# Developing a bioenergetics model for *Euphausia pacifica* larvae in the California Current

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PICES XVI

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# Talk Overview

1. Motivations

2. Some basics on models used in biological oceanography;

   Rationale for an individual-based bioenergetics model

3. Development of the bioenergetics model; comparison to 2002 field data

4. Brief look at model sensitivity to select parameters

5. There's always room for improvement and more work…

# Meet *Euphausia pacifica*

Most numerically abundant euphausiid (krill) species off the coast of Oregon

(Has been considered for commercial harvest as salmon farm supplement)

Long life span (2+ years off Oregon)

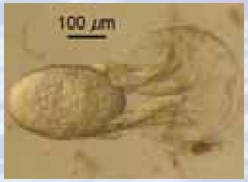
Important link between lower and higher trophic levels:

***E. pacifica* eats**: phytoplankton, some copepods, ciliates, nano- and picoplankton (with transparent exopolymer particles)

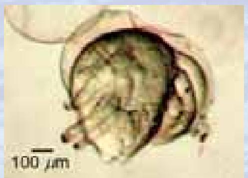
***E. pacifica* eaten by**: salmon juveniles, birds, whales

Sampling on the NH line over 10 years (1996-2005) shows peak egg abundance from June-September --> “upwelling spawner”

# *Euphausia pacifica* Life Stages




**Nauplius (1 - 2)** – oval unsegmented body, no compound eyes, 3 pairs of appendages (which ultimately become the 2 pairs of antennae and 1 pair of mouthparts)




**Metanauplius** – body divided into two parts, only first 2 pairs of appendages

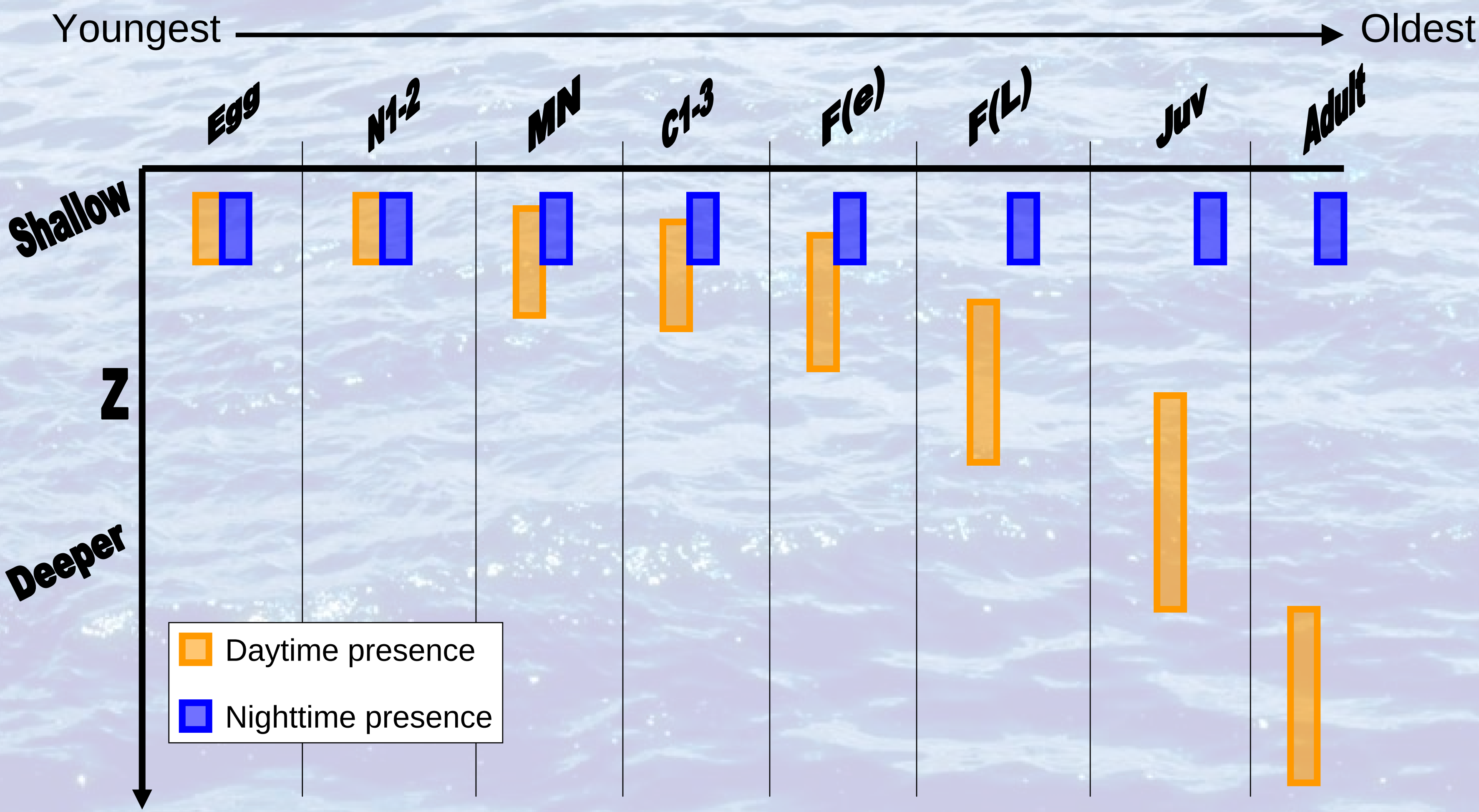
**Calyptopis (1 – 3)** – body clearly divided into cephalothorax and abdomen, which begins to segment; compound eyes begin to form; antennae and **mouthpart appendages present**

**Furcilia (1 – 7)** – compound eyes developed, **antennae still used for swimming, thoracic legs and abdominal pleopods begin to develop**

**Juvenile** – all **limbs developed**, but not yet full sized or sexually mature

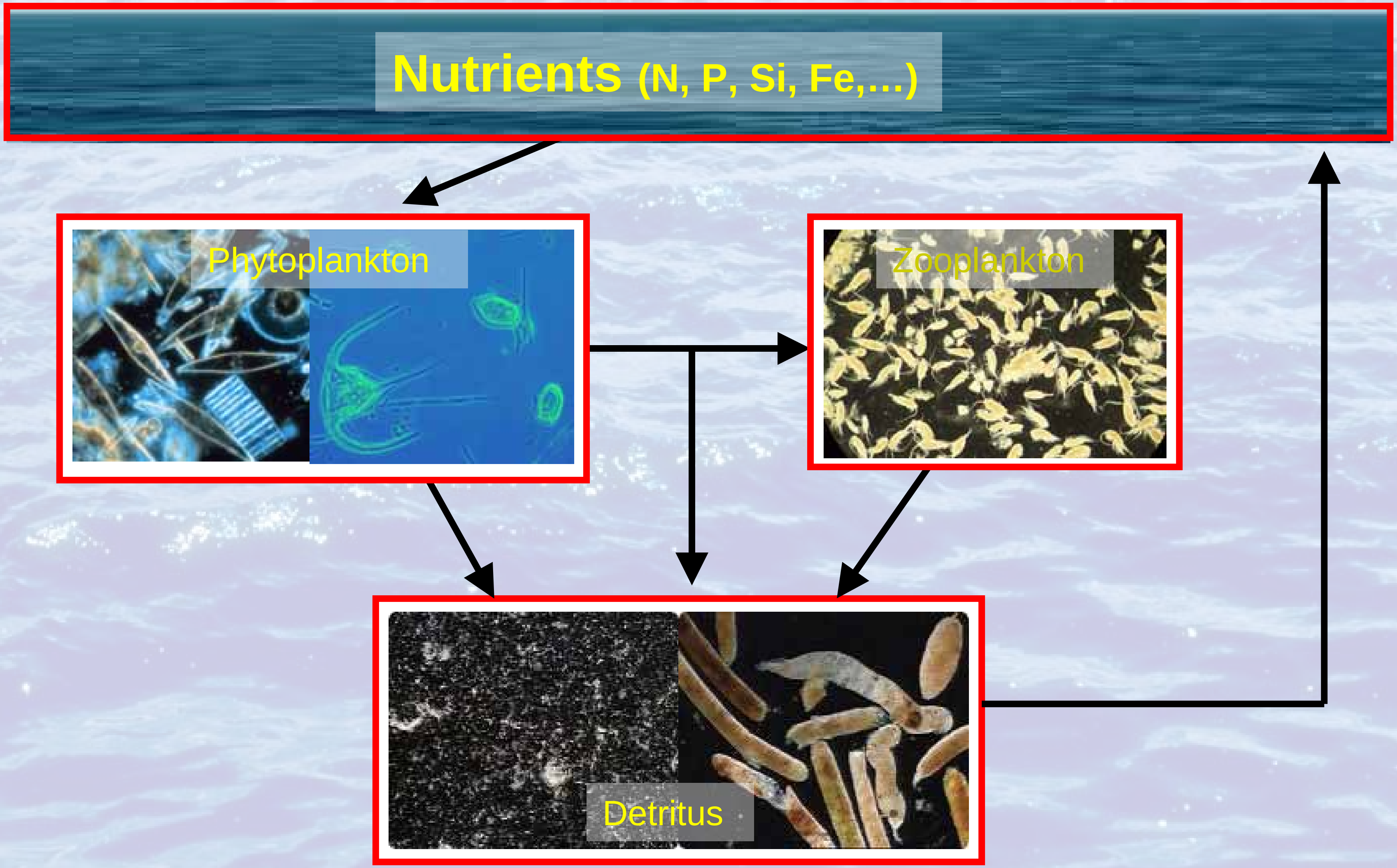
**Adult** – reproductively mature

# *Euphausia pacifica* off the Oregon Coast




Stage-based differences in vertical migration extent (schematic based on Vance et al, 2002)

# A Basic Ecosystem Model: NPZD



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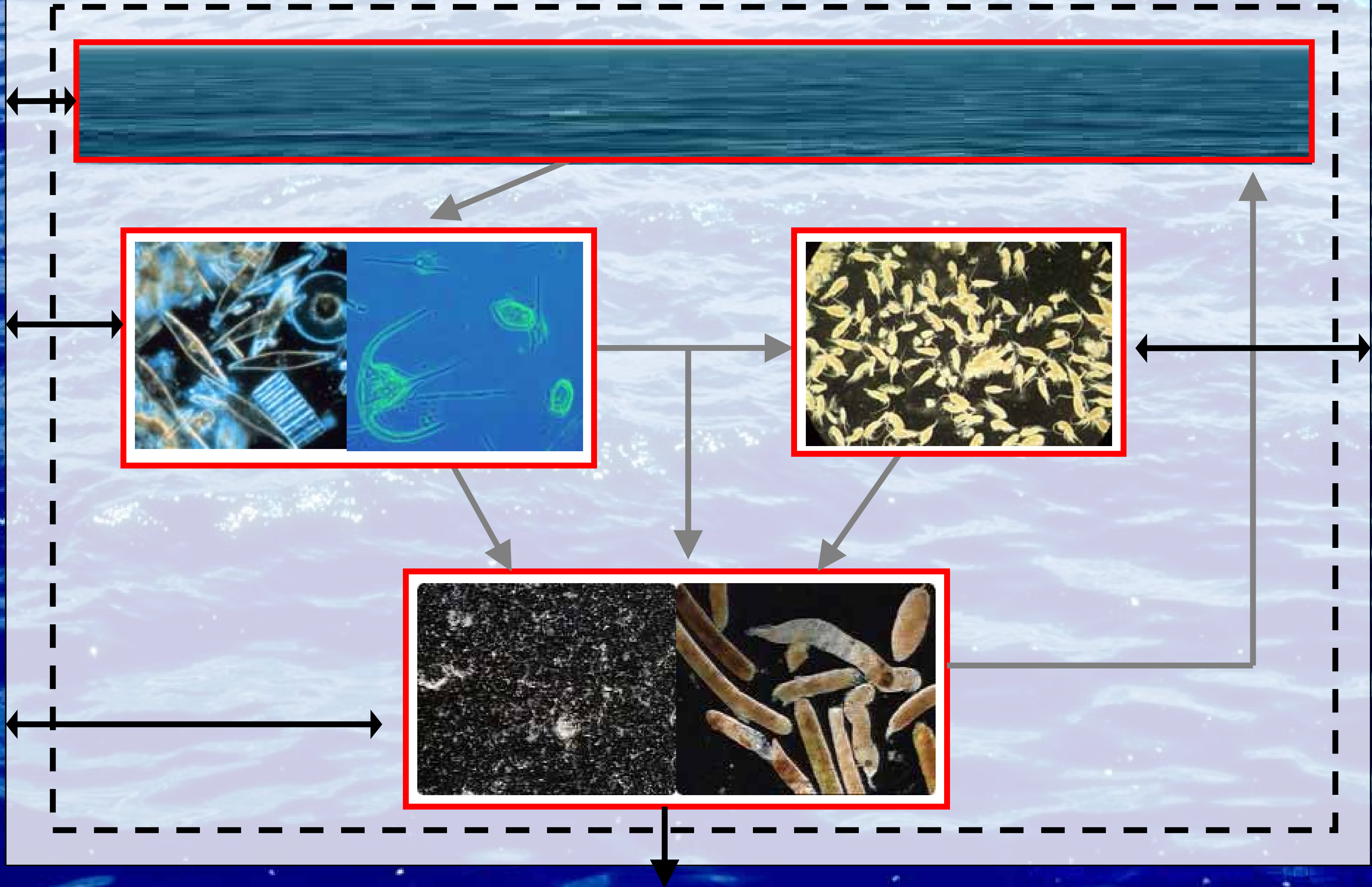
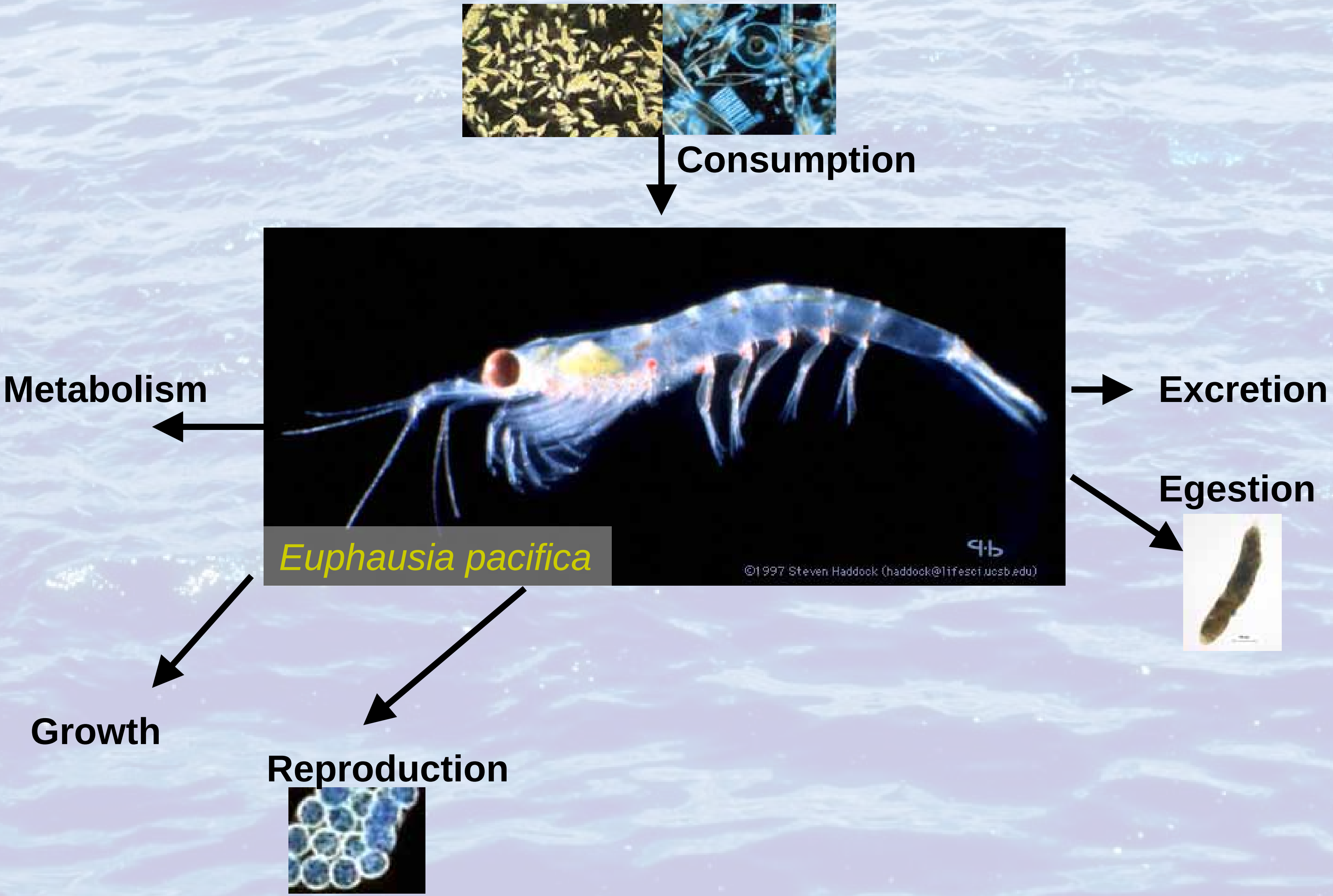
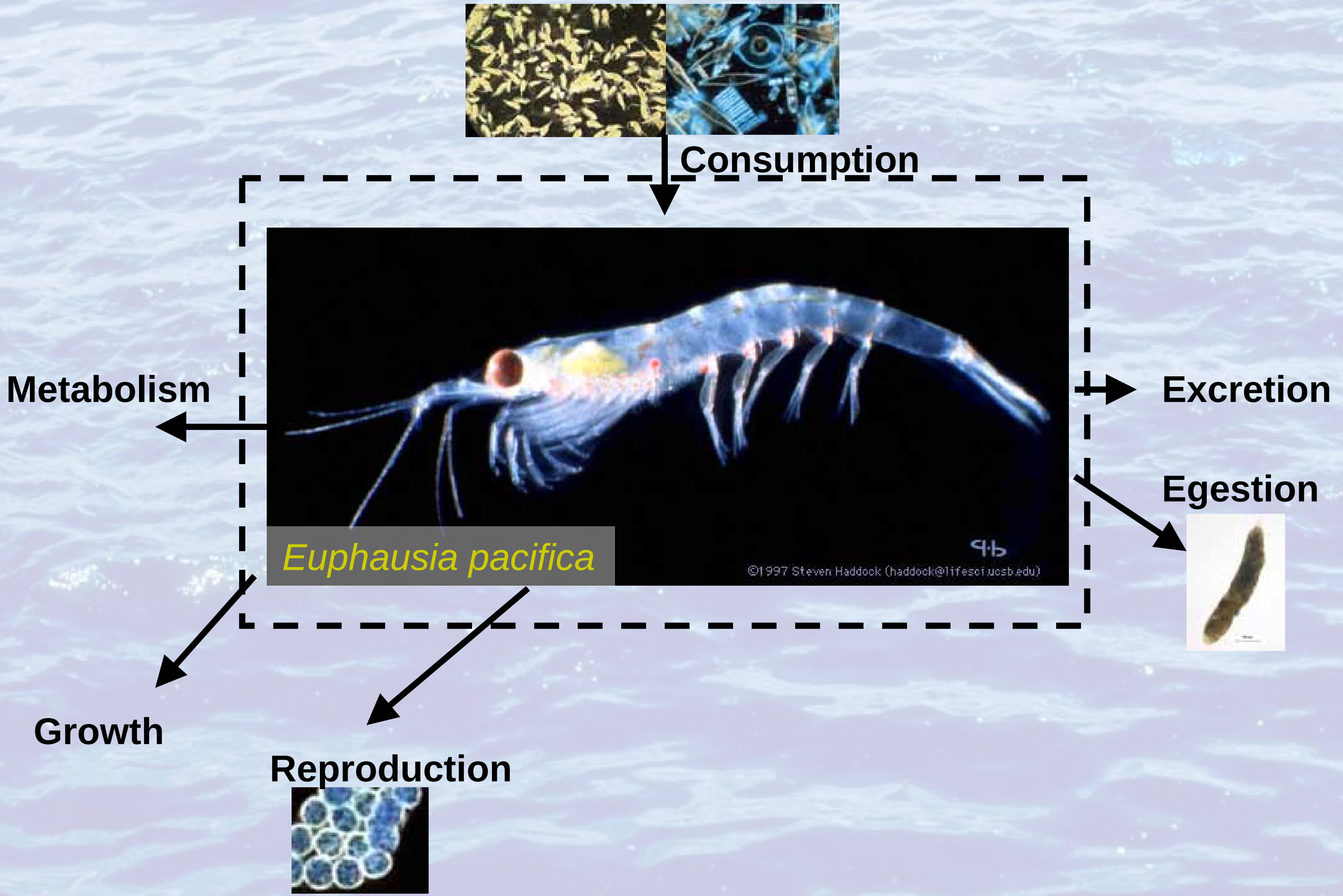


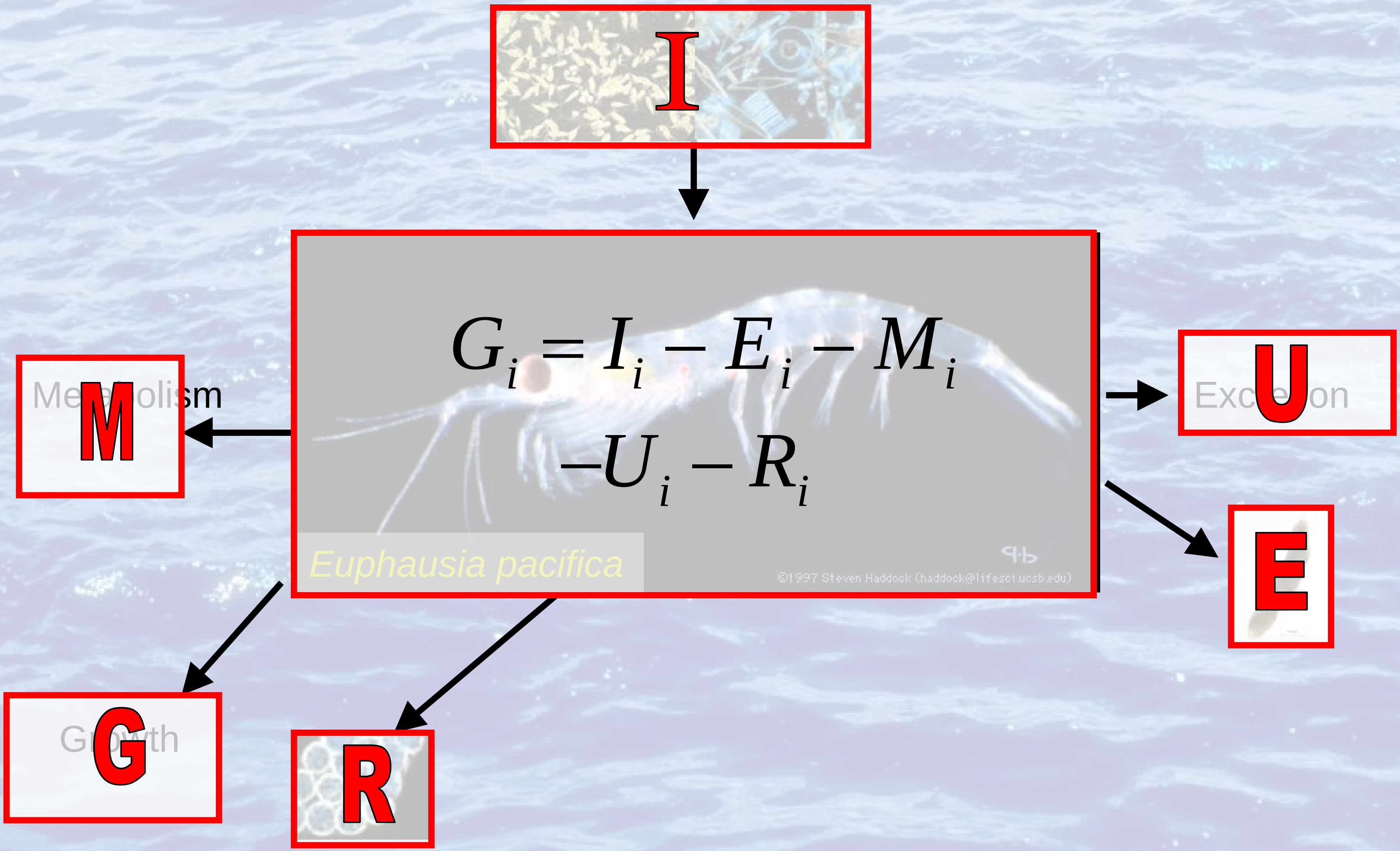
# A Bioenergetics Model



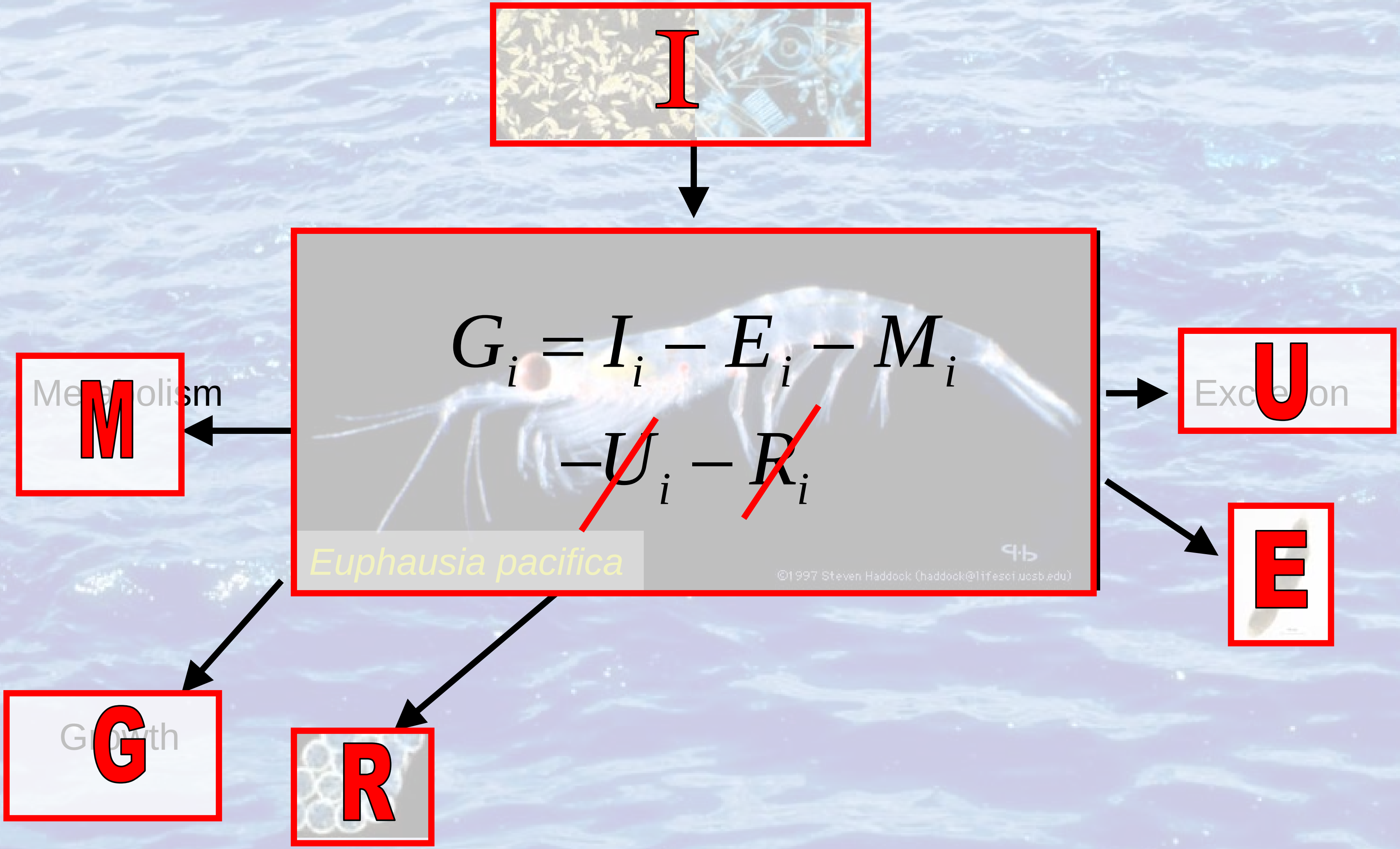
# A Bioenergetics Model (Individual)



# Developing the Bioenergetics Model



# Developing the Bioenergetics Model



# Developing the Bioenergetics Model

**Stage-specific relationships**

**Respiration – allometric relationship, based on R.M. Ross's work (1982)**

$$R = aW^b$$

**Ingestion, growth – allometric, based on Ross (1982), and observed growth trajectories (Feinberg and Peterson, pers. comm.)**

Depends primarily on *food*, secondarily on *temperature*

**Development – Stage-based, Belehradek curve with empirically-derived parameters**

Depends exclusively on *temperature*

# Developing the Bioenergetics Model - Growth

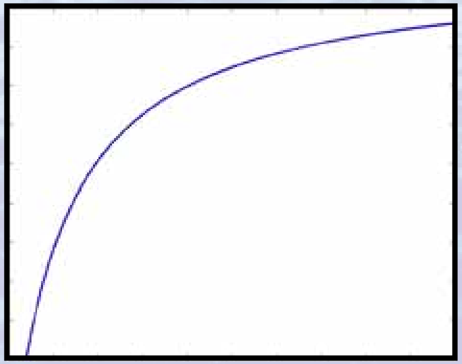
**Respiration**

$$R_{TOT} = R_A + R_B$$

**Ingestion**

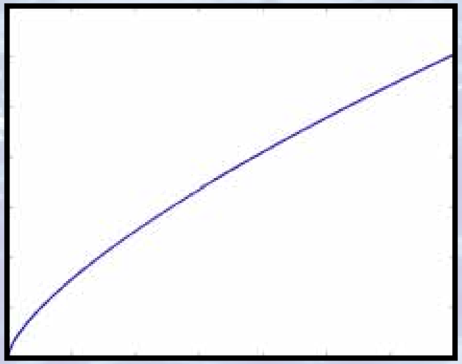
$$I_{TOT} = I_{max} * F_1 * F_2 * F_3$$

F1



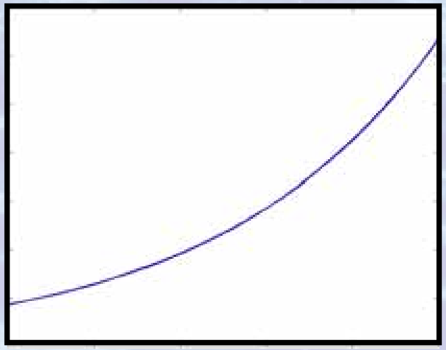
Food Concentration

F2



Body Weight

F3



Temperature

# Developing the Bioenergetics Model - Development

*E. pacifica* Belehradek function for time to stage as function of temperature

Basic Form is:

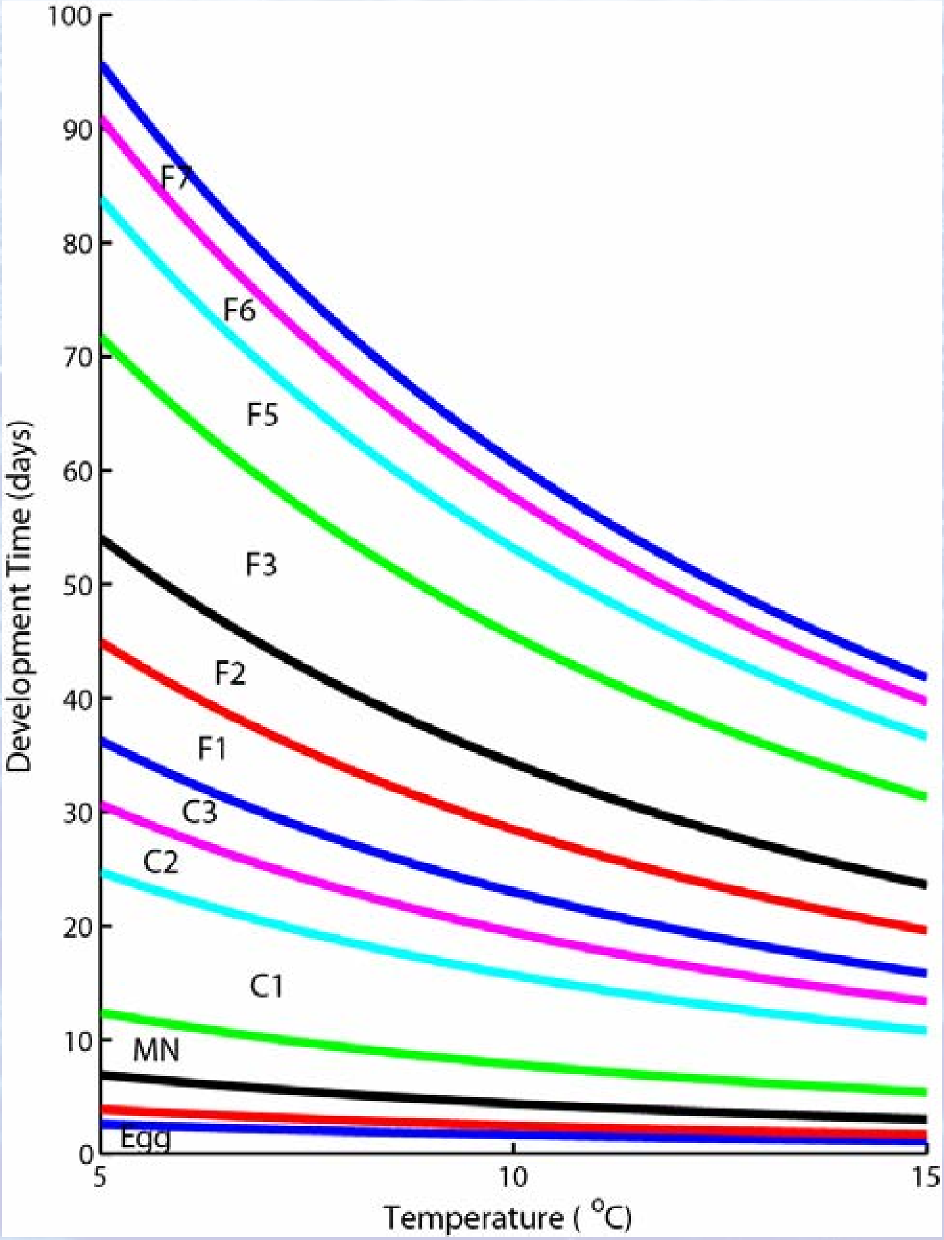
$$D_i = a_i (T + b)^c$$

**$D_i$** is the time (days) from egg to stage i

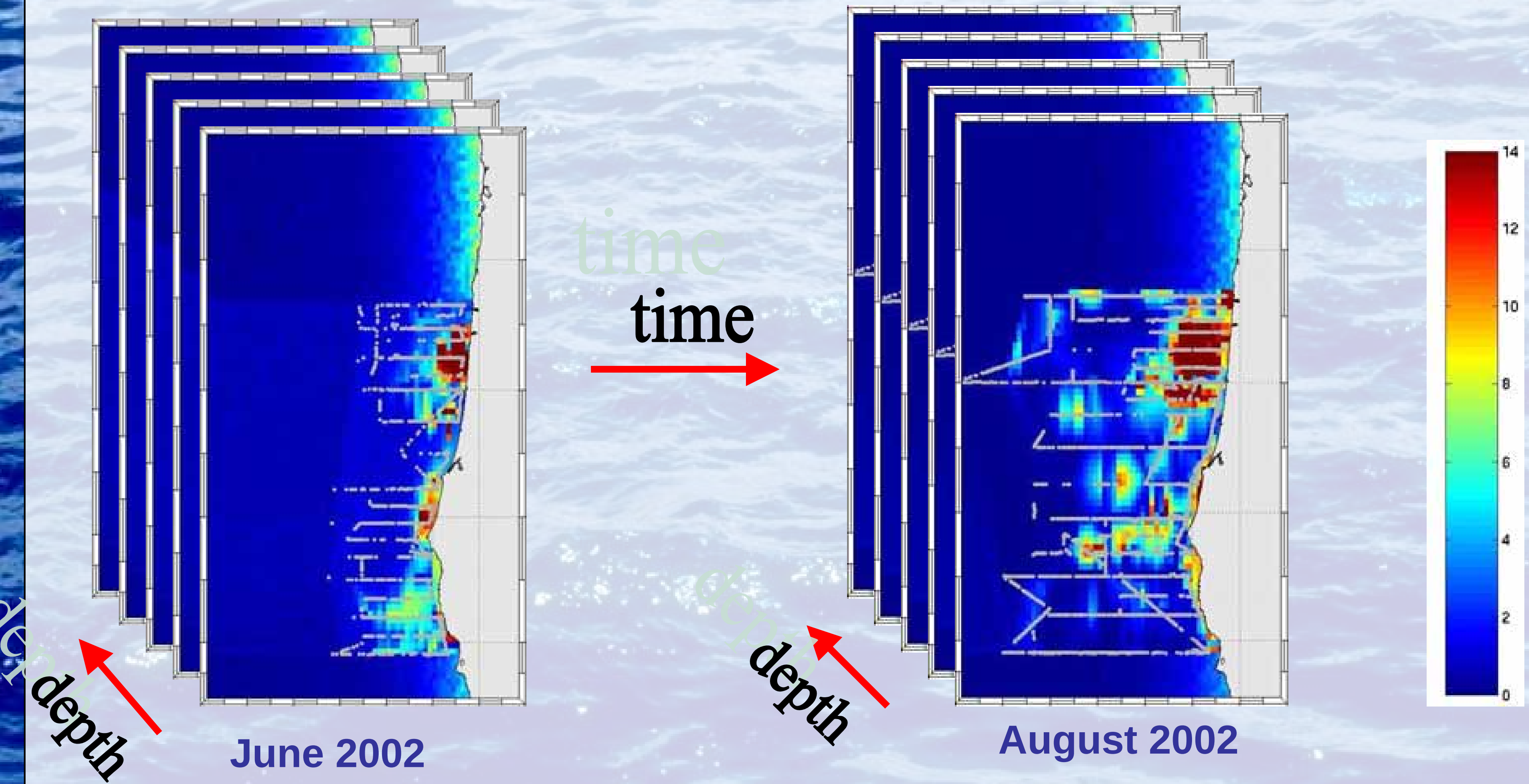
**$a_i$** is a stage specific constant

**b** is a stage-independent shift in temperature

**c** is assumed to be -2.05 (commonly observed from experiments; determines the curvature)

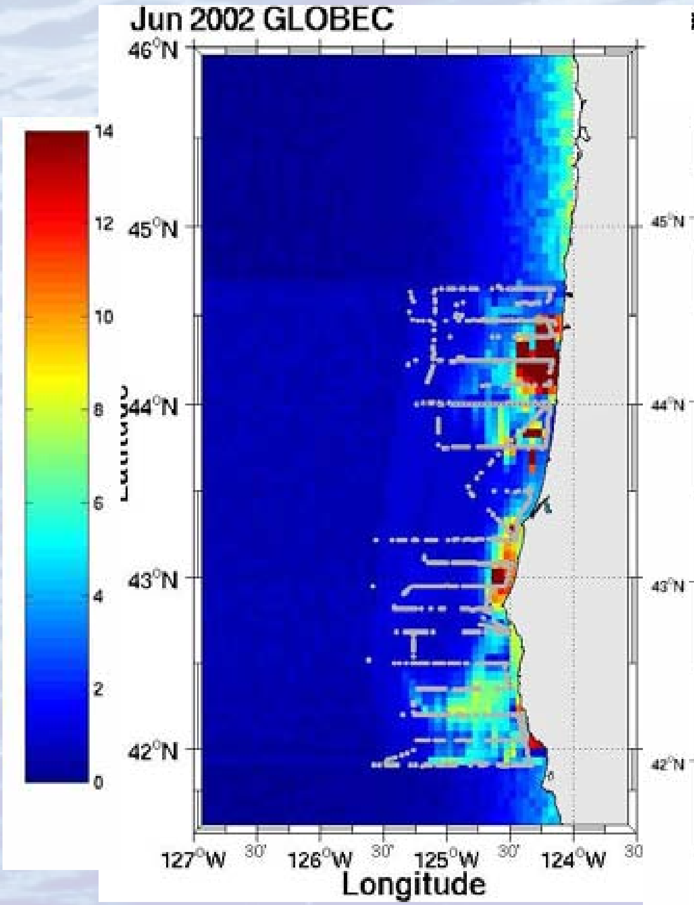


# Food fields (Phytoplankton)

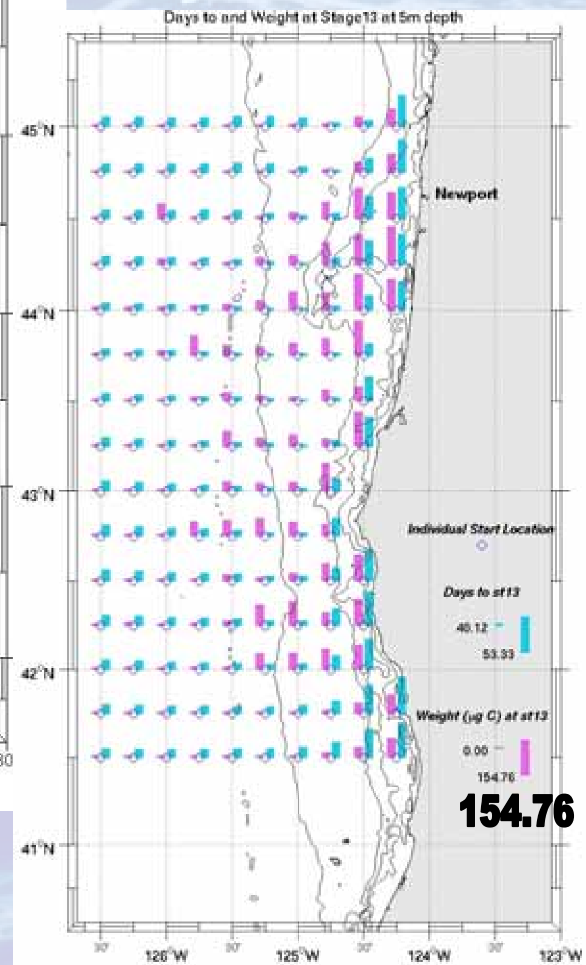


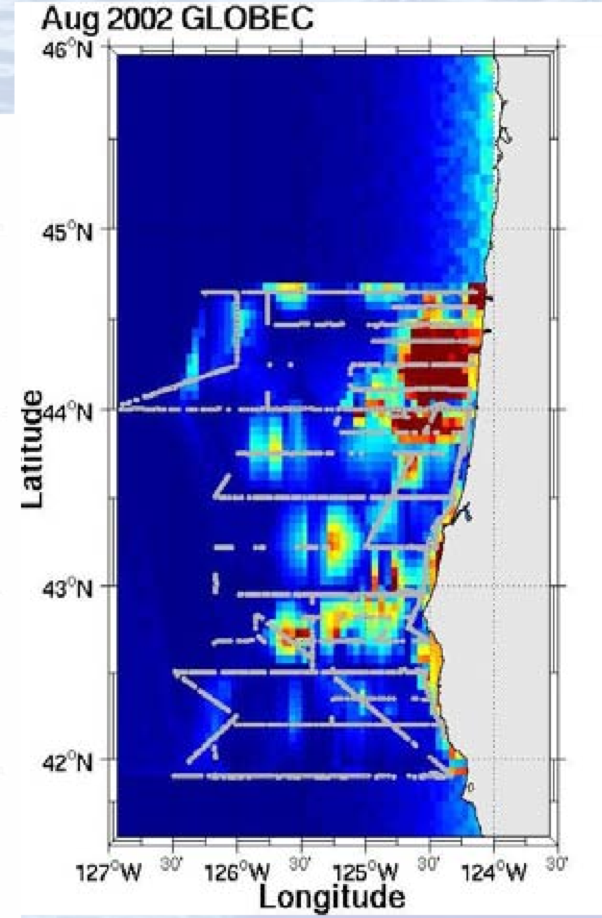

**SEASOAR (chlorophyll) observations from US GLOBEC Cruises**

# Early Results – Growth (No Behavior)




June 1, 2002




August 10, 2002

**5-m Depth**

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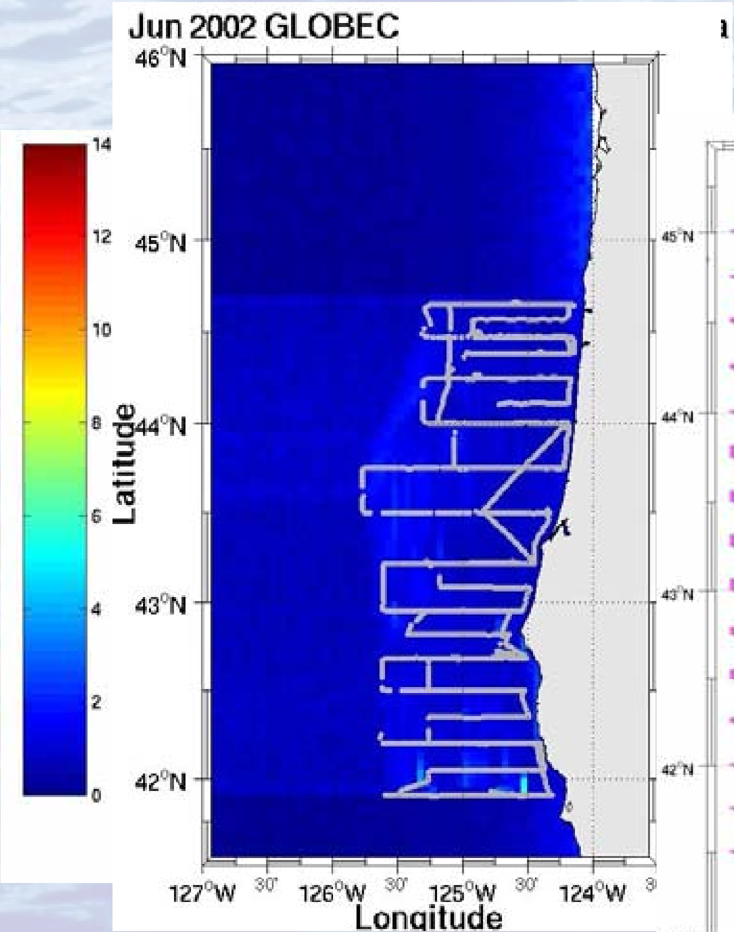


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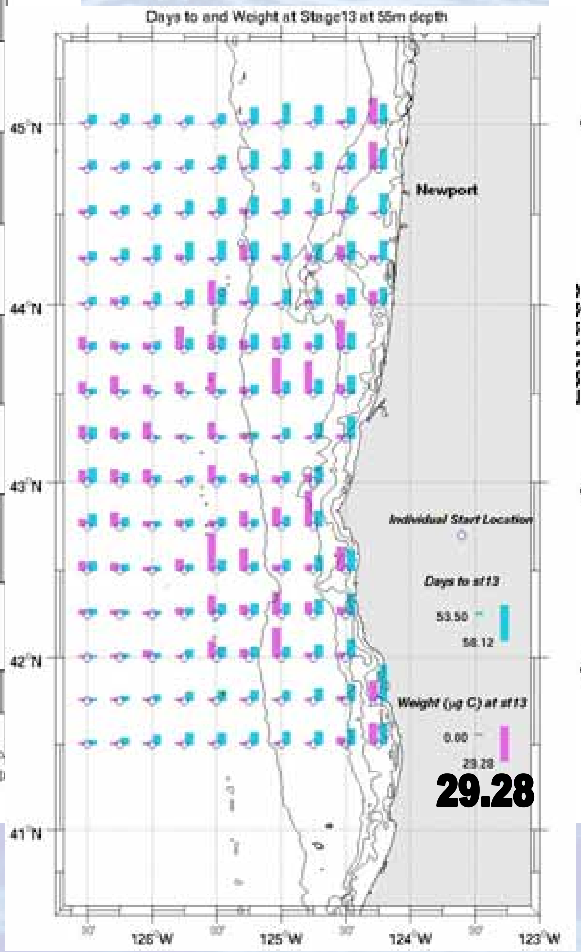
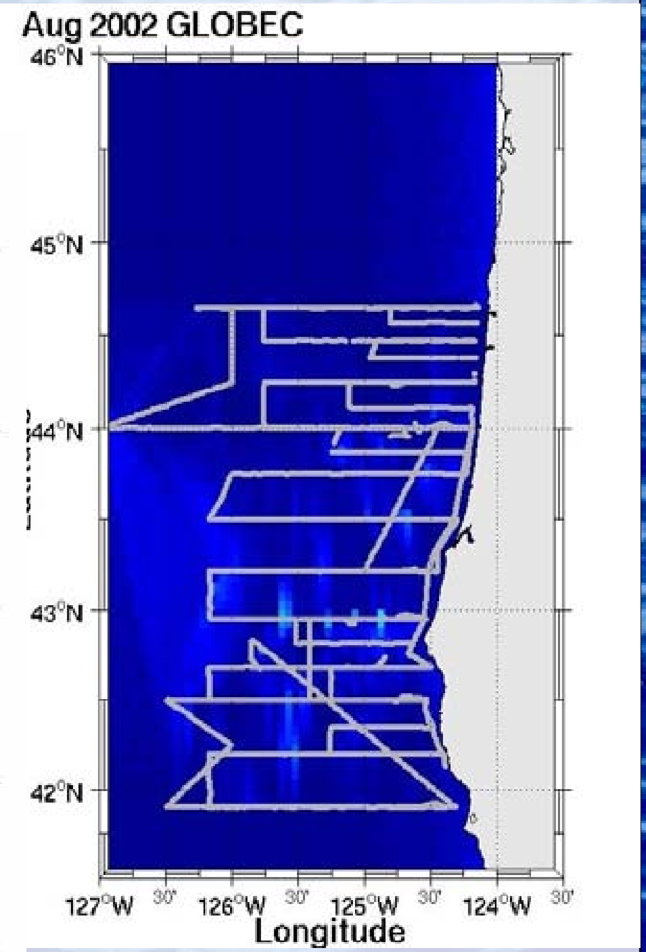
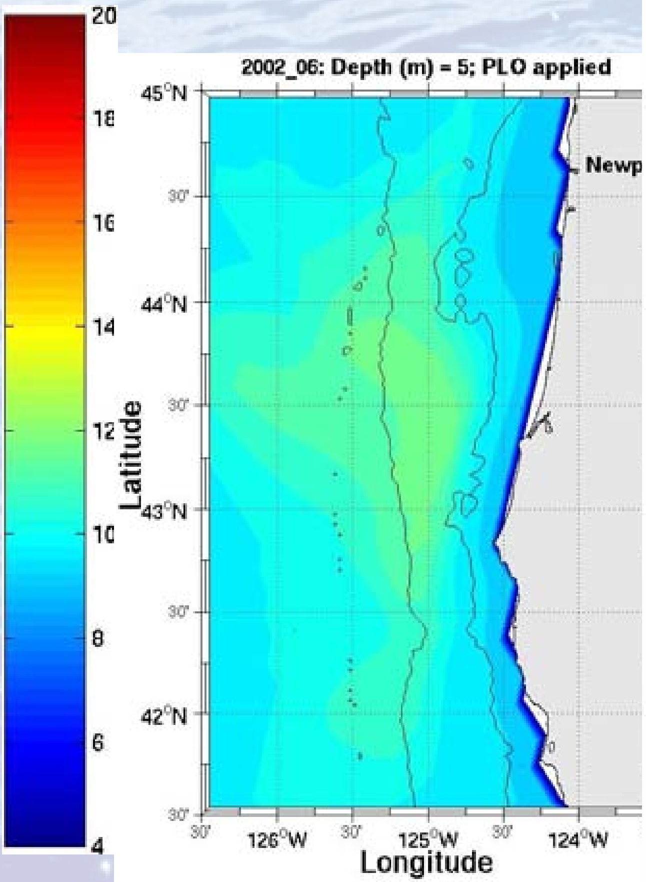


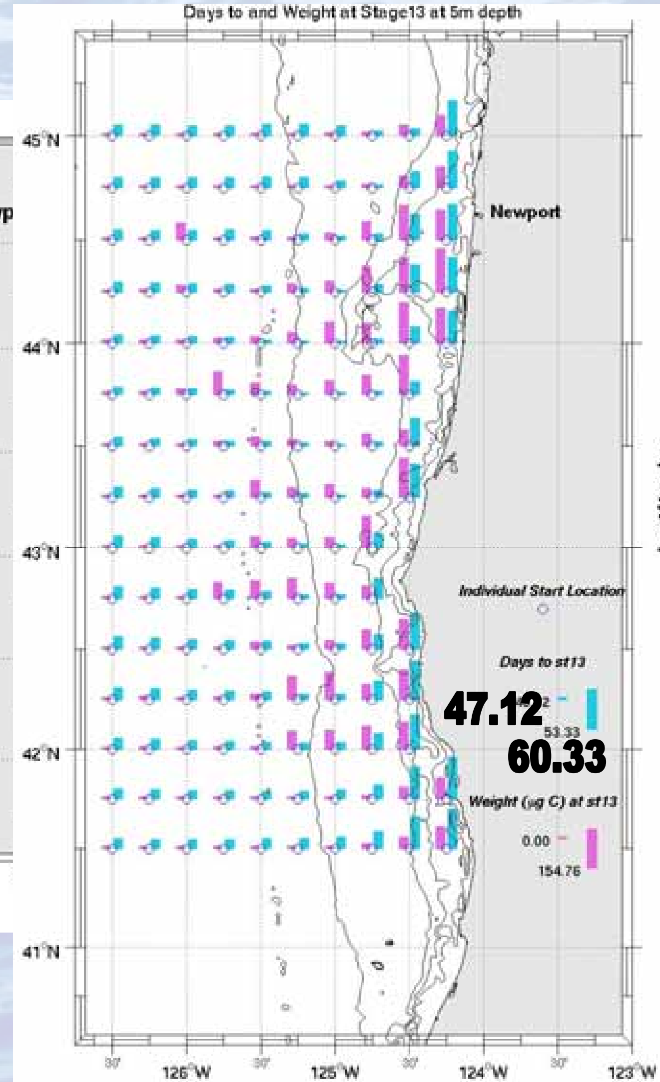

August 10, 2002

**55-m Depth**

# Early Results – Development (No Behavior)




June 2002

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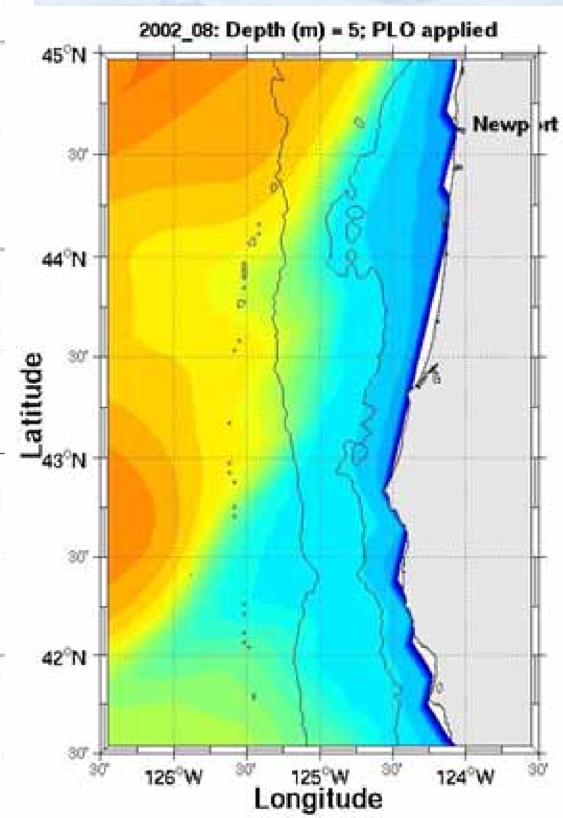


August 2002

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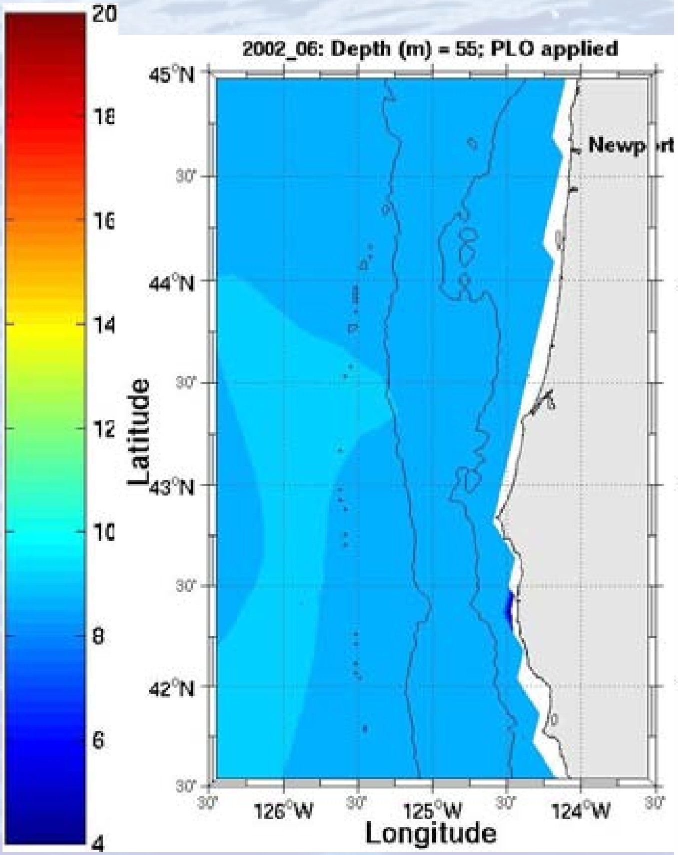


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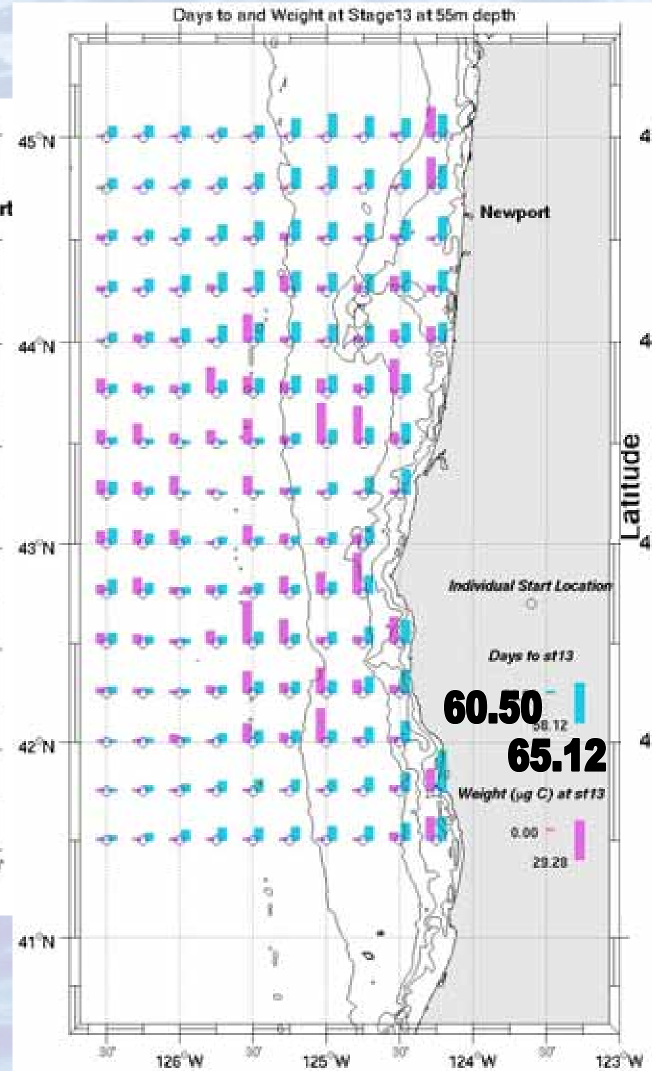
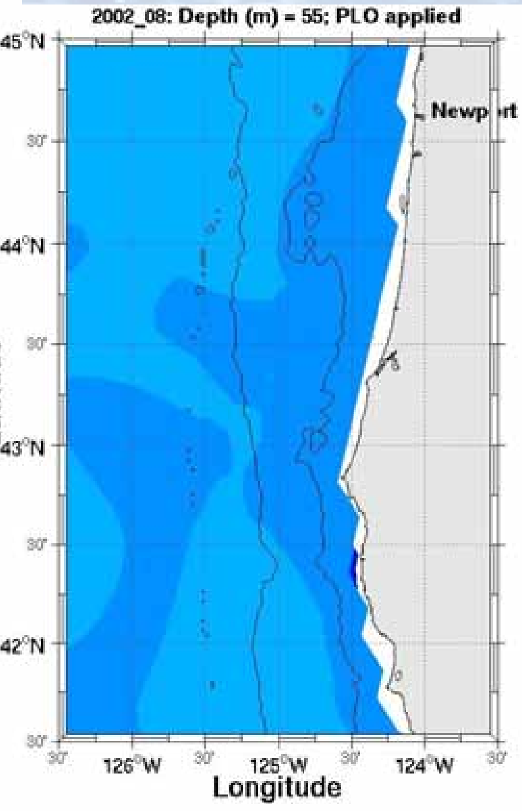



55-m Depth




August 2002

# Early Results – Comparisons

Data:

| Stage | Median time | @ 10.5ºC | Range in stage |
|---|---|---|---|
| N1 | 0.3 | | 0 – 4.0 (4) |
| N2 | 1.1 | | 1.0 – 7.1 (6.1) |
| MET | 3.0 | | 1.0 – 7.5 (6.5) |
| C1 | 6.4 | | 5.5 – 20.6 (15.1) |
| C2 | 14.1 | | 10.1 – 23.1(13) |
| C3 | 17.8 | | 13.5 – 26.1 (12.6) |
| FI | 21.3 | | 17.1 – 36.2 (19.1) |
| FII | 26.7 | | 19.6 – 43.6 (24) |
| FIII | 32.4 | | 22.5 – 58.2 (35.7) |
| FIV/V | 43.4 | | 27.1 – 67.1 (40) |
| FVI | 51.0 | | 33.2 – 75.2 (42) |
| FVII | 55.4 | | 36.7 – 75.0 (38.3) |
| JUV | 58.4 | | 40.6 |

Feinberg et al. (2006) - MEPS 316:127-137

Model:

Time to Furcilia 7:

5-m: 47.12 - 60.33d

55-m: 60.50 - 65.12d

# Early Results – Comparisons

Data:

Furcilia 7 range from 41.93 - 120.64 ugC:

71.94 ± 22.97 ugC (n=15)

(Feinberg, Shaw and Peterson, unpublished data)

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Model:

At *5-m depth*: Furcilia 7 stages were present at up to 154.76 ugC

Too big

At *55-m depth*: Furcilia 7 stages were present at up to 29.28 ug

Too small

Time to Furcilia 7:

5-m: 47.12 - 60.33d

55-m: 60.50 - 65.12d

# <u>Early Results – Comparisons</u>

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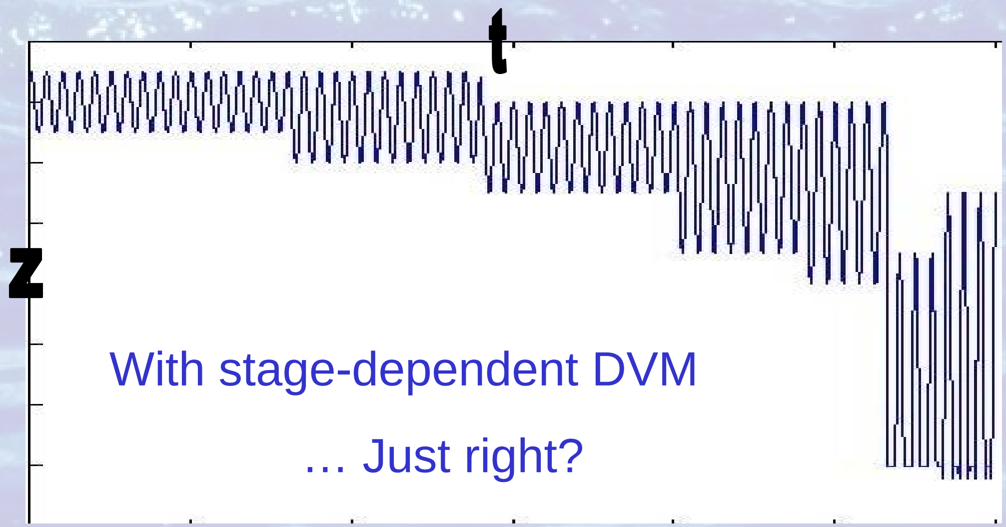


# Early Results – With Behavior

Model:

Time to F7: 51.54 - 62.04d

(Recall Feinberg et al median 55.4d to F7)

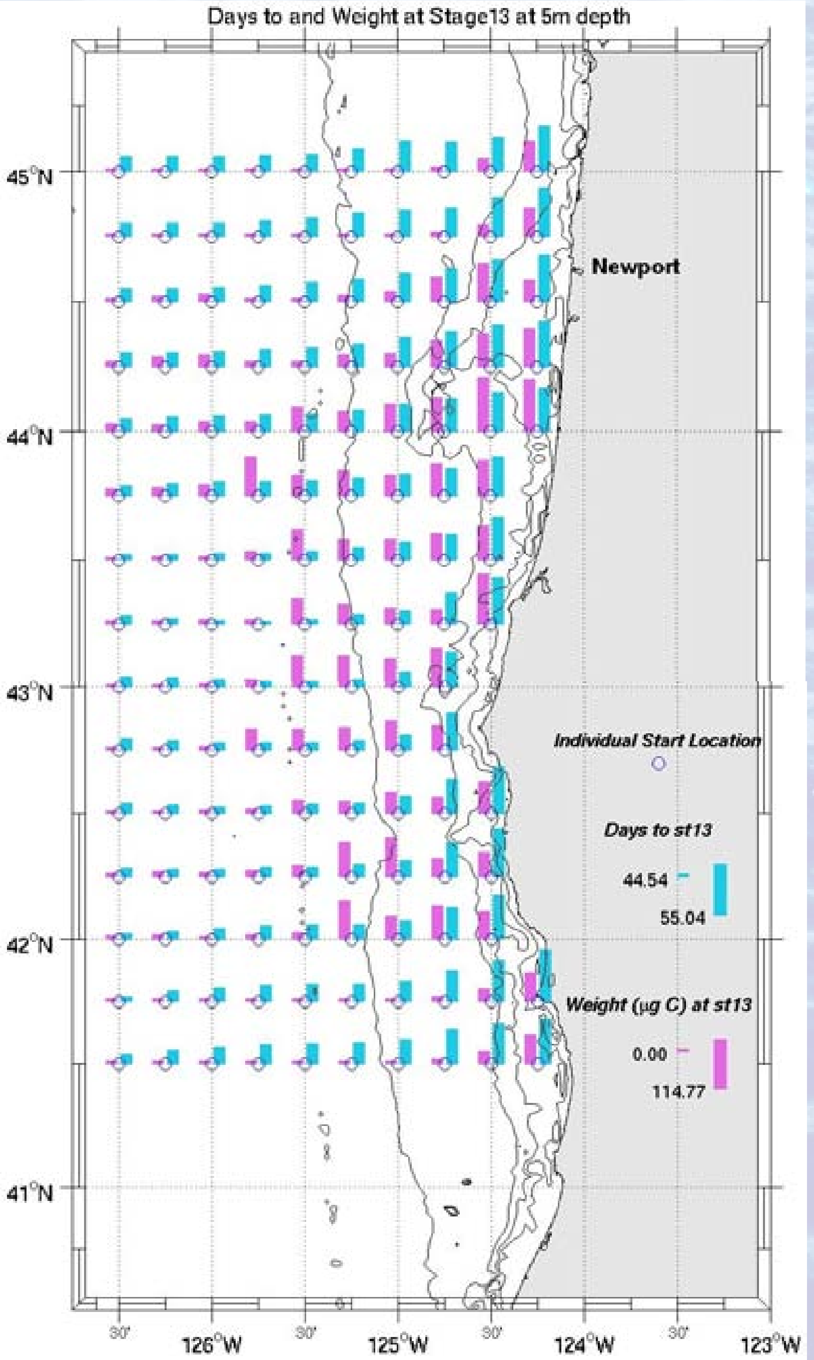
F7s weigh up to 114.77 ugC;

If those that have starved are ignored, the F7s weigh:

65.07 ± 17.62 ugC

(closer to 71.94 ± 22.97)

DVM is important



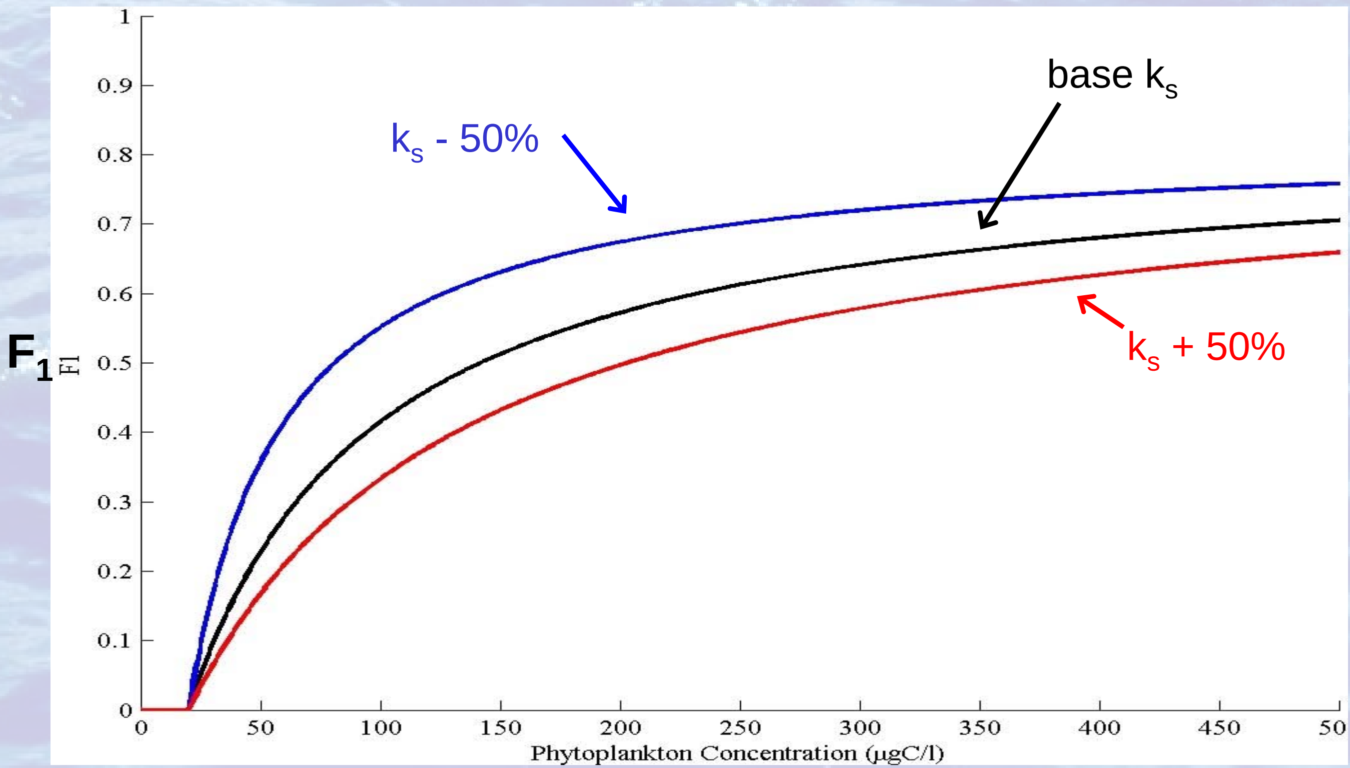
# Model Sensitivity

Ingestion terms:

$$S = \frac{\text{Fractional change in response}}{\text{Fractional change in parameter}}$$

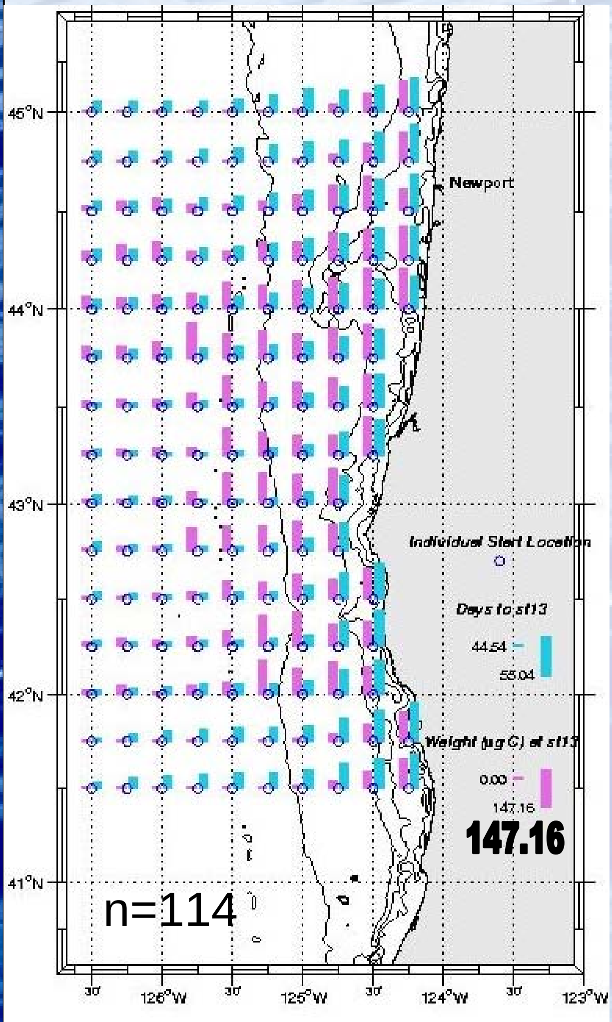
$$I_{max}*F_1 = I_{max}*[(P - thr)/(k_s + (P - thr))]$$

$k_s \pm 50\%$:



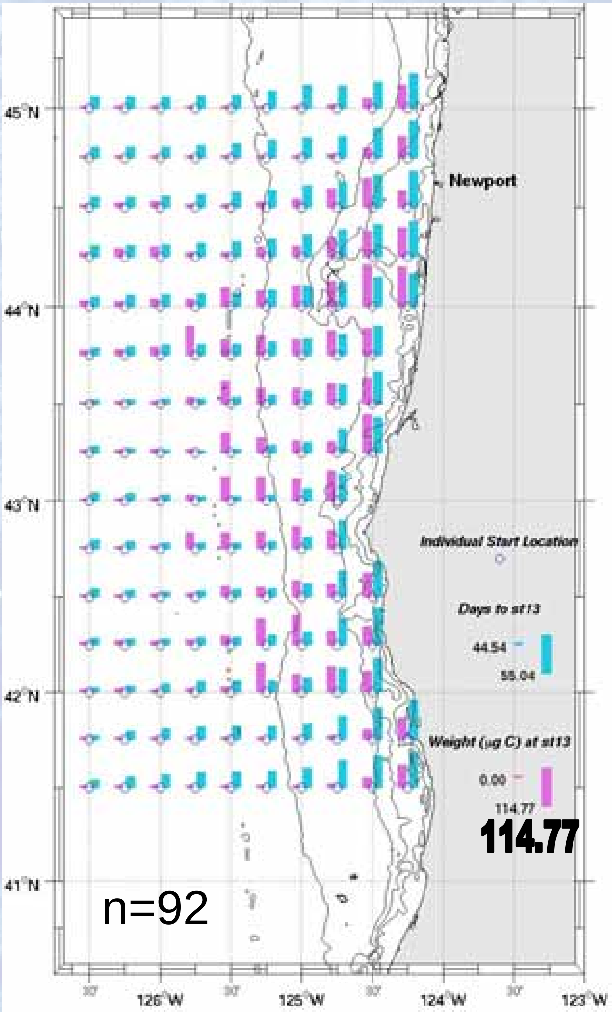
# Model Sensitivity

$k_s$ - 50% (S=1.0)



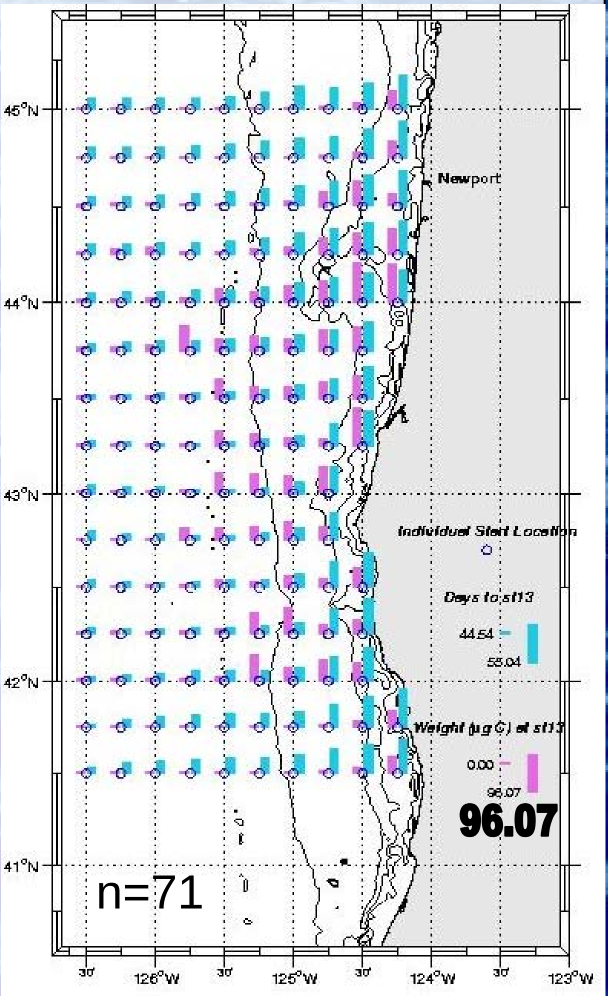

mean wt = base + 52%

$k_s$ in base case




base case

$k_s$ + 50% (S=0.38)




mean wt = base - 19%

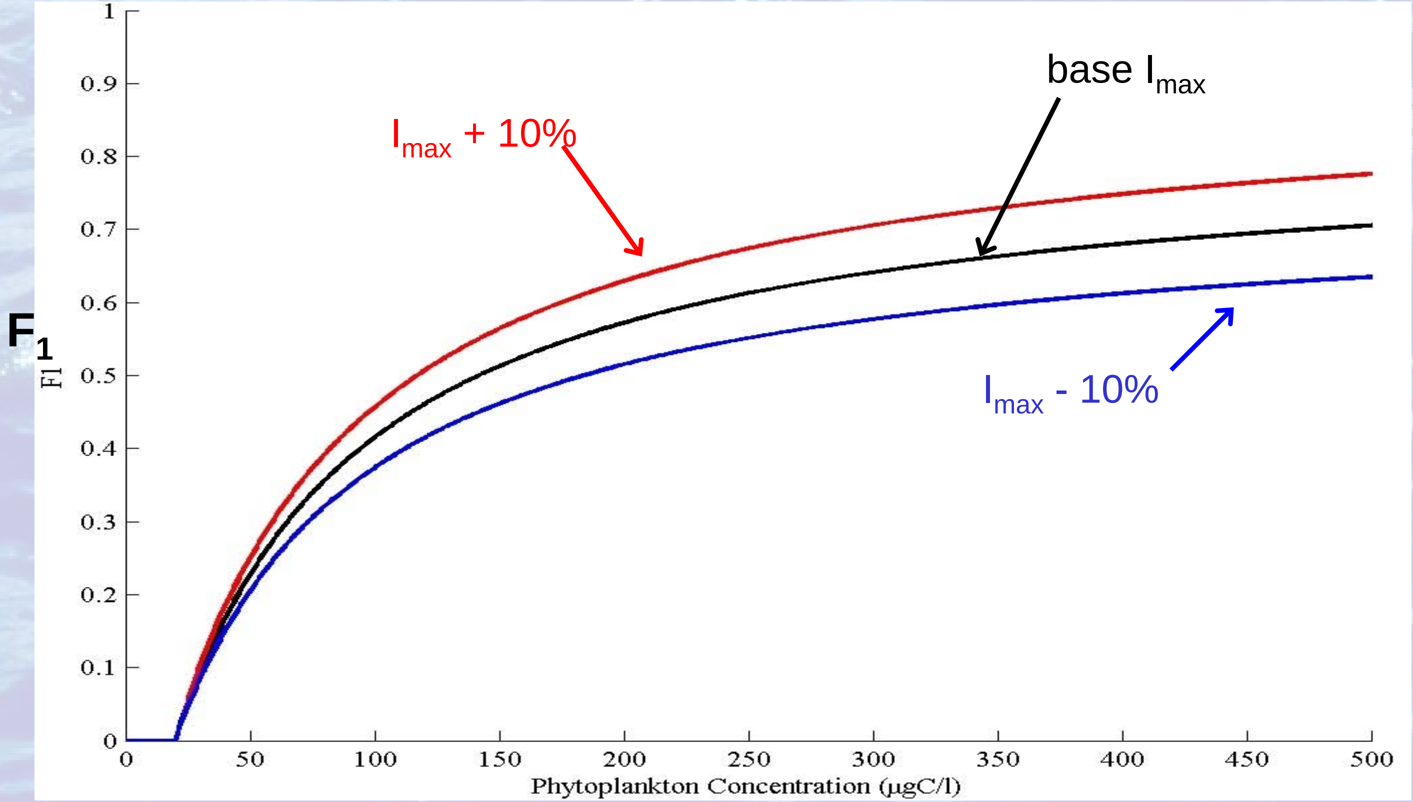
# Model Sensitivity

Ingestion terms:

$$S = \frac{\text{Fractional change in response}}{\text{Fractional change in parameter}}$$

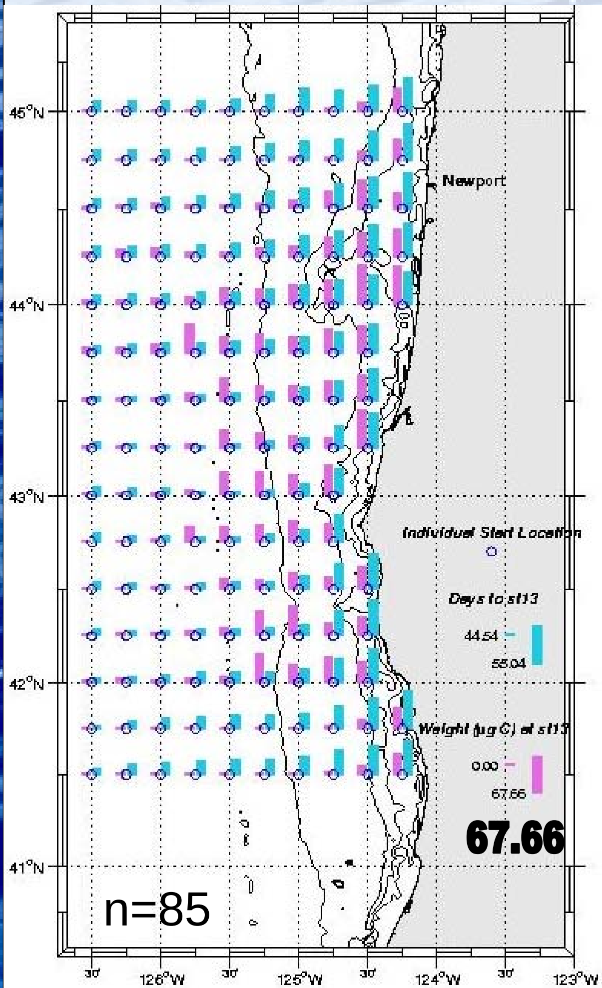
$$I_{max} * F_1 = I_{max} * [(P - thr)/(k_s + (P - thr))]$$

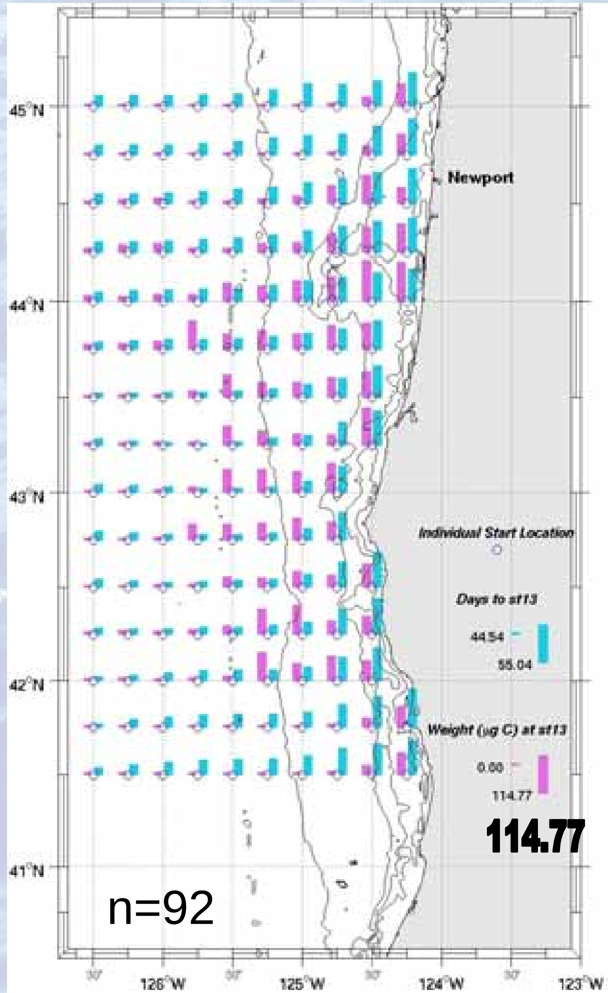
$I_{max} \pm 10\%$:

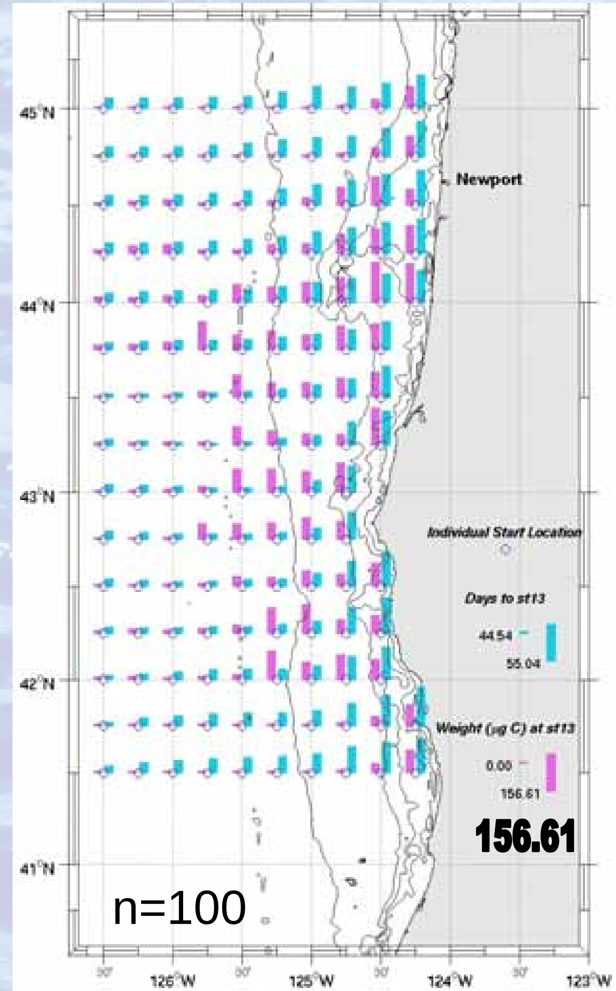


# Model Sensitivity

$I_{max}$ - 10% (S=2.5) | $I_{max}$ base case | $I_{max}$ + 10% (S=2.8)




mean wt = base - 25% | base case | mean wt = base + 28%

# Summary and Conclusions

**Spatially-explicit euphausiid model that decoupled growth and development**

**The model that incorporated information on DVM did better at providing development duration and weights than models that did not.**

**Model is more sensitive to changes in $I_{max}$ than to $k_s$**

***Need to be sure of max ingestion rates!***

**Bill Peterson's lab to the rescue:**

**will inform us of appropriate values**

# Future Work– Plenty Left to Do

**Implement:**

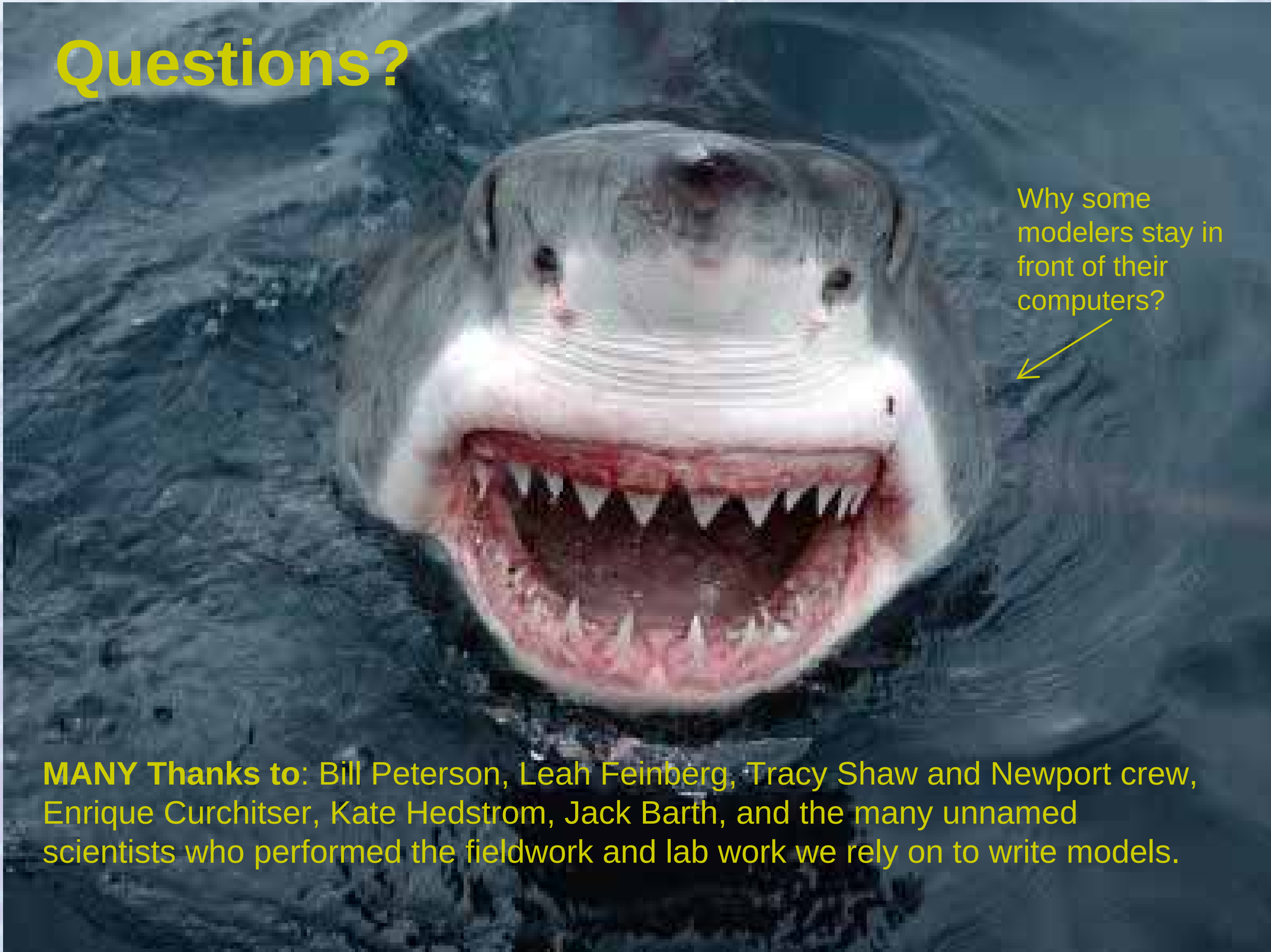
**Explicit molting function**

**Starvation (critical weights per stage)**

**Expand to non-feeding larval stages and reproductive adults**

**Present model is geographically fixed --> Move to 3-D transport ☐**

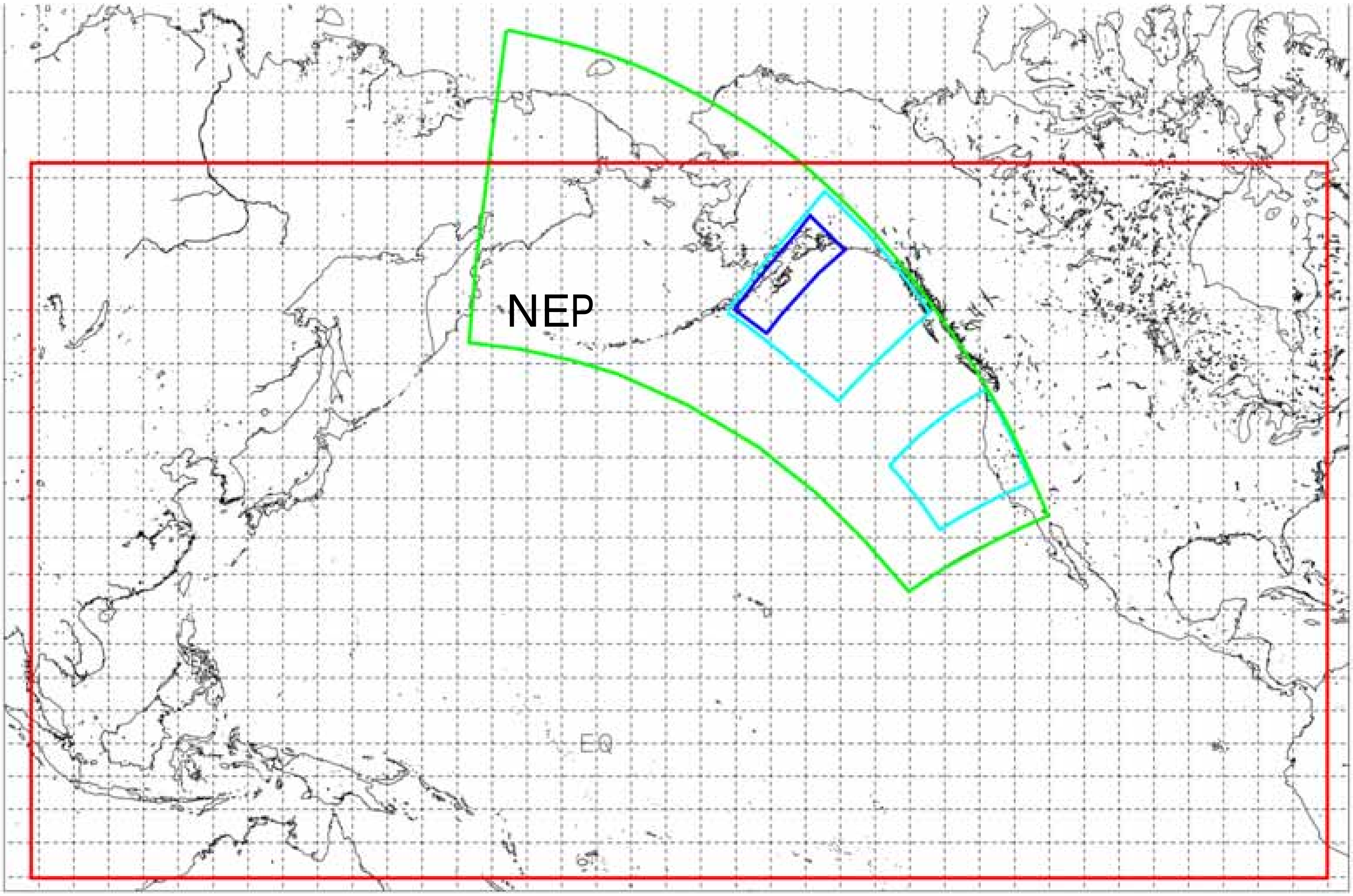
# Questions?



Why some modelers stay in front of their computers?

**MANY Thanks to**: Bill Peterson, Leah Feinberg, Tracy Shaw and Newport crew, Enrique Curchitser, Kate Hedstrom, Jack Barth, and the many unnamed scientists who performed the fieldwork and lab work we rely on to write models.

# U.S. GLOBEC Nested Model Domains




Delta x = 20 40 km Delta x = 10 km Delta x = 3 km Delta x = 1 km

# NEP Implementation

Domain: 20 - 73N, 115 – 210E

ROMS: 226 x 642 x 42 gridpoints

Subdaily (6 hr) T42 CORE wind and fluxes (Large and Yeager)

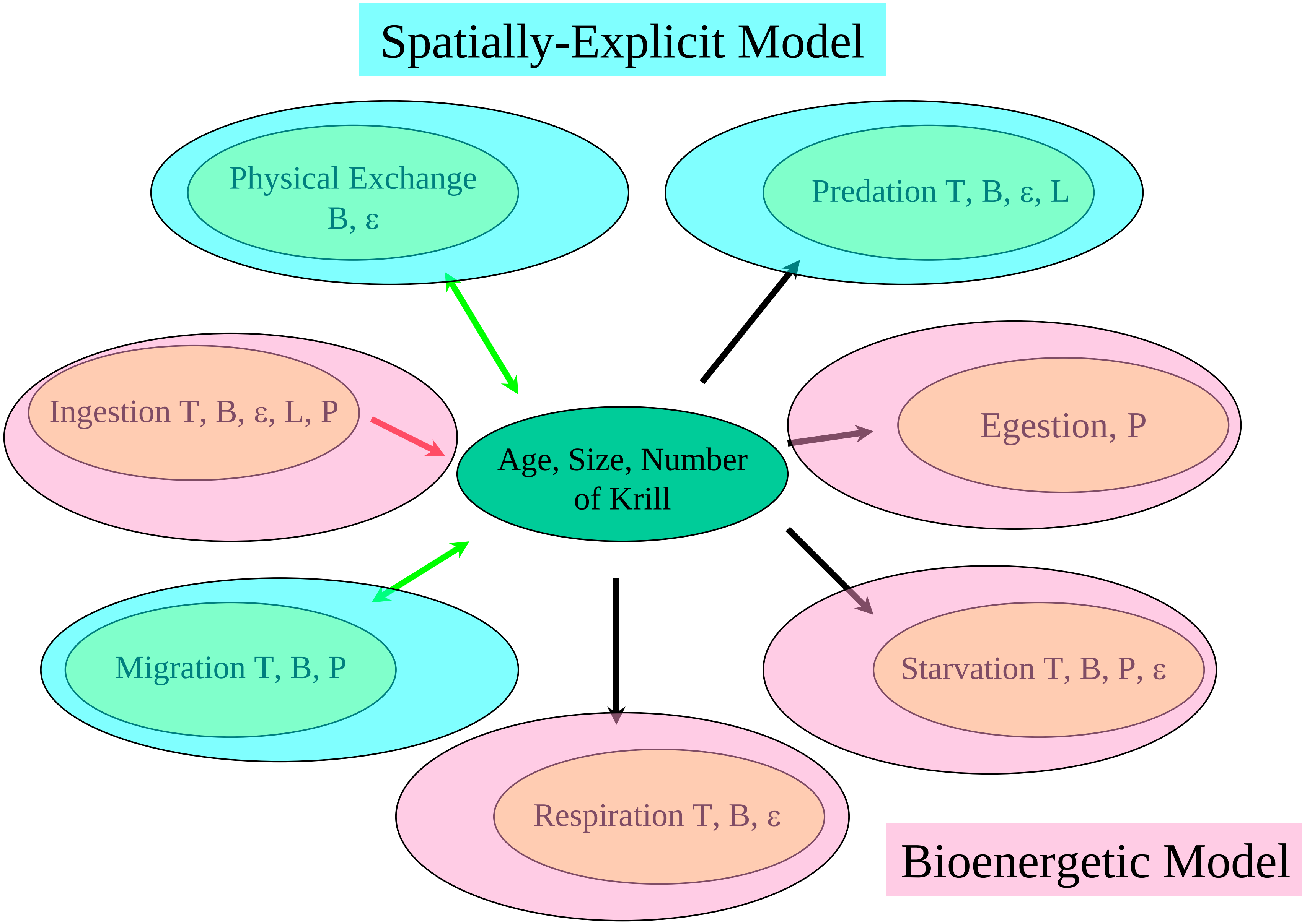
Initial/boundary conditions provided by CCSM-POP hindcast model

Forward run for 1958-2004—includes multiple El Nino's, Regime Shifts, and 2002 cold intrusion

Daily averaged physical snapshots of velocity, temperature, etc.

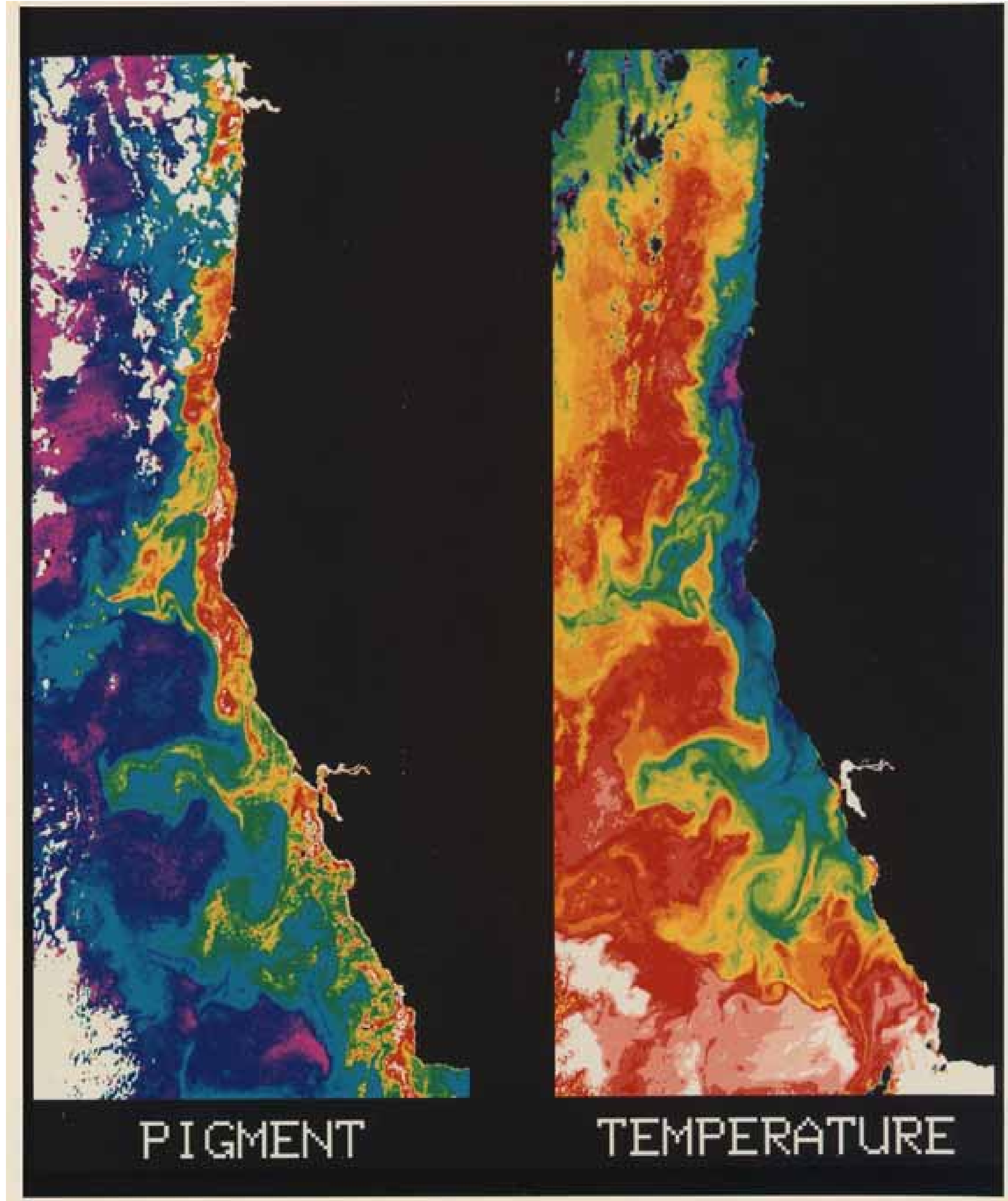
Especially want to thank Enrique Curchitser (Rutgers) and Kate Hedstrom (UAF) for providing these model fields.

# Processes and Environmental Variables Influencing Krill Growth and Number




T = Temperature; B=Behavior; ε=Turbulence; P=Prey; L=Light

# California Current Mesoscale Spatial Variability

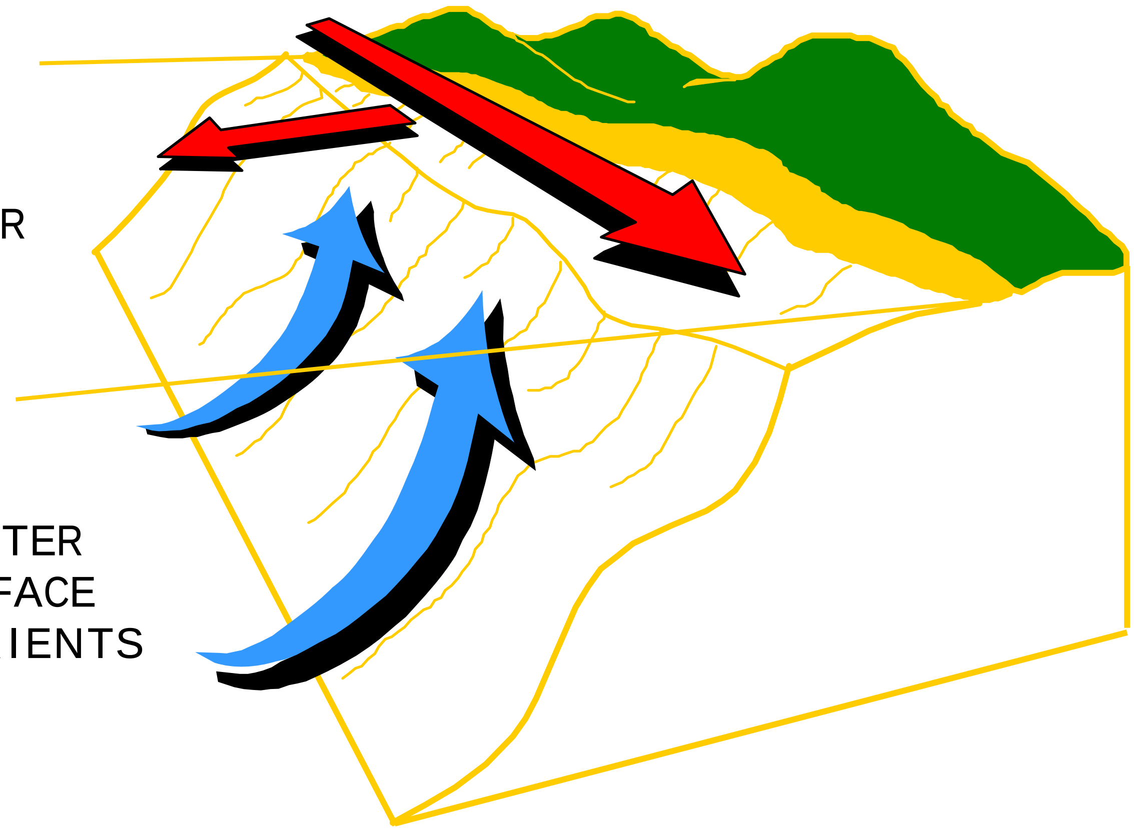



(From Abbott and Zion)

# Coastal Upwelling is the Fuel for the High Productivity in the Northern California Current

## EQUATORWARD WINDS (Summer)

WINDS PUSH
SURFACE WATER
OFFSHORE



COLD DEEP WATER
MOVES TO SURFACE
BRINGING NUTRIENTS