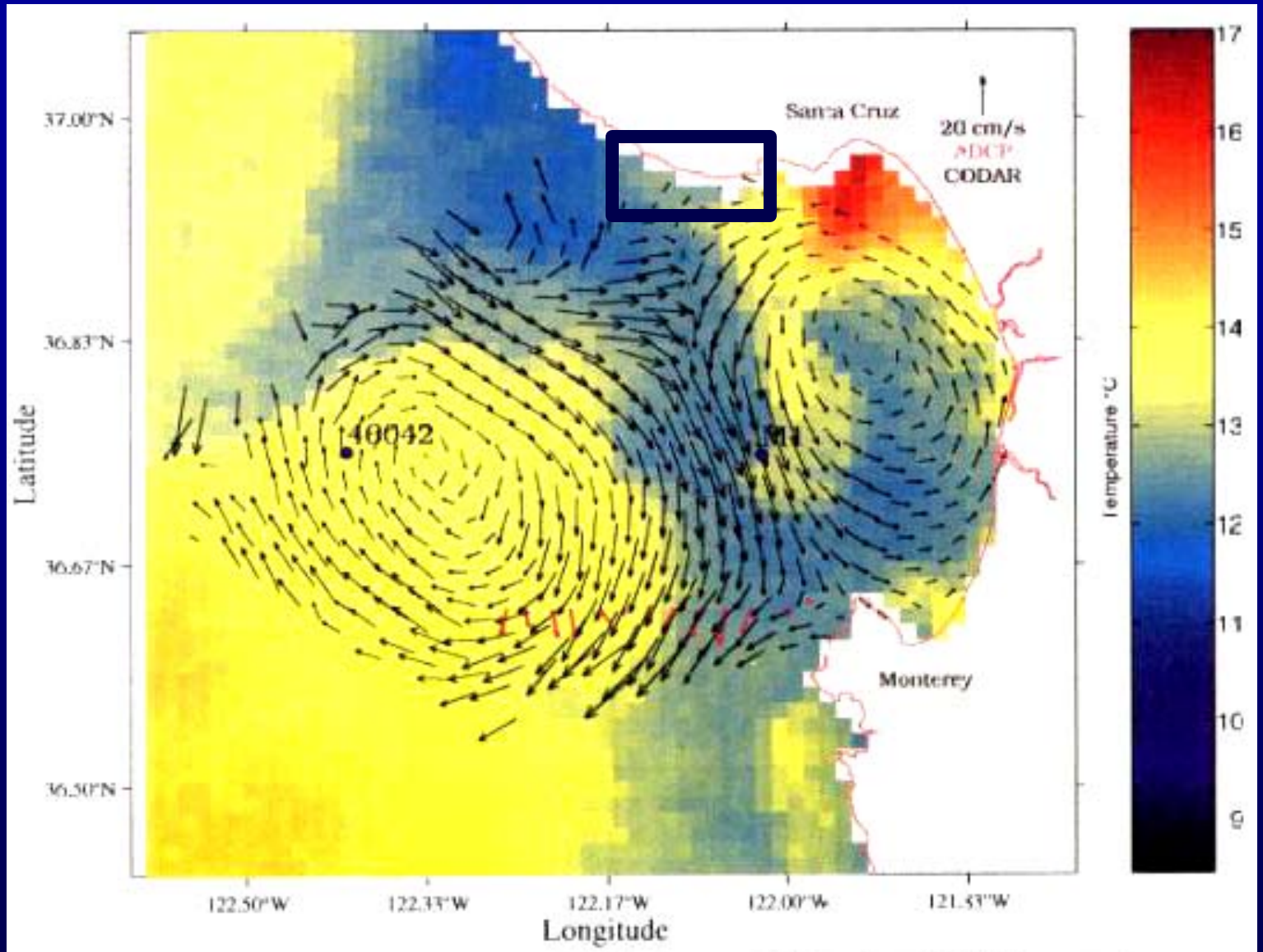


Plate 1. Average radar-derived vectors for the period [illegible] UT on August 6 to [illegible] UT on August 7, 1991 (black arrows) and average VM ADCP vectors for the period [illegible] UT on August 6 to [illegible] UT on August 7, 1991 (magenta arrows), shown with uncorrected AVHRR channel 4 surface temperatures from [illegible] UT on August 6, 1991.

From Paduan & Rosenfeld 1996 (J. Geophys. Res.)

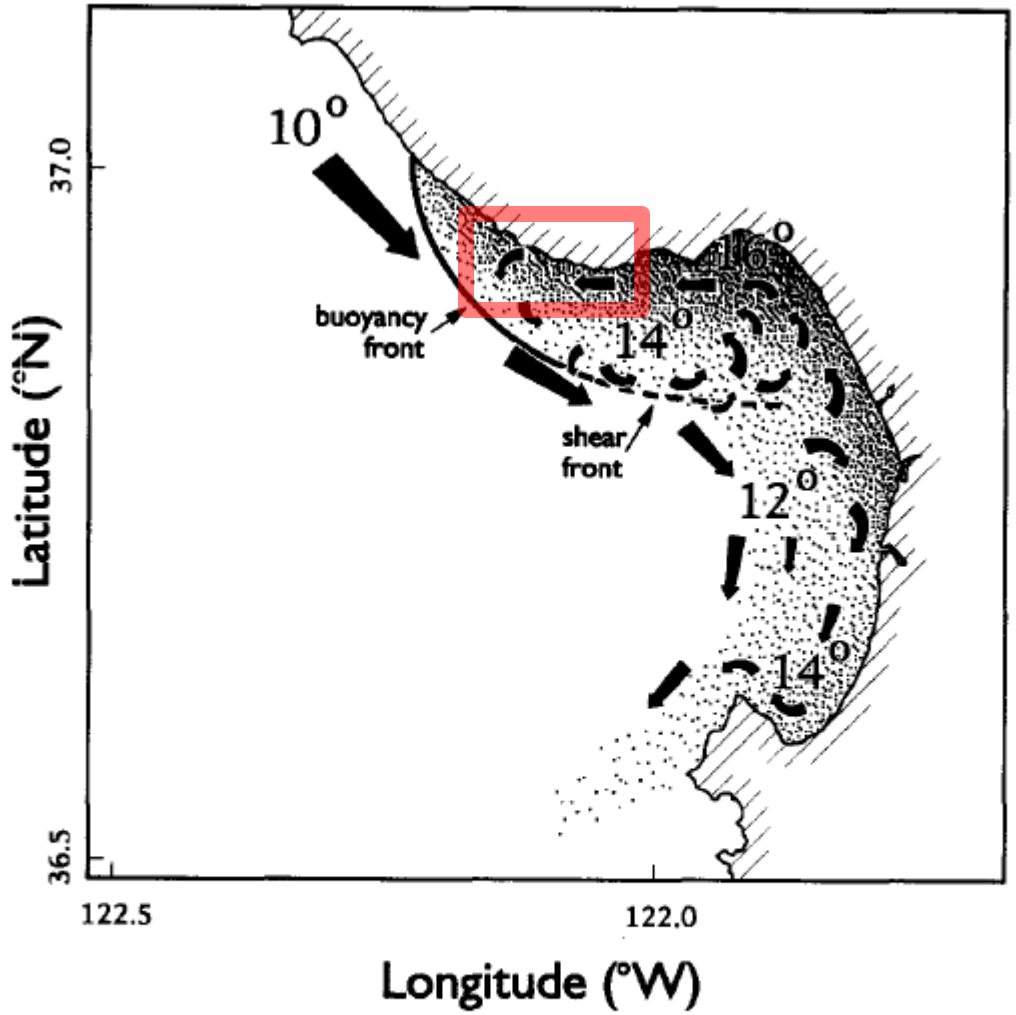
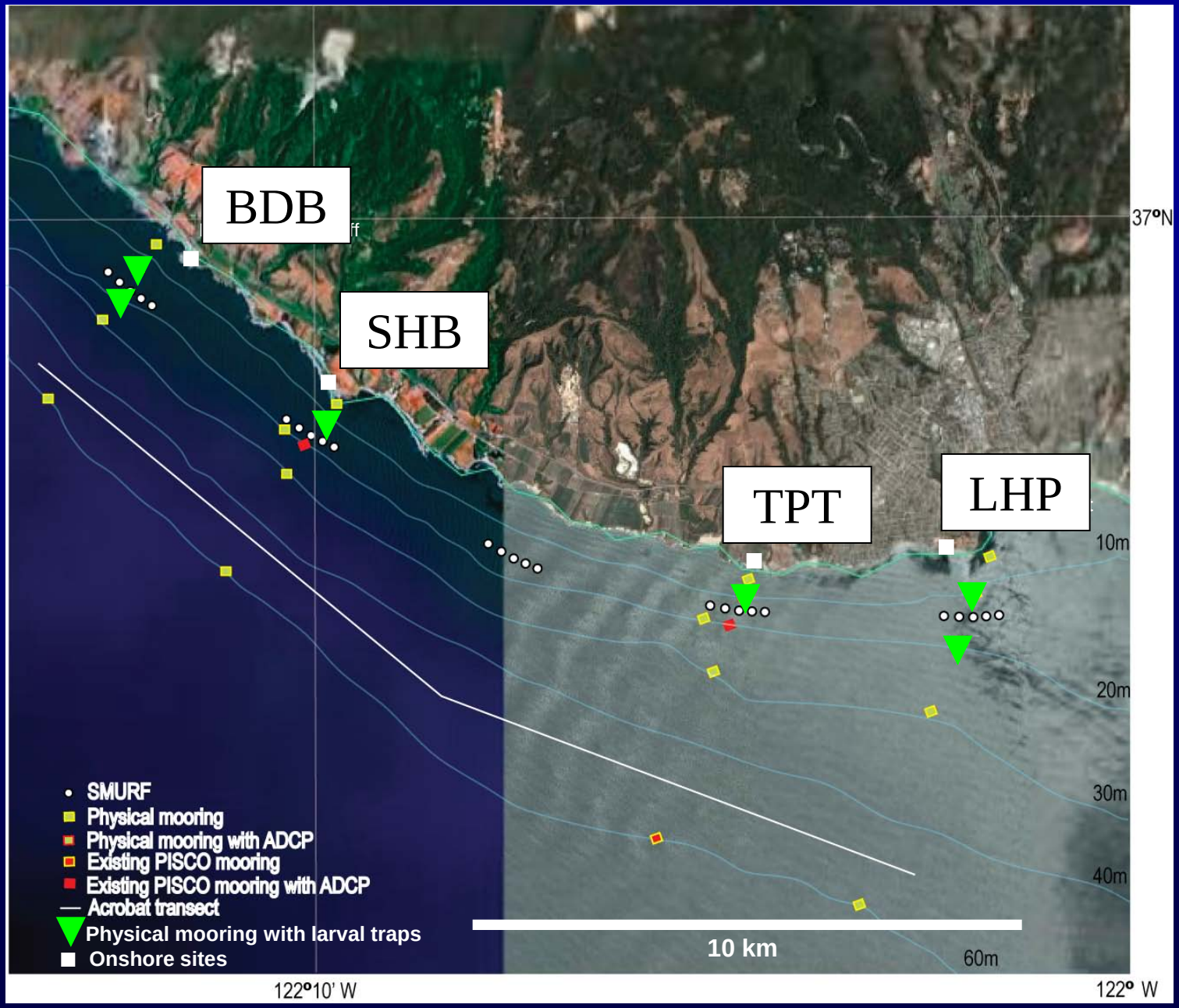


Fig. 11. Hypothetical circulation of the Monterey Bay upwelling shadow (compare to Fig. 2). Arrows represent direction and relative magnitude of flow including a north-westwardly flowing nearshore buoyancy current in the northern bay and leakage of warm water past Point Piños in the southern bay. Degree of stippling represents the magnitude of heating (temperatures are indicated).

From Graham & Largier 1997 (Cont. Shelf Res.)

2007 PISCO Biophysical Study



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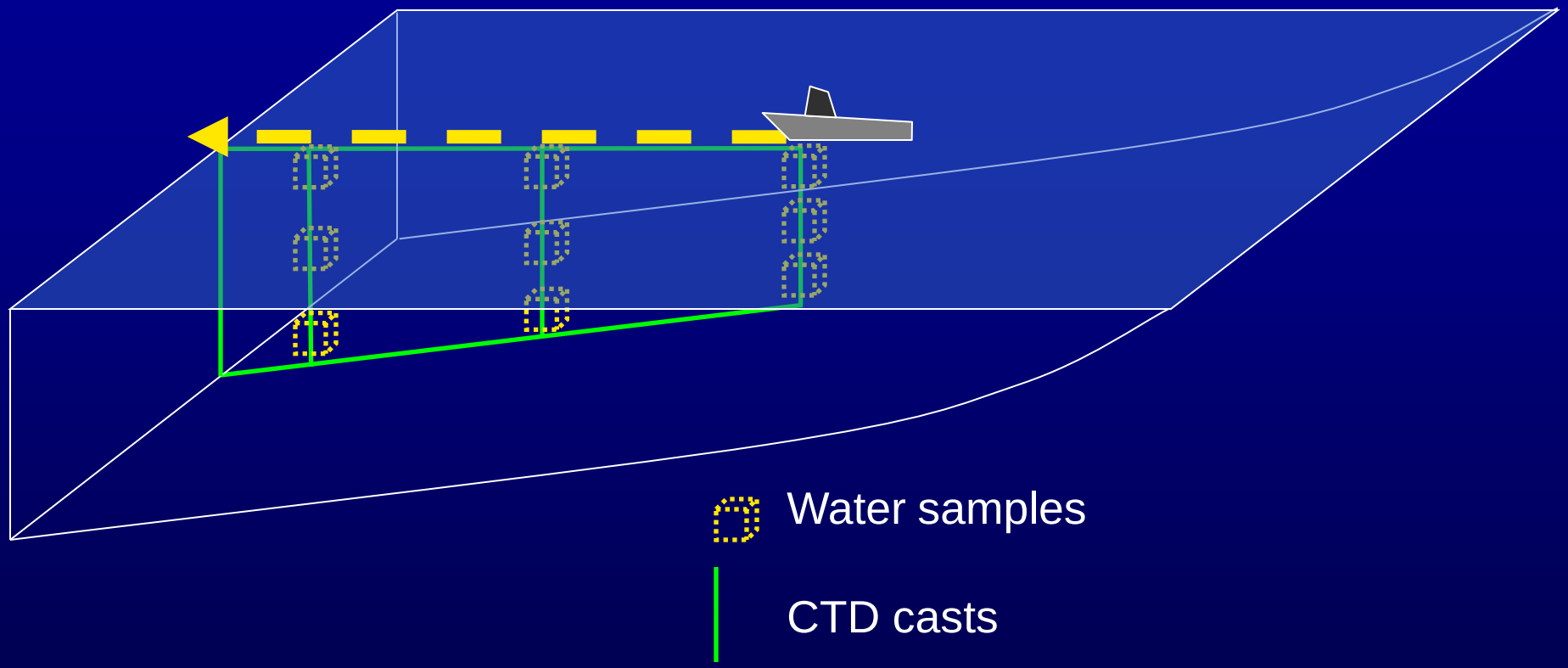
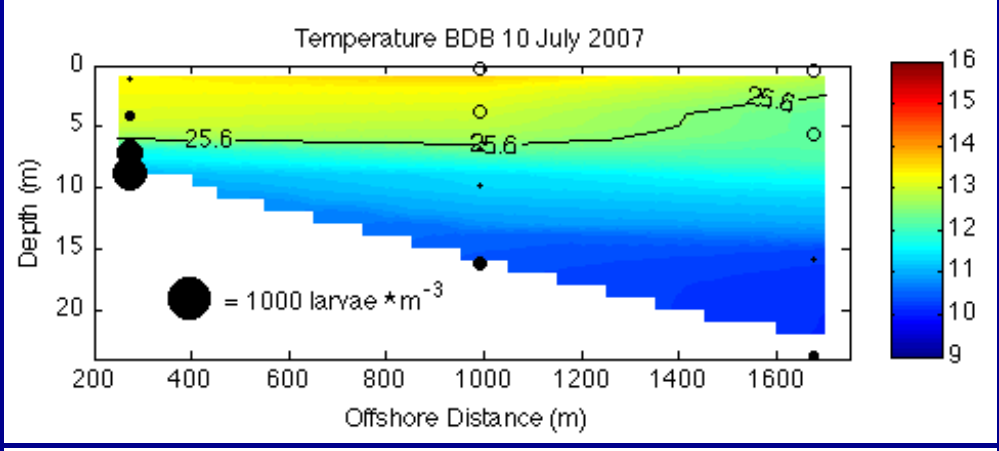
Discrete sampling scheme

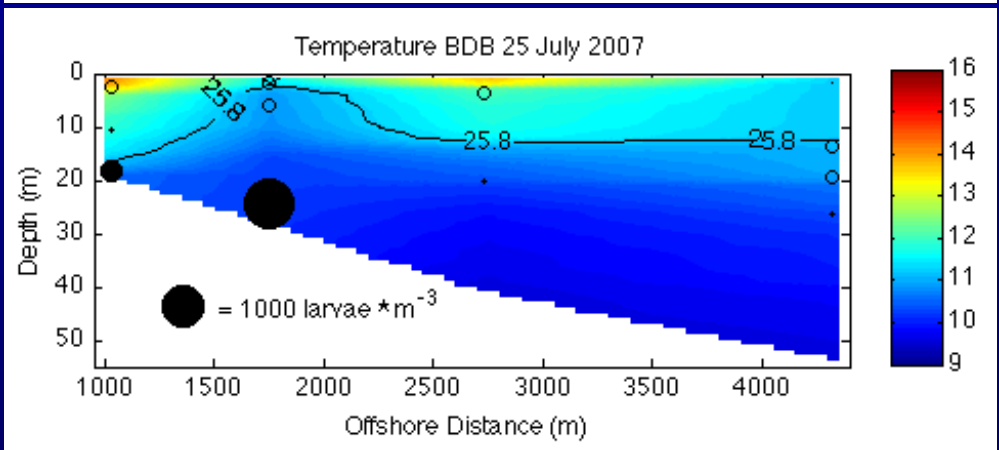


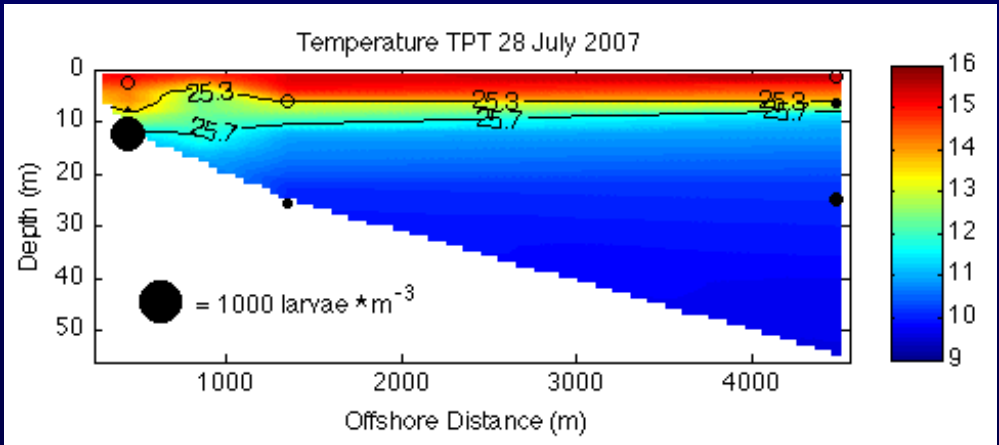
Offshore larval sampling

Balanus crenatus cyprid abundance

- Concentrated nearshore (< 2 km)
- Abundance increases with depth, greatest near bottom
- Consistent with recent findings by Mace & Morgan (2006), Shanks & Shearman (2009)







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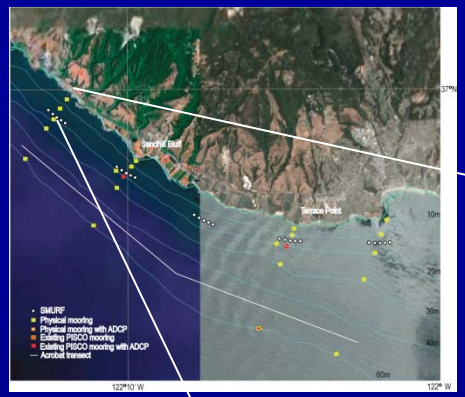
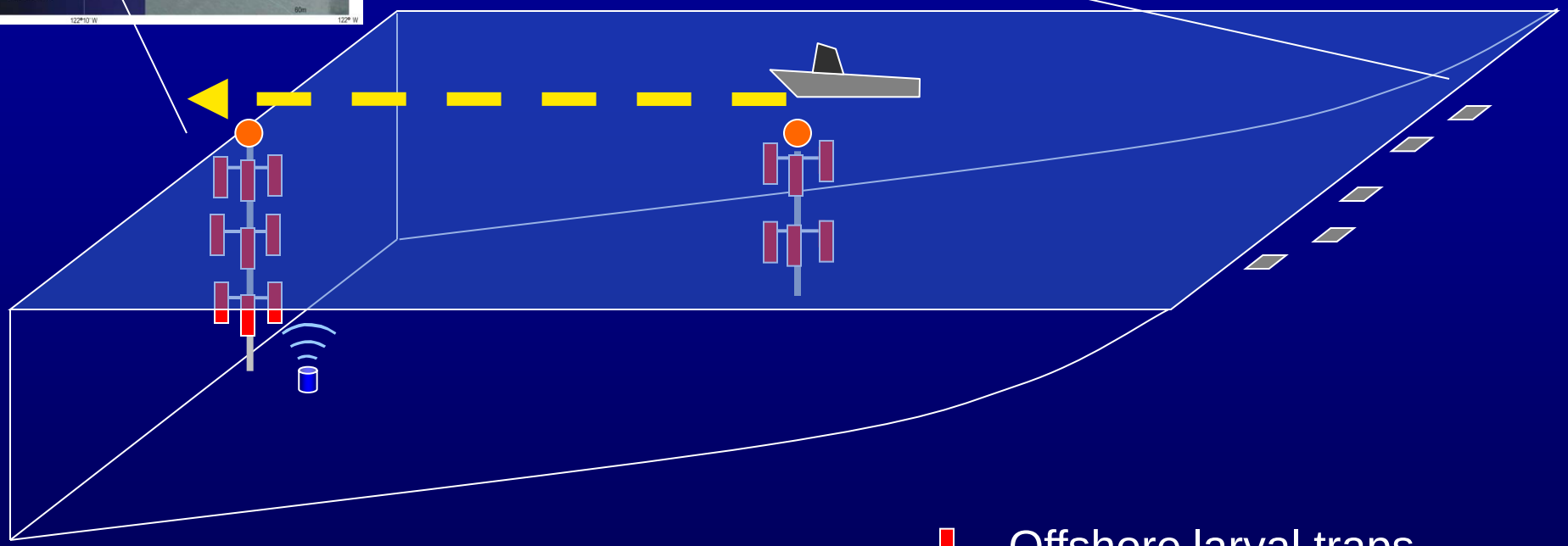
Integrated sampling scheme





Offshore larval traps

Plates (barnacle settlement)

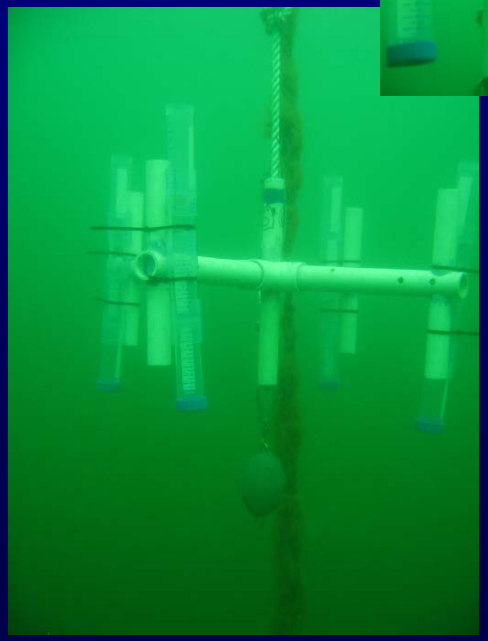
Buoy

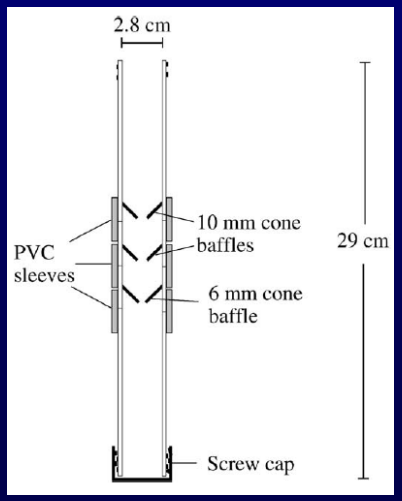
ADCP

Settlement plates & larval traps

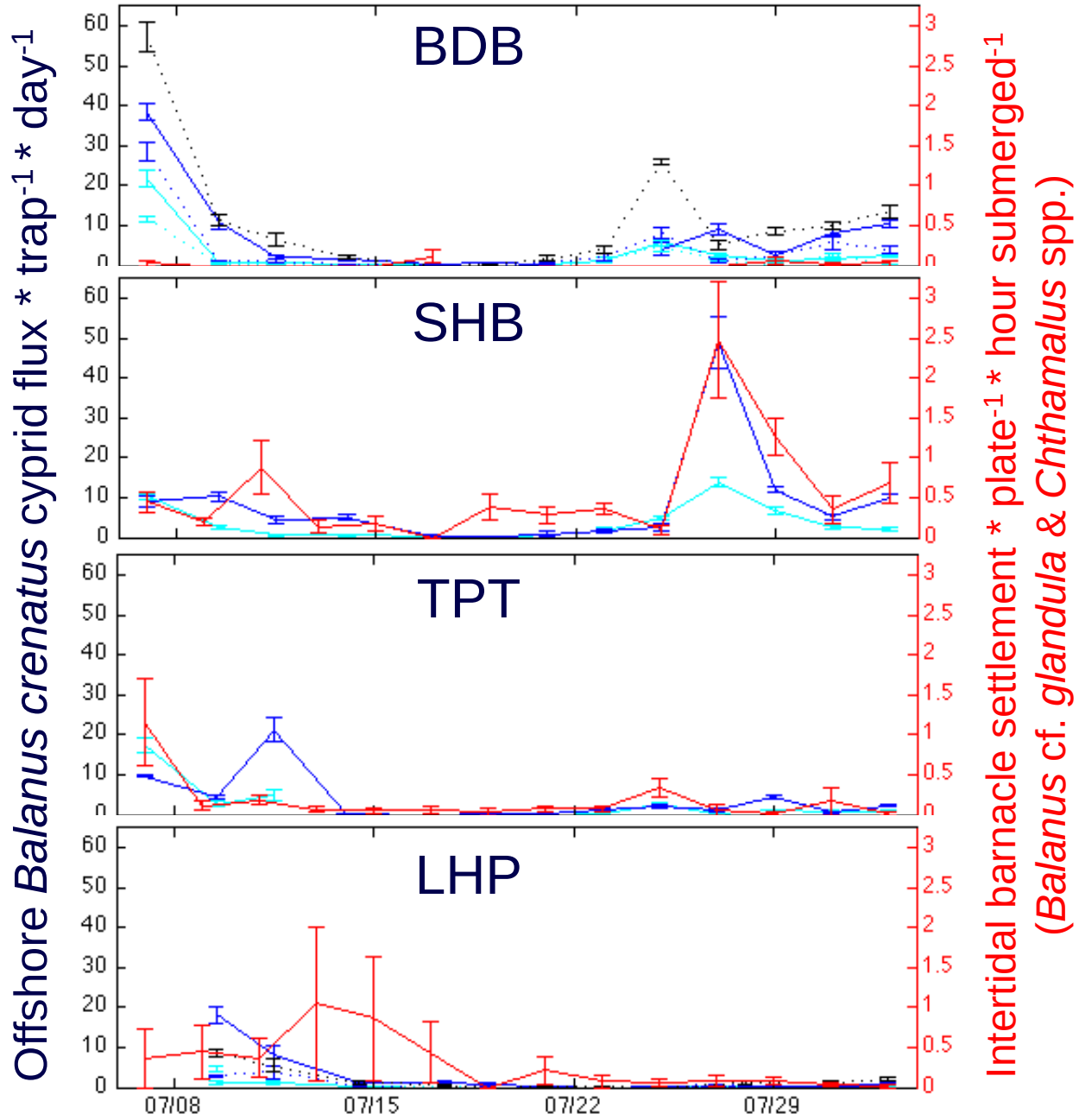
Onshore

Offshore





(Todd 2003)



Correlation w/ settlement

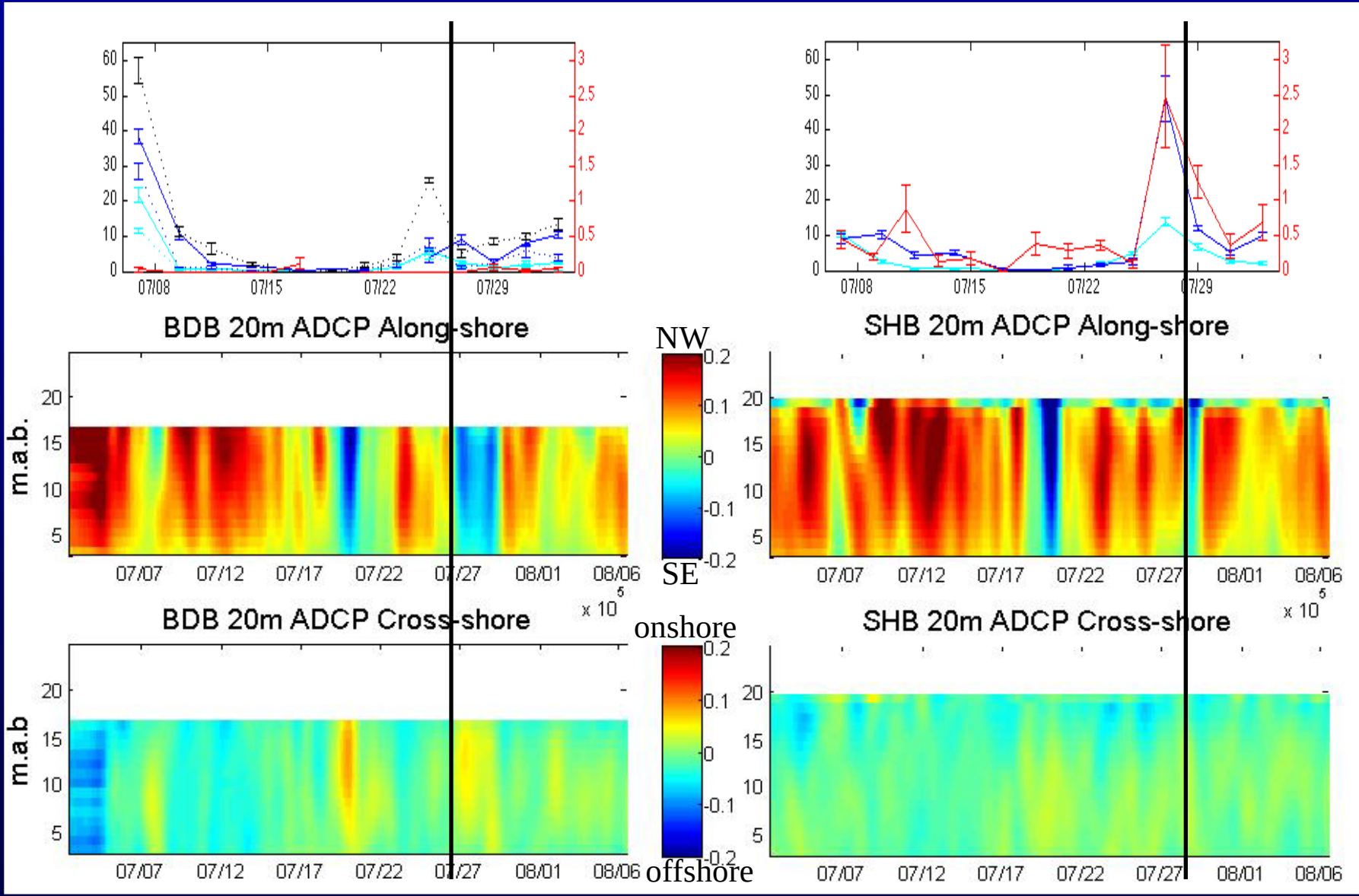
ns

1m R_s=0.48*
7m R_s=0.61*

1m R_s=0.58*

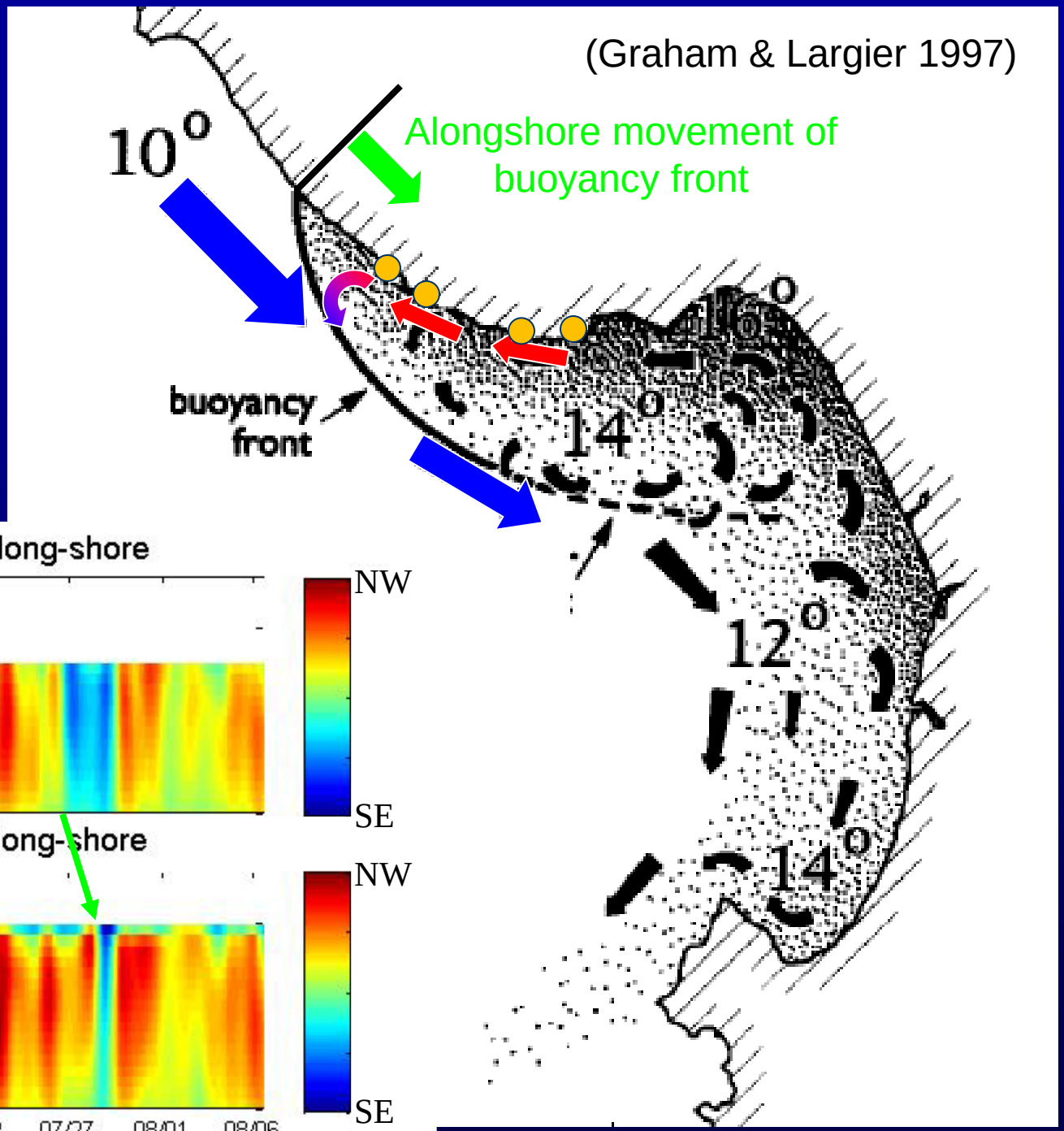
1m R_s=0.83*
7m R_s=0.58*

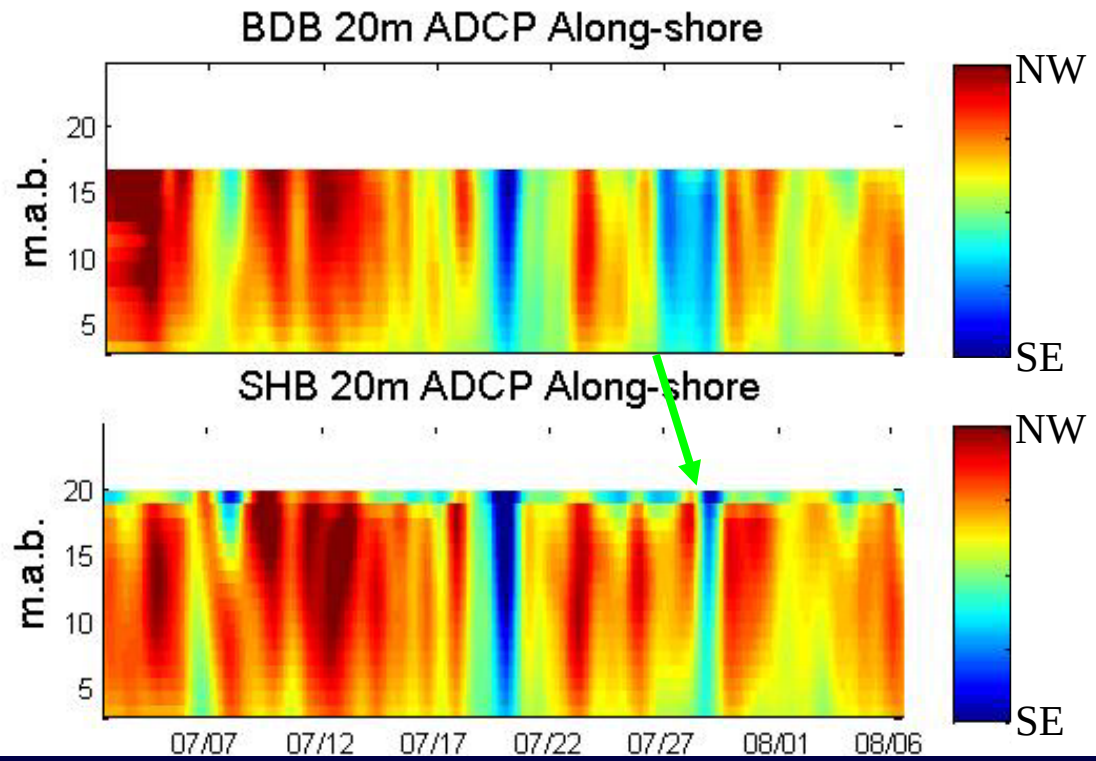
Larval flux and currents



Warm (northwestward current) = front north of mooring

Cool (southeastward current) = front south of mooring





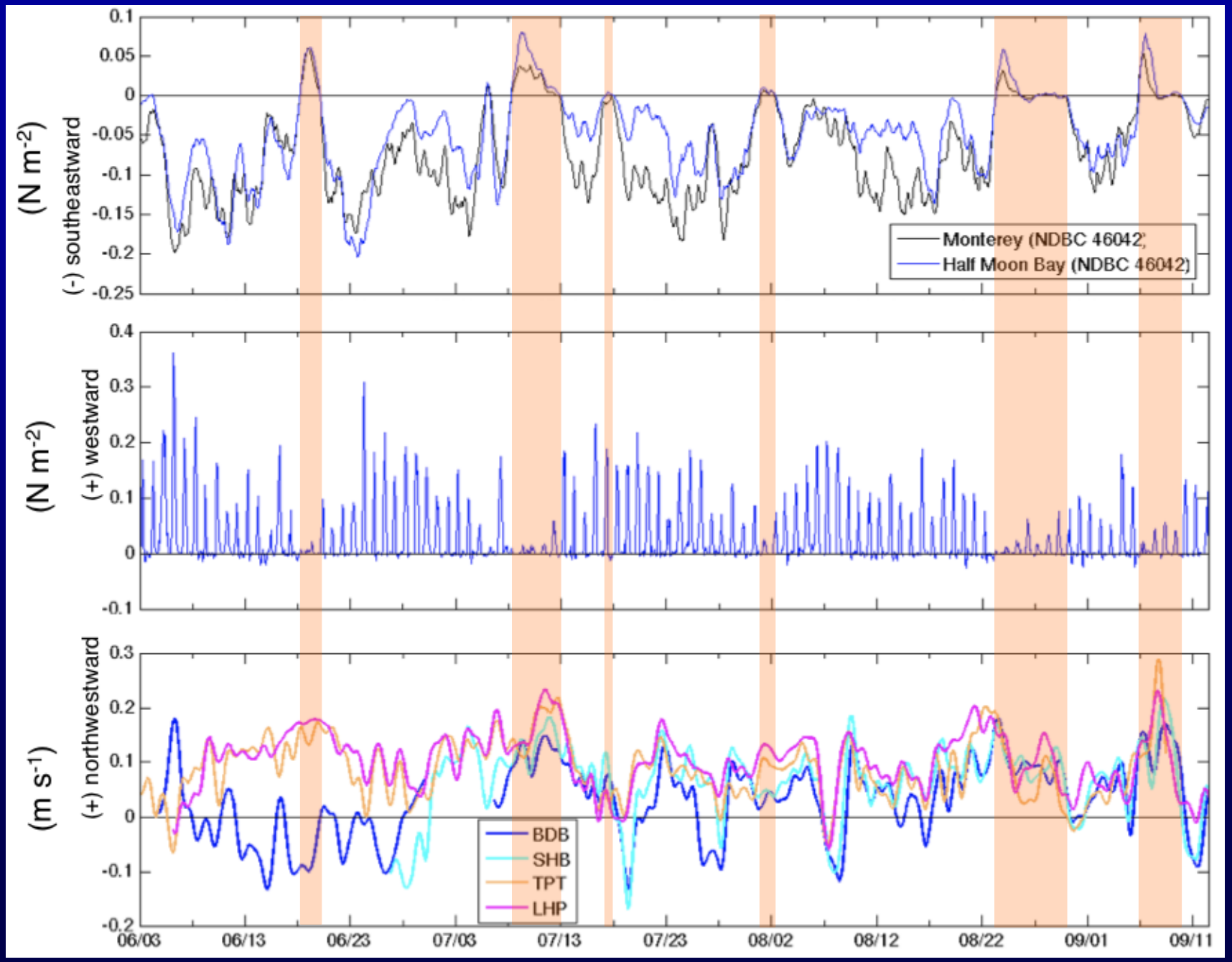
Categorizing physical processes

- Regional relaxation:
  - decreased offshore upwelling winds (NDBC 46042)
- Front passage:
  - switch to [southeastward/northwestward] alongshore currents
  - rapid [cooling/warming] of entire water column
- Diurnal upwelling:
  - strong local diurnal upwelling winds (onshore weather station)
  - currents: offshore near surface, onshore at depth, southeastward alongshore
  - significant stratification that decreases along with temperature in upper water column

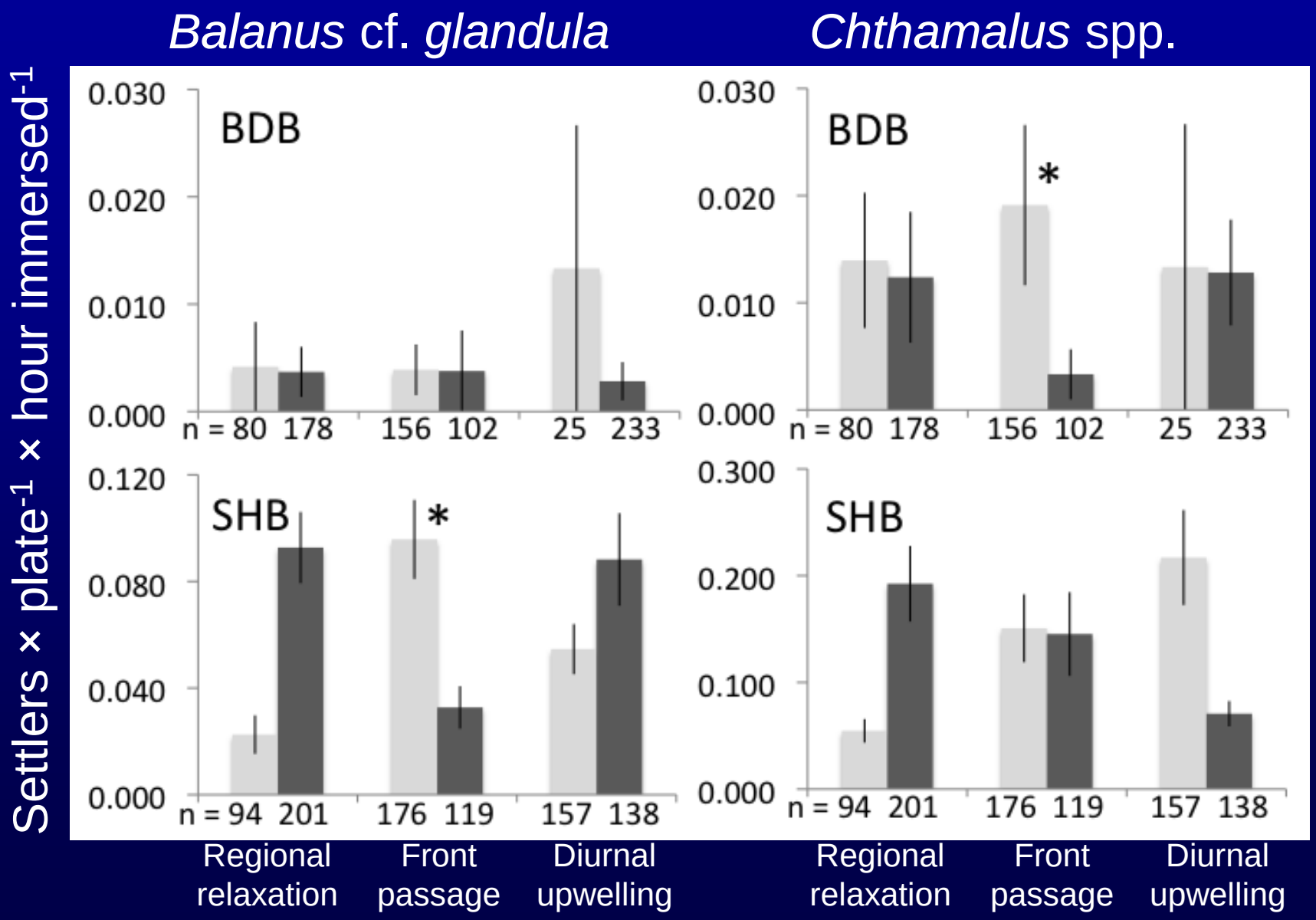
Regional wind stress

Local wind stress

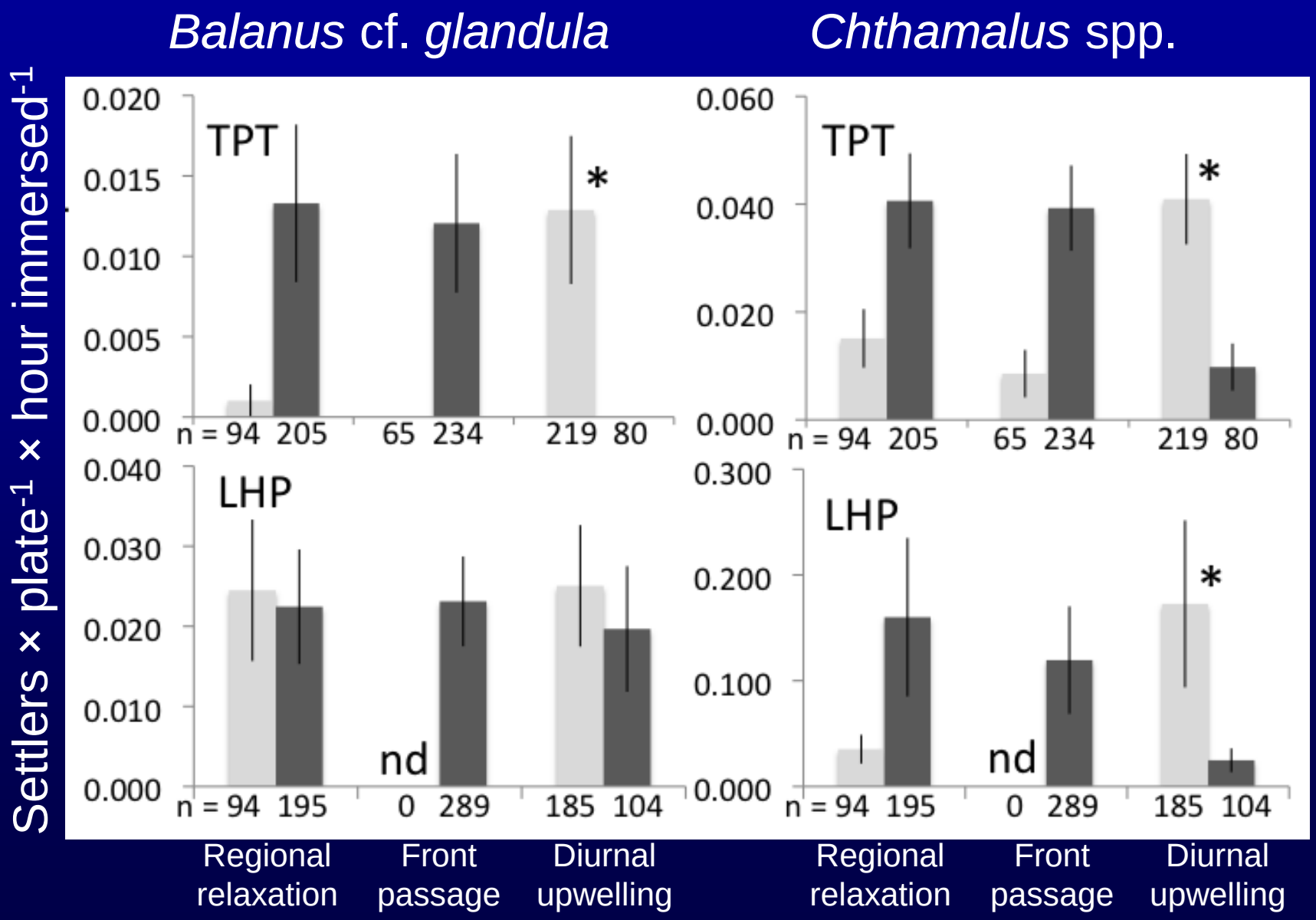
Depth-averaged current velocity



Association with processes



Association with processes



Conclusions

- Offshore abundance of subtidal barnacle cyprids was 40-70 times greater than that of intertidal species – which was so low that patterns of abundance were difficult to determine.

- Patterns of intertidal barnacle settlement were correlated with those of subtidal barnacle cyprid flux on moorings.

- Sequential peaks in settlement and offshore flux at two sites corresponded passage of the buoyancy front.

- Settlement was associated with passage of convergent buoyancy front (at BDB & SHB) and diurnal upwelling (at TPT & LHP).

Project goals

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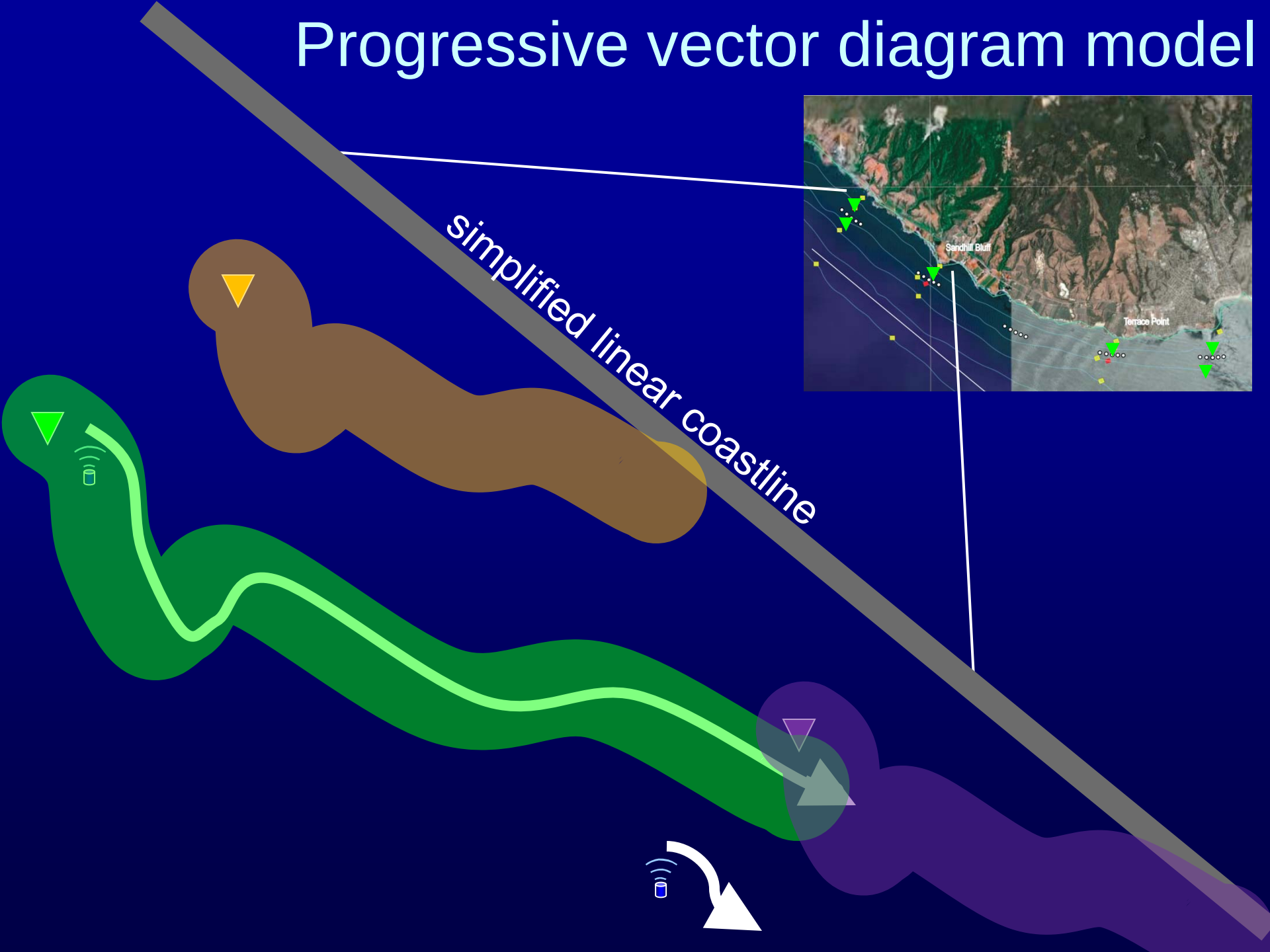
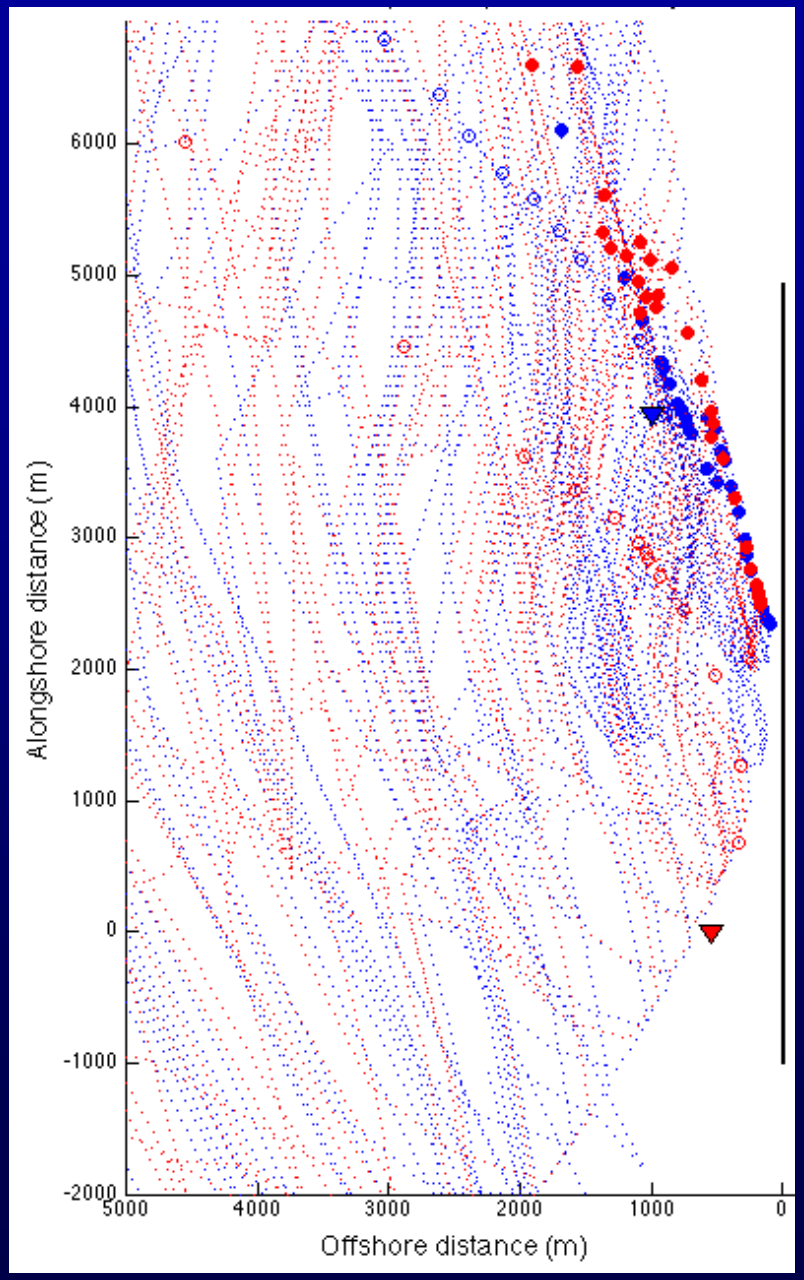
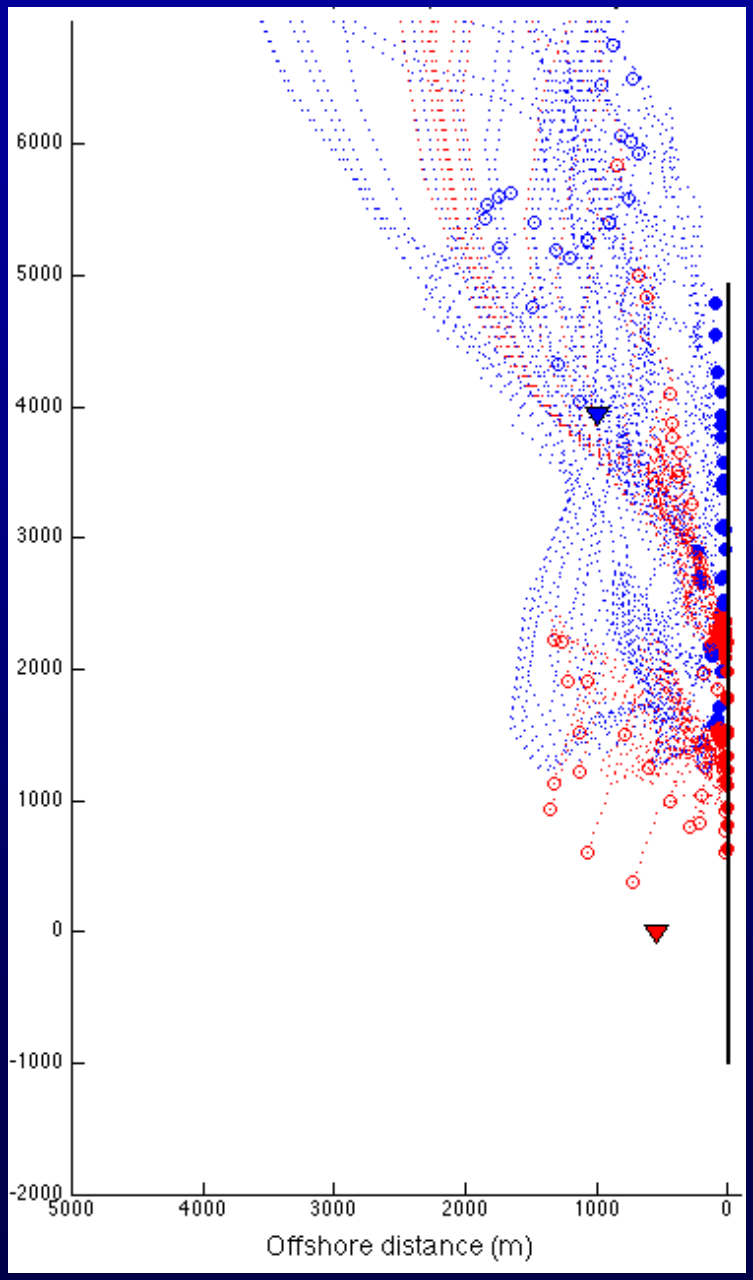
Progressive vector diagram model



Near surface



Near bottom



Summary

- Instantaneous sampling (pump):
  - subtidal barnacle larvae are concentrated nearshore at depth.
- Integrated sampling (plates and traps):
  - Intertidal barnacle settlement is correlated with subtidal barnacle cyprid flux on nearshore moorings.
  - Physical processes appear to be involved in nearshore transport and delivery and to vary by site.
    - Passage of convergent buoyancy front at outer sites (BDB & SHB)
    - Diurnal upwelling at inner sites (TPT & LHP)
- Modeling (preliminary):
  - Onshore transport of passive particles strongest at depth.
  - Timing of onshore delivery of passive particles corresponds to settlement.

Working hypotheses

- Competent barnacle larvae (cyprids) are generally found nearshore at depth.
- Settlement pulses occur when processes stratify the innermost shelf (just outside the surf zone) and facilitate cross-shore circulation (specifically onshore transport at depth).

Future objectives

- Refine and explore model to gain insight into the impact of each physical process on particle trajectories.
- Compare model output versus observed settlement and larval trap flux.

Acknowledgements

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Committee members
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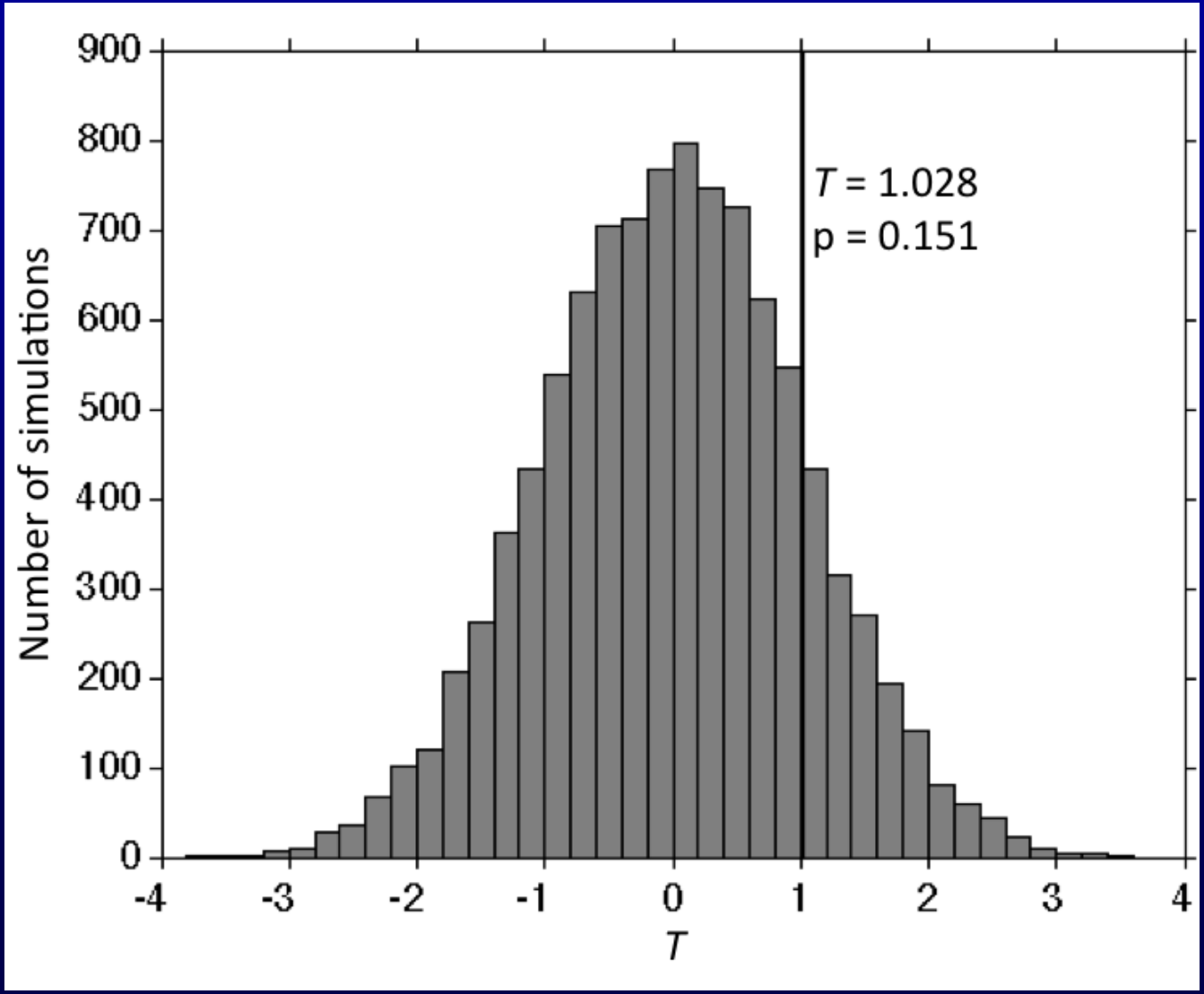
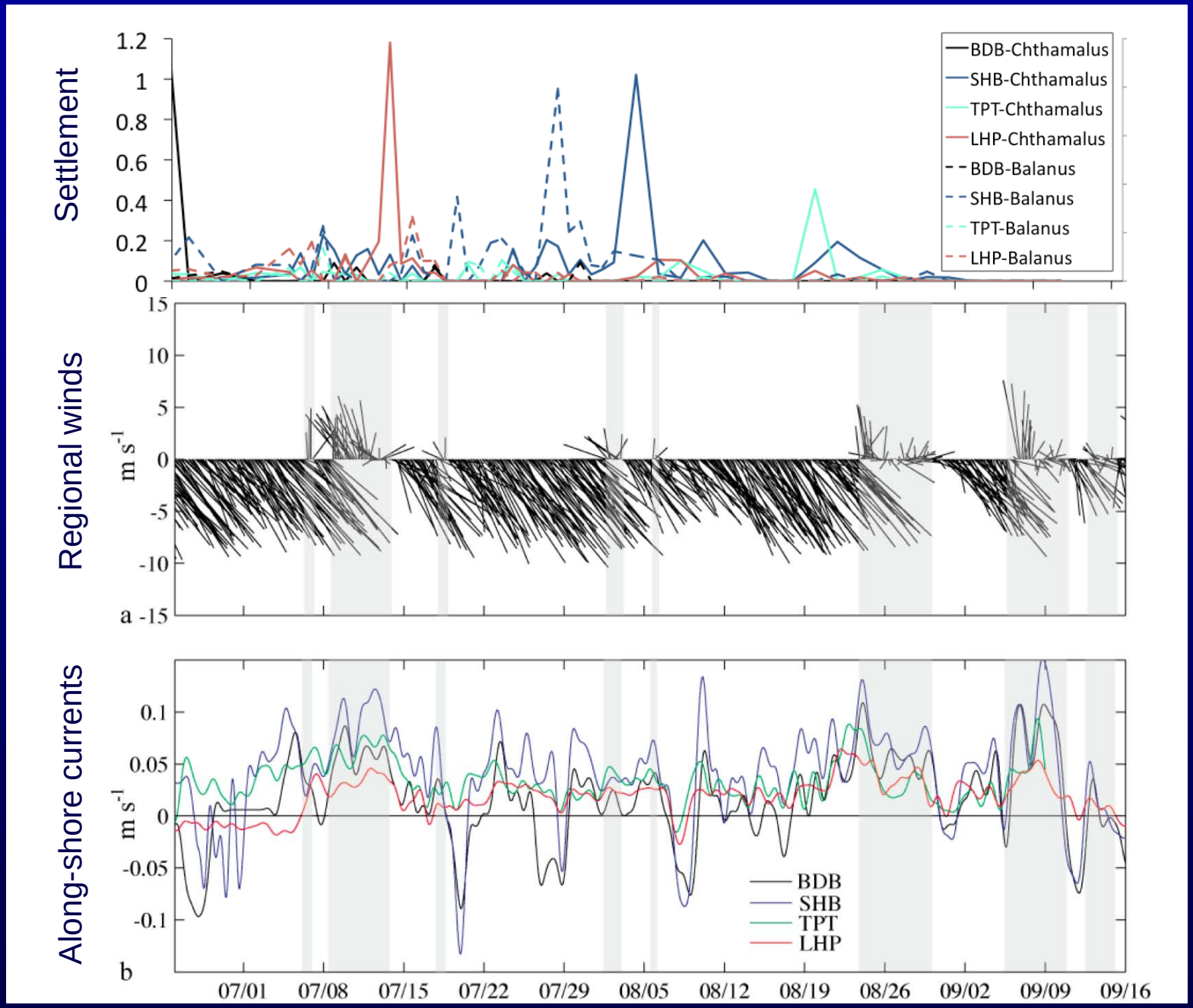
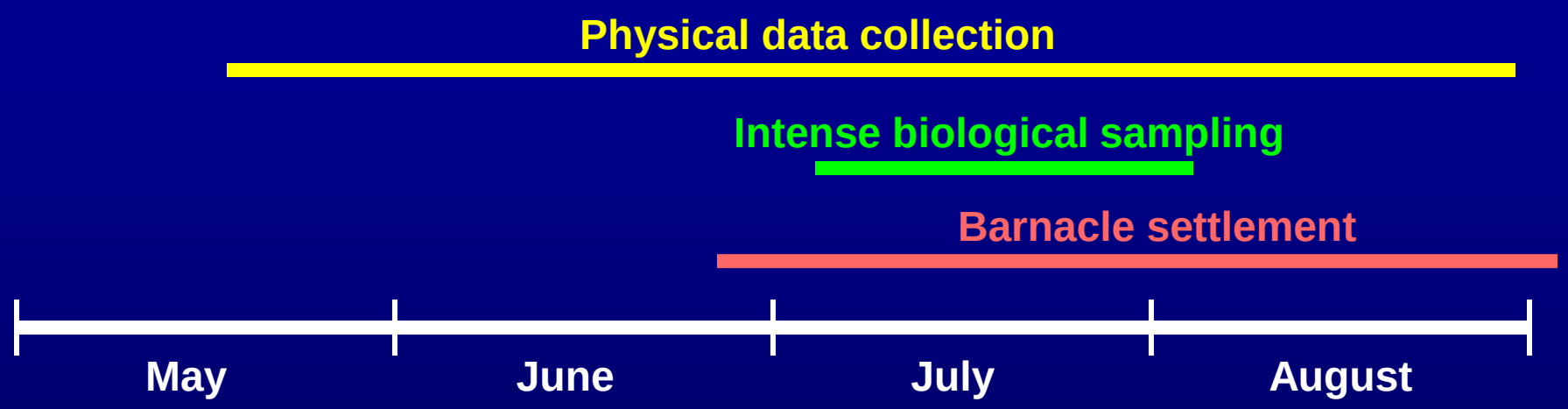
Superposed epoch analysis




Settlement
1.2
1
0.8
0.6
0.4
0.2
0
BDB-Chthamalus
SHB-Chthamalus
TPT-Chthamalus
LHP-Chthamalus
BDB-Balanus
SHB-Balanus
TPT-Balanus
LHP-Balanus
Regional winds
15
10
5
0
-5
-10
-15
m s-1
a
Along-shore currents
0.1
0.05
0
-0.05
-0.1
m s-1
b
BDB
SHB
TPT
LHP
07/01
07/08
07/15
07/22
07/29
08/05
08/12
08/19
08/26
09/02
09/09
09/16

Study sampling timeline

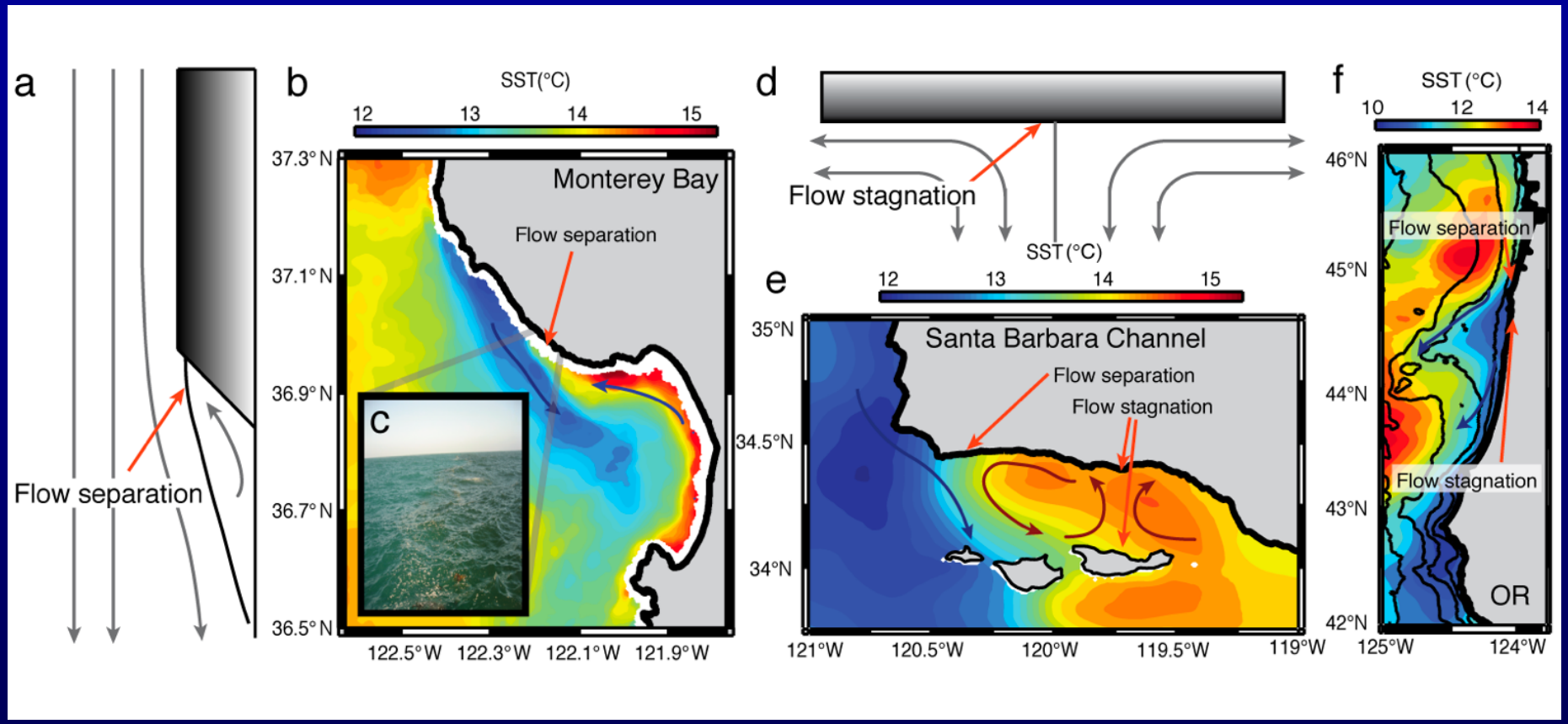


Continuous physical data
- ADCP
- Temp/salinity loggers

Instantaneous sampling
- CTD/Acrobat profiles
- Larval pump samples

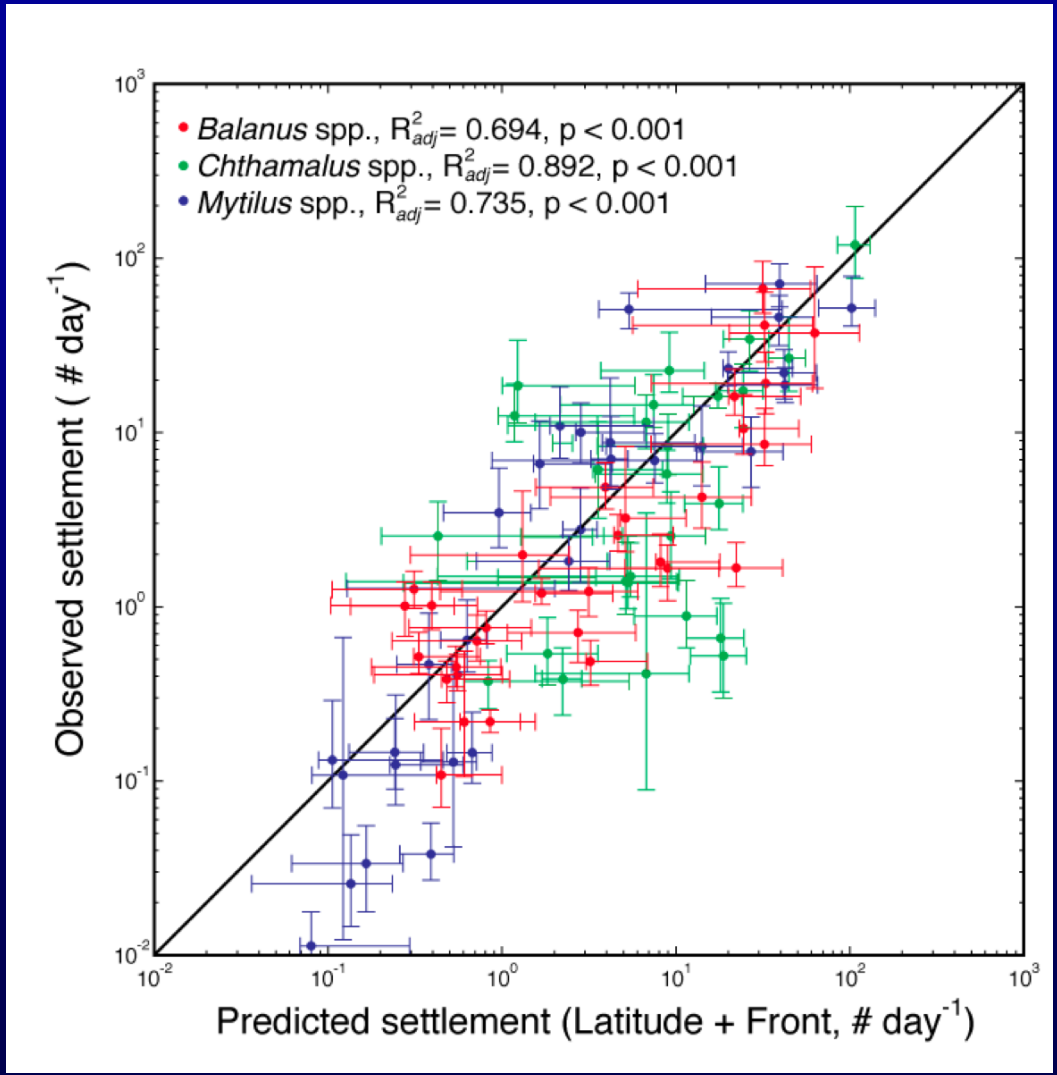
Integrated sampling
- Onshore larval supply
- Offshore larval flux
- Onshore barnacle settlement

Generality of convergent fronts



(Woodson et al. *submitted*)

Front probability predicts settlement



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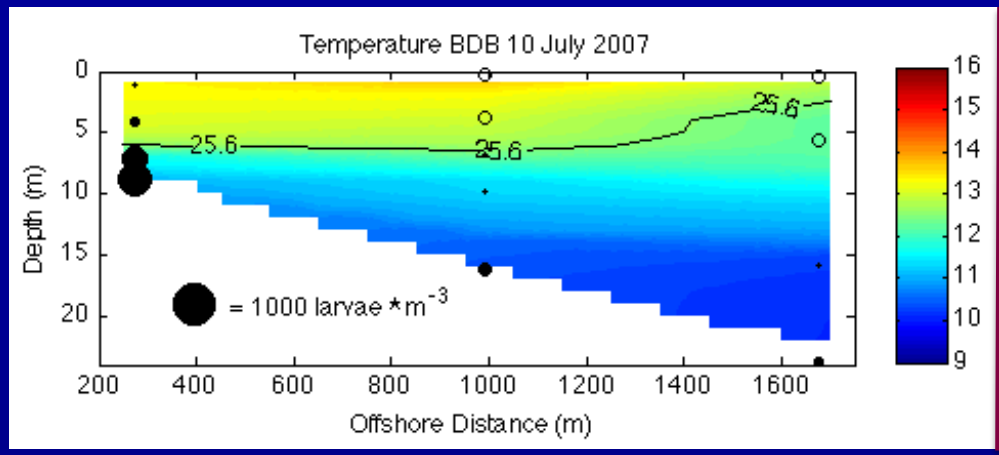
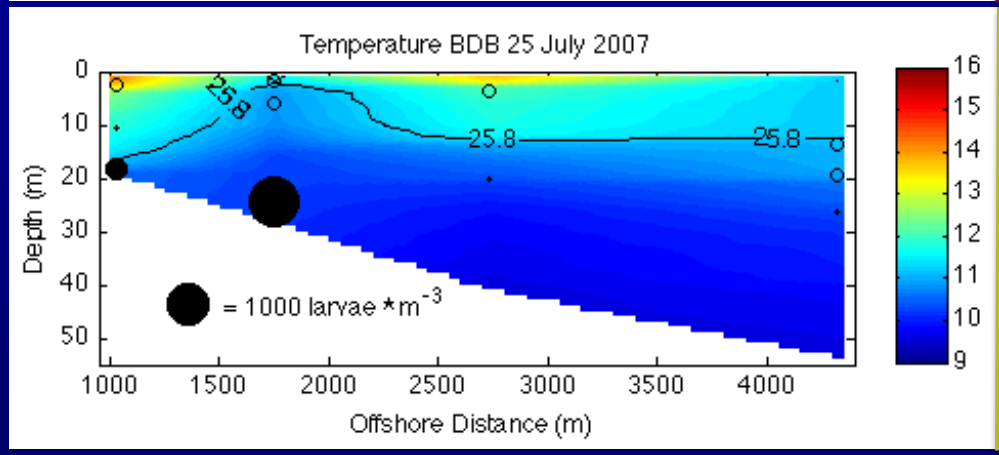
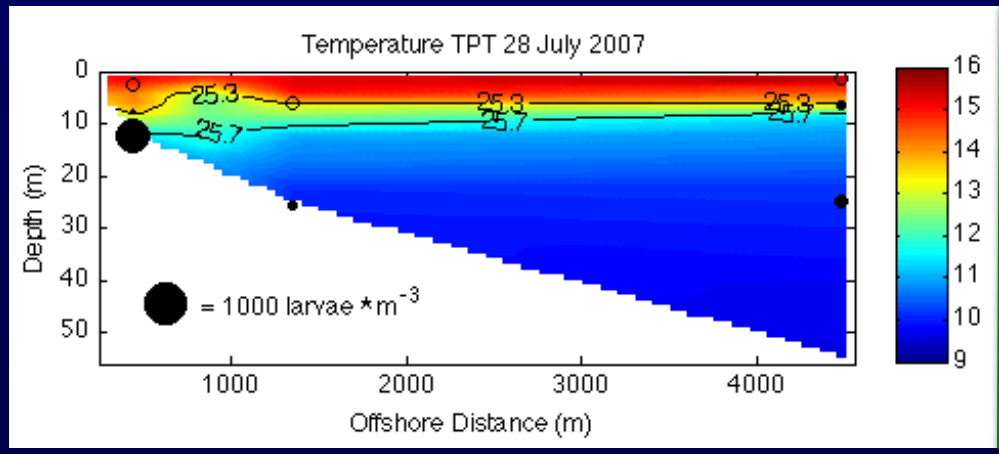
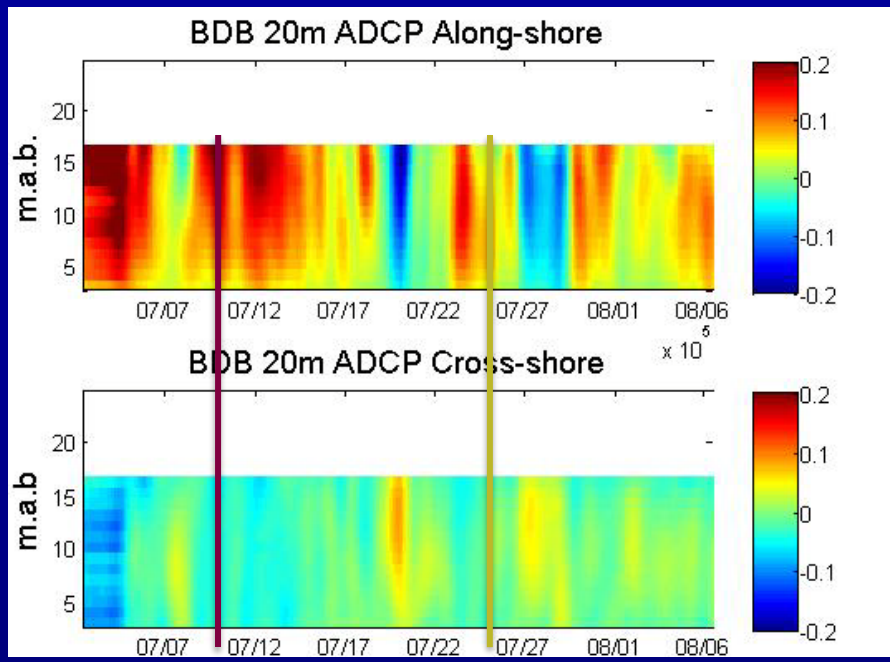
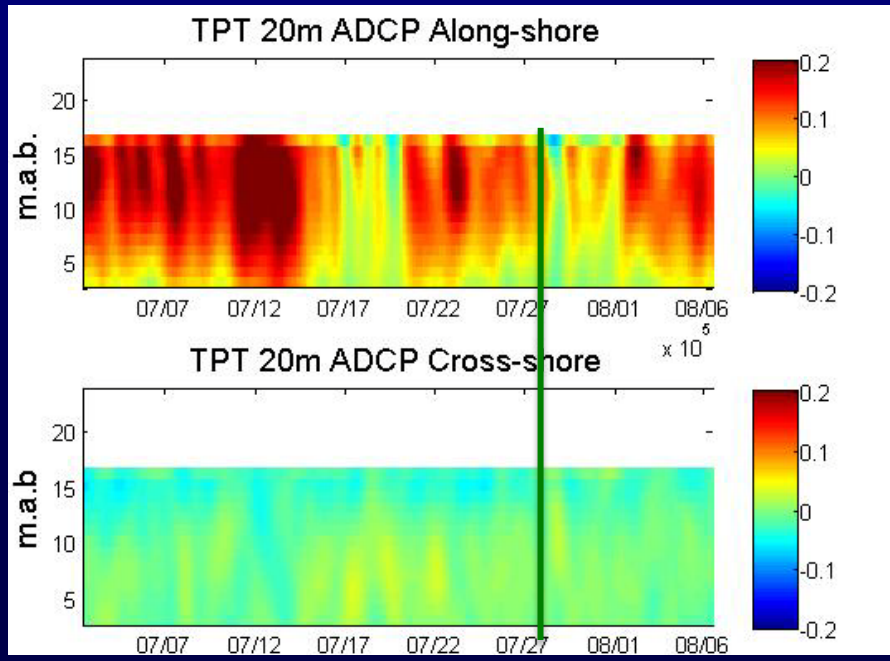

Temperature BDB 10 July 2007
Depth (m)
Offshore Distance (m)
25.6
= 1000 larvae *m^-3


Temperature BDB 25 July 2007
Depth (m)
Offshore Distance (m)
25.8
= 1000 larvae *m^-3


Temperature TPT 28 July 2007
Depth (m)
Offshore Distance (m)
25.3
25.7
= 1000 larvae *m^-3


BDB 20m ADCP Along-shore
m.a.b.
BDB 20m ADCP Cross-shore
m.a.b
07/07
07/12
07/17
07/22
07/27
08/01
08/06
x 10^5


TPT 20m ADCP Along-shore
m.a.b.
TPT 20m ADCP Cross-shore
m.a.b
07/07
07/12
07/17
07/22
07/27
08/01
08/06
x 10^5