Striped Bass Modeling in the Bay-Delta

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Overview

- Model description and data sources
- Study purpose
- Does the model work?
- Level of model accuracy
- Quality assurance/certification
- Uncertainty
- Support

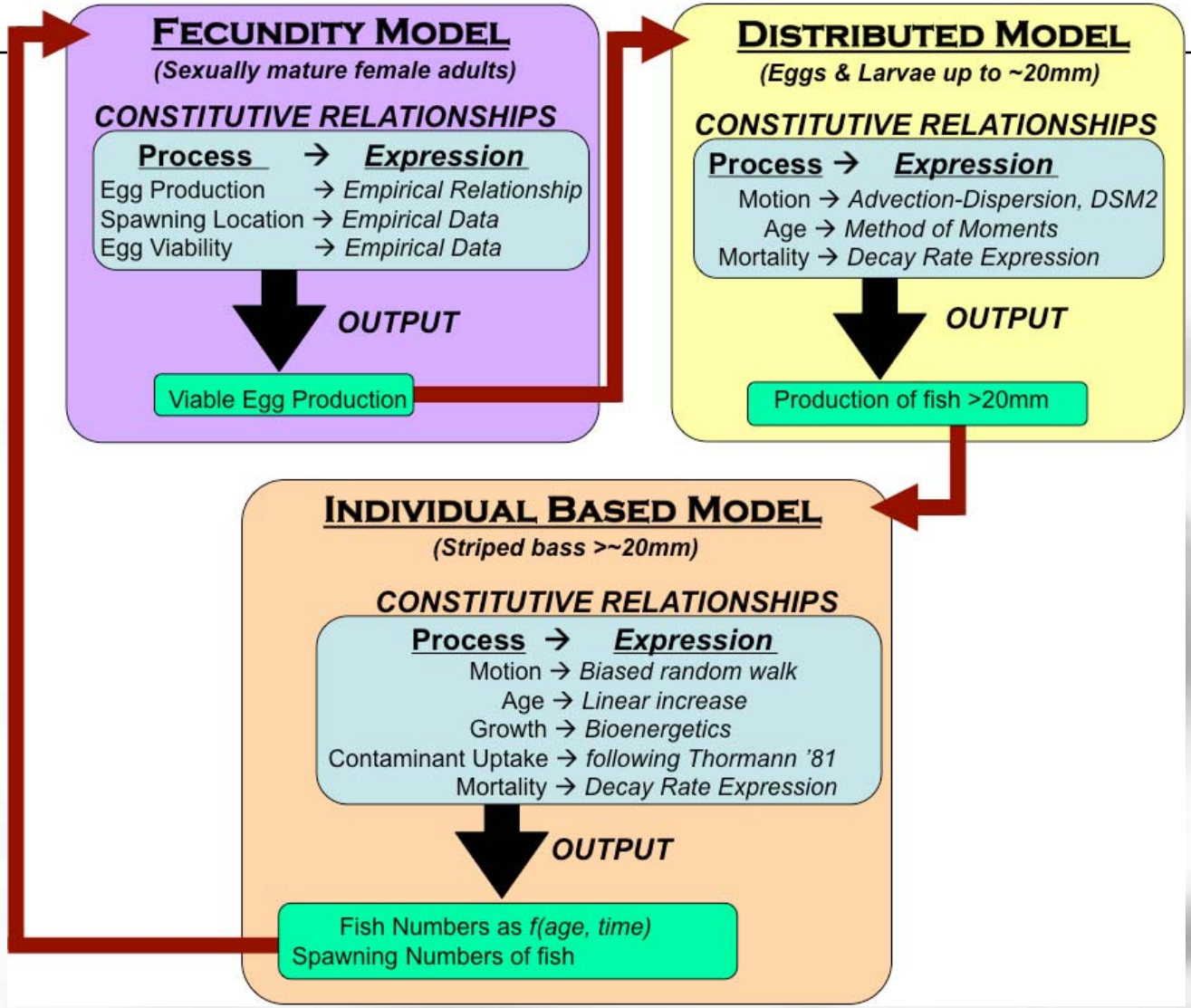
Modeled Life Stages

- Eggs
  - 0 to ~36 hrs
- Larvae
  - Up to ~20 mm
- Striped bass
  - FL > 20mm

Distributed Model

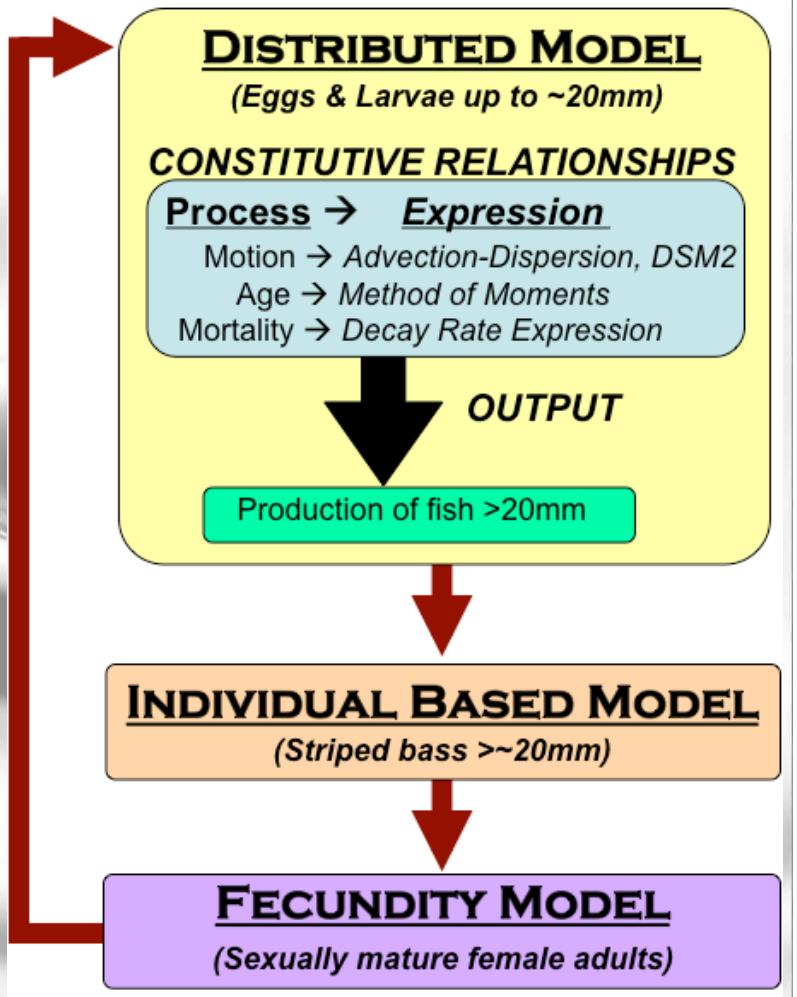
Individual Based Model

Modeling Overview



Distributed Model

- Model Considers:
  - Transport of eggs and larvae downstream
    - Advection/Dispersion coupled with DSM2
  - Mortality of eggs and larvae
    - Decay rate expression
  - Transition viable eggs into larvae and viable larvae into ~20mm fish based on age and temperature



Distributed Model: Transport and Mortality Expressions

- Advection-dispersion equation for eggs and larvae motion and mortality:

$$\frac{\partial AC(x,t)}{\partial t} + \frac{\partial QC(x,t)}{\partial x} = \frac{\partial}{\partial x}\left(AD\frac{\partial C(x,t)}{\partial x} \right) - Ak_d C(x,t) + AP(x,t)$$

- Where,

C: concentration of eggs or larvae
A: cross-sectional area of the river reach, *from DSM2*
Q: flow rate at the location, *from DSM2*
D: mechanical dispersion coefficient, *calibration parameter based on DFG egg and larvae survey data*
k_d: decay rate for eggs and larvae, *calibration parameter*
P: production rate of eggs, *from fecundity model.*

Distributed Model: Age Expression

- Method of moments governs age:
  - Governing equation for the mean age:

$$\frac{\partial A\bar{a}}{\partial t}+\frac{\partial Q\bar{a}}{\partial x}=\frac{1}{C(x,t)}\frac{\partial}{\partial x}\left(C(x,t)AD\frac{\partial \bar{a}}{\partial x}\right)-\frac{\bar{a}AP(x,t)}{C(x,t)}+A$$

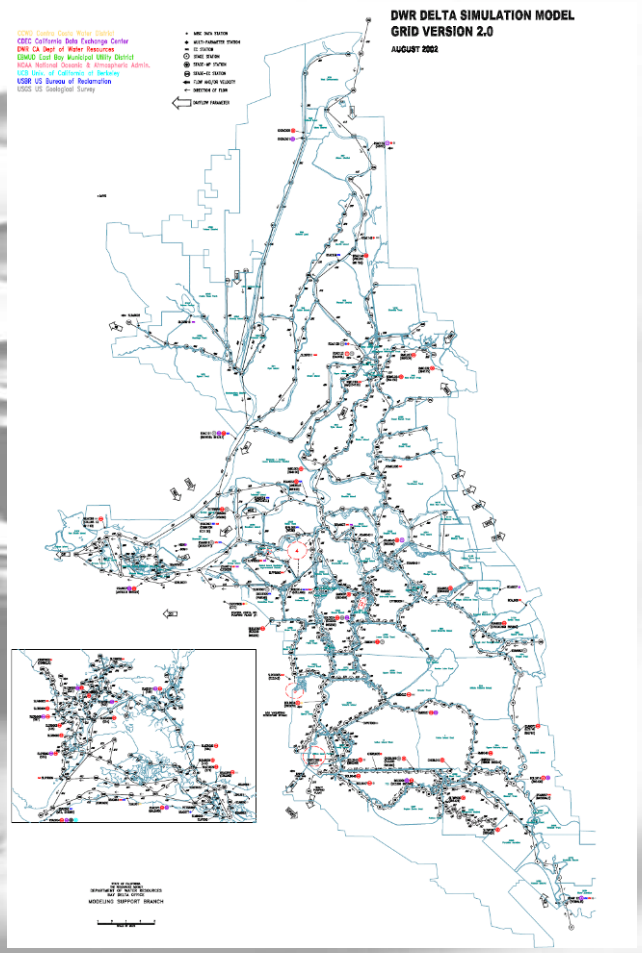
  - Governing equation age distribution:

$$C(a)=\frac{C}{\bar{a}}e^{-\frac{a}{\bar{a}}}$$

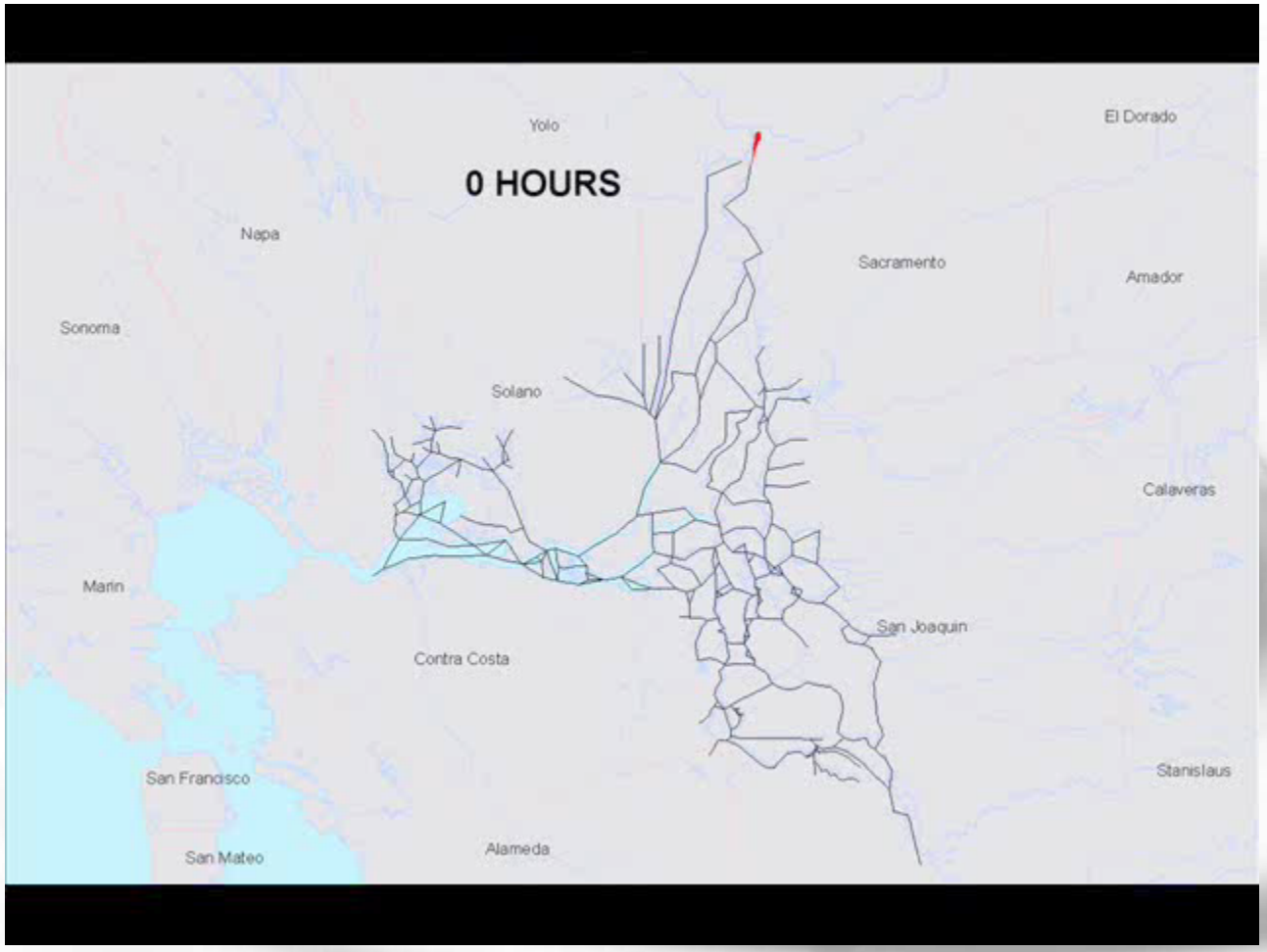
  - where, $\bar{a}$: mean age of eggs

Distributed Model: Transport Data Source

- DSM2
  - 1-D hydrodynamic model
  - Simulates hydrodynamics and water quality in a network of river and estuary channels

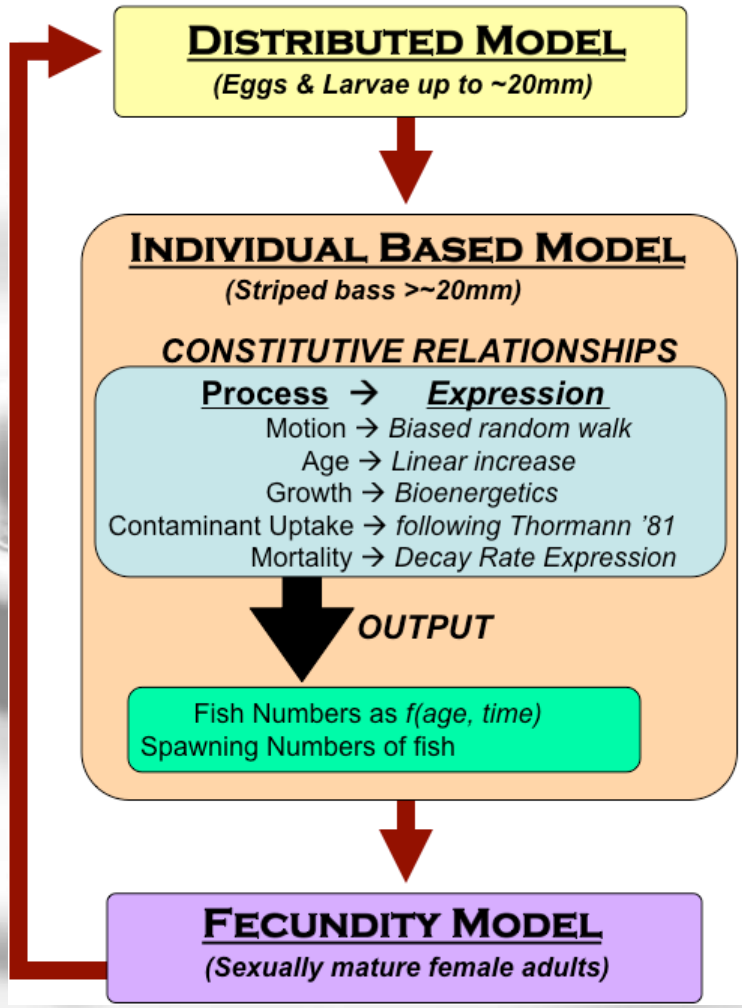


Distributed Model: Example of Output



Individual Based Model

- Model considers:
  - Movement
    - Levy Flight, biased random walk
  - Growth
    - Bioenergetics, following Hartman 1995
  - Age fish
  - Contaminant uptake
    - Following Thormann 1981
  - Mortality
    - Unknown, with some literature values



Individual Based Model: Movement Model

- Movement occurs on a grided map of Bay/Delta
- Every model iteration fish randomly ‘chooses’:
  - Swimming velocity, direction and time
  - Step length = velocity * time
- Swimming time biased where favorable habitat returns a shorter swimming time (hence step length)
  - Depth, salinity, temperature, and prey availability define bias

Individual Based Model: Growth Model

- Striped bass grow according to a bioenergetics model
- Bioenergetics models operate off a balanced energy budget:
  - Energy Consumed = Metabolism + Waste + Growth + Spawning
  - Require water temperature, species specific constants, diet, and weight

Individual Based Model: Contaminant Uptake

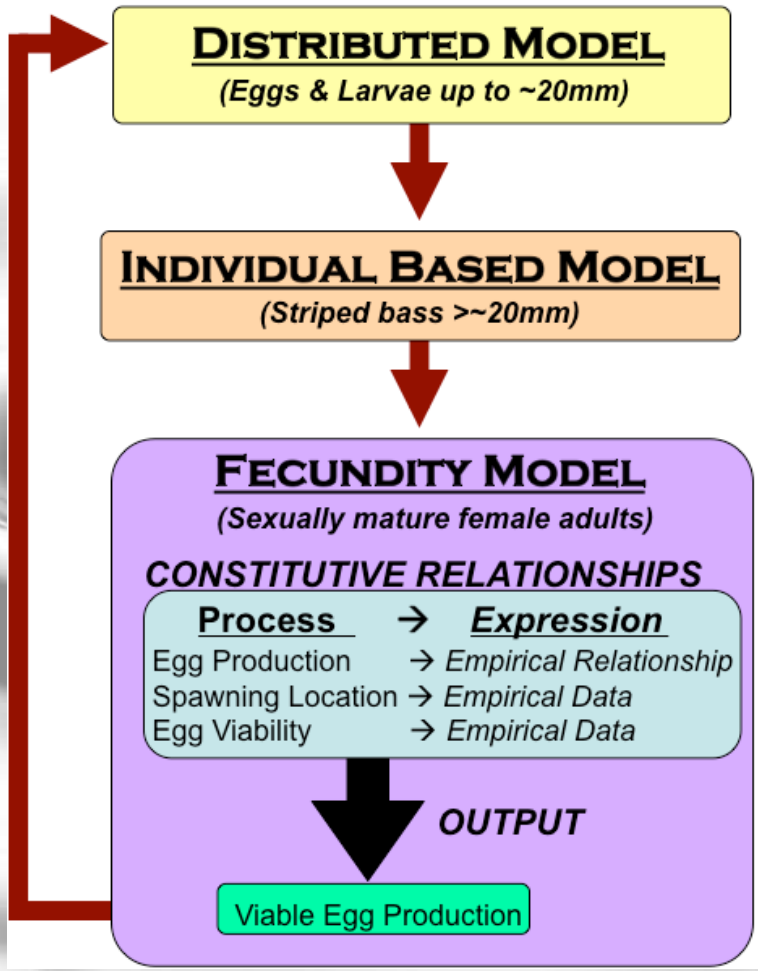
- Uptake guided by a mass-balance approach
  - Following Thormann 1981
  - $Mass_{accumulation} = Mass_{in} - Mass_{out}$
  - Contaminant mass gained through water and food sources
  - Contaminant mass lost through waste and maternal transfer to eggs (certain compounds)
- PCBs used as example contaminant

Individual Based Model: Mortality

- Mortality of a fish currently described by:
  - $x < k_d * dt$
  - Where,
    - x = uniformly distributed random number between 0-1
    - k_d = decay rate, *largely unknown but some values available from literature sources*
    - dt = time step

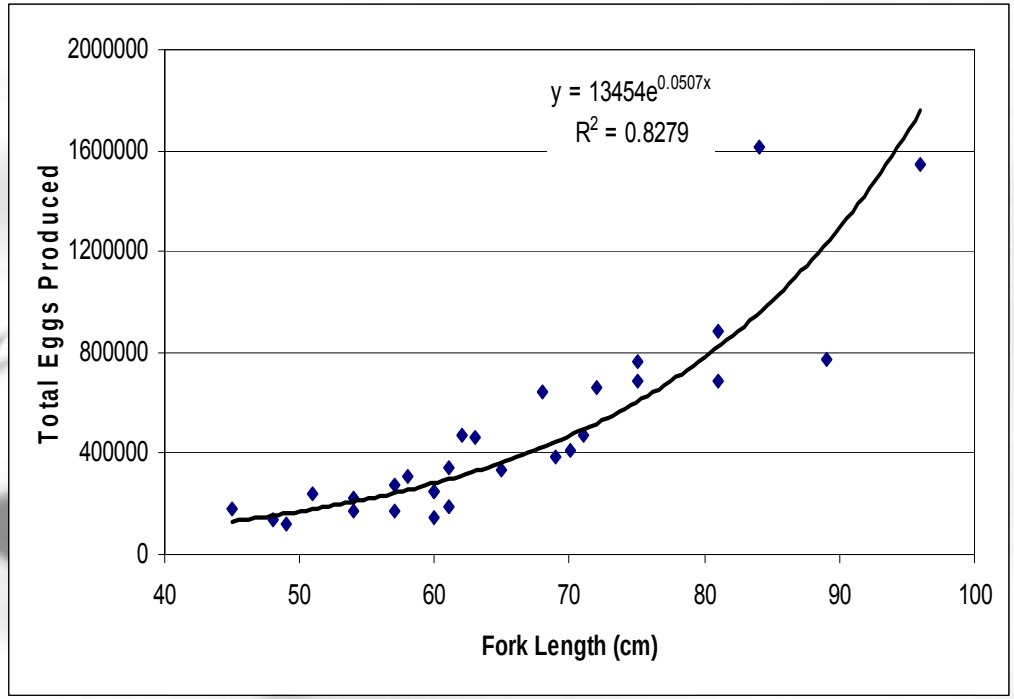
Fecundity Model

- Model considers:
  - Egg Production
  - Spawning Locations
  - Egg Viability



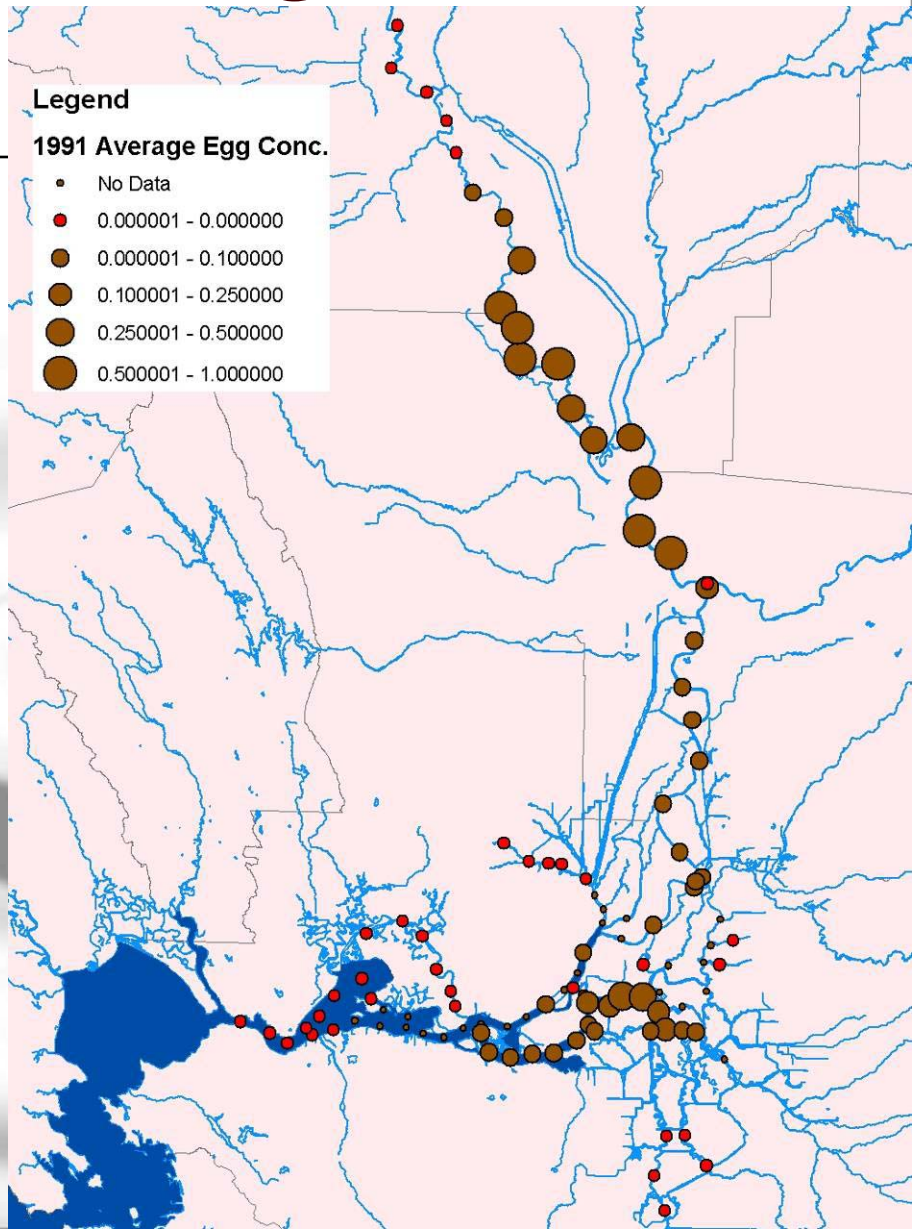
Fecundity Model: Egg Production

- Fecundity relationship defined from DFG field data
- Relationships to age and weight also possible
  - Length provided "best fit"



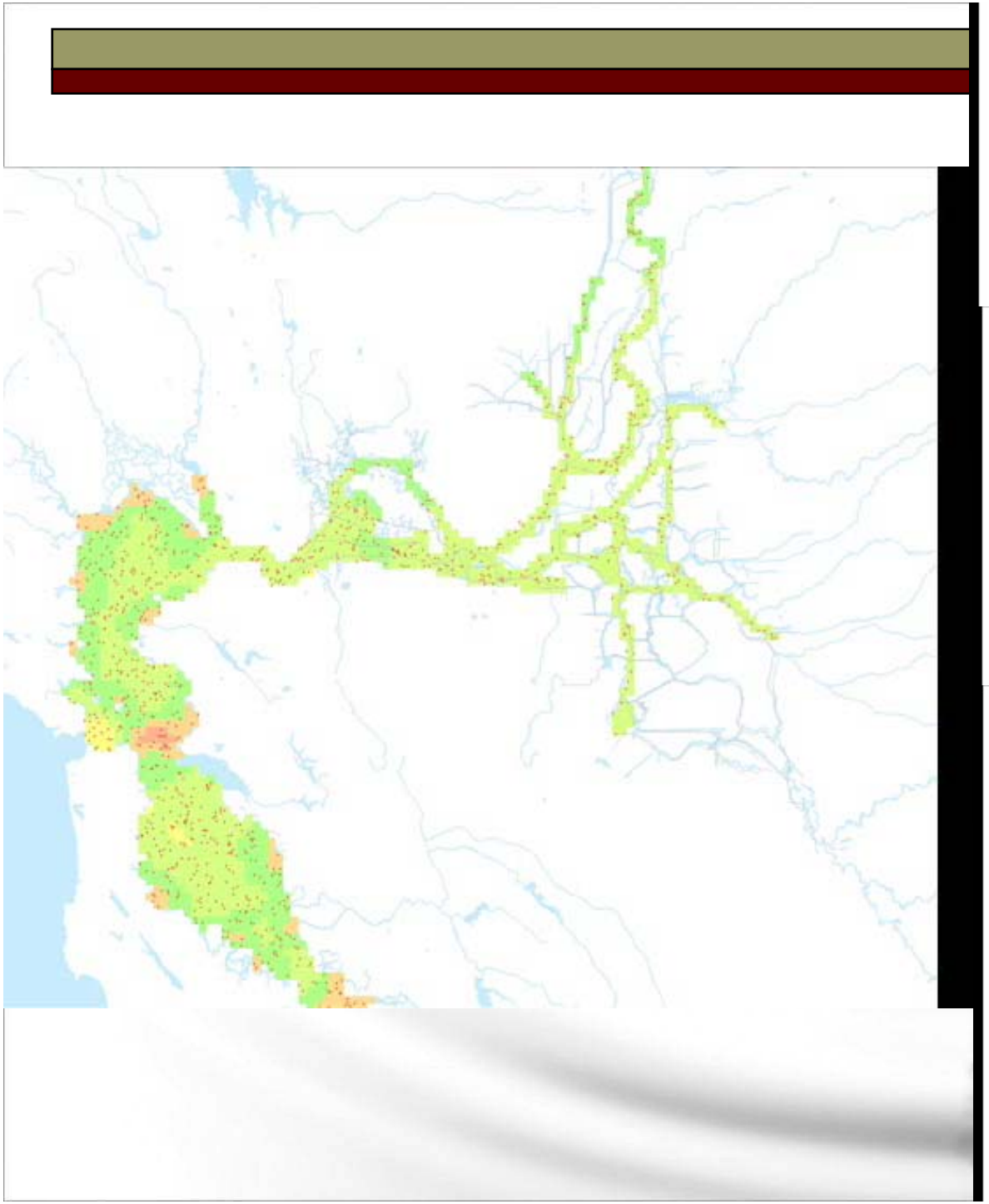
Fecundity Model: Spawning Locations

- DFG striped bass egg and larval field surveys
  - 0 - 8hr old eggs

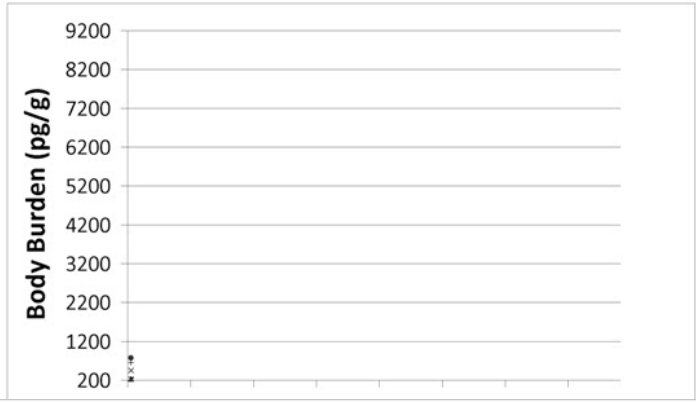


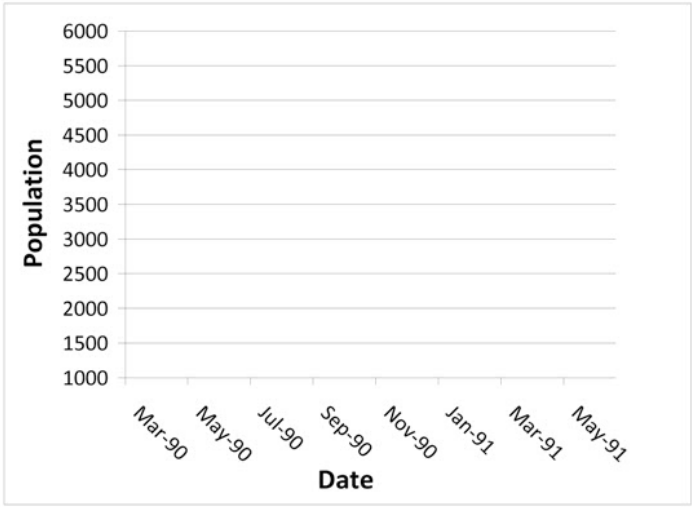
Fecundity Model: Egg Viability

- Represents actual number of eggs input into Distributed Model
- Viable eggs a function of:
  - Egg production
    - Fecundity-Length relationship
  - Contaminant burden
    - Ostach et al.



Weight (g)
6000
5000
4000
3000
2000
1000
0

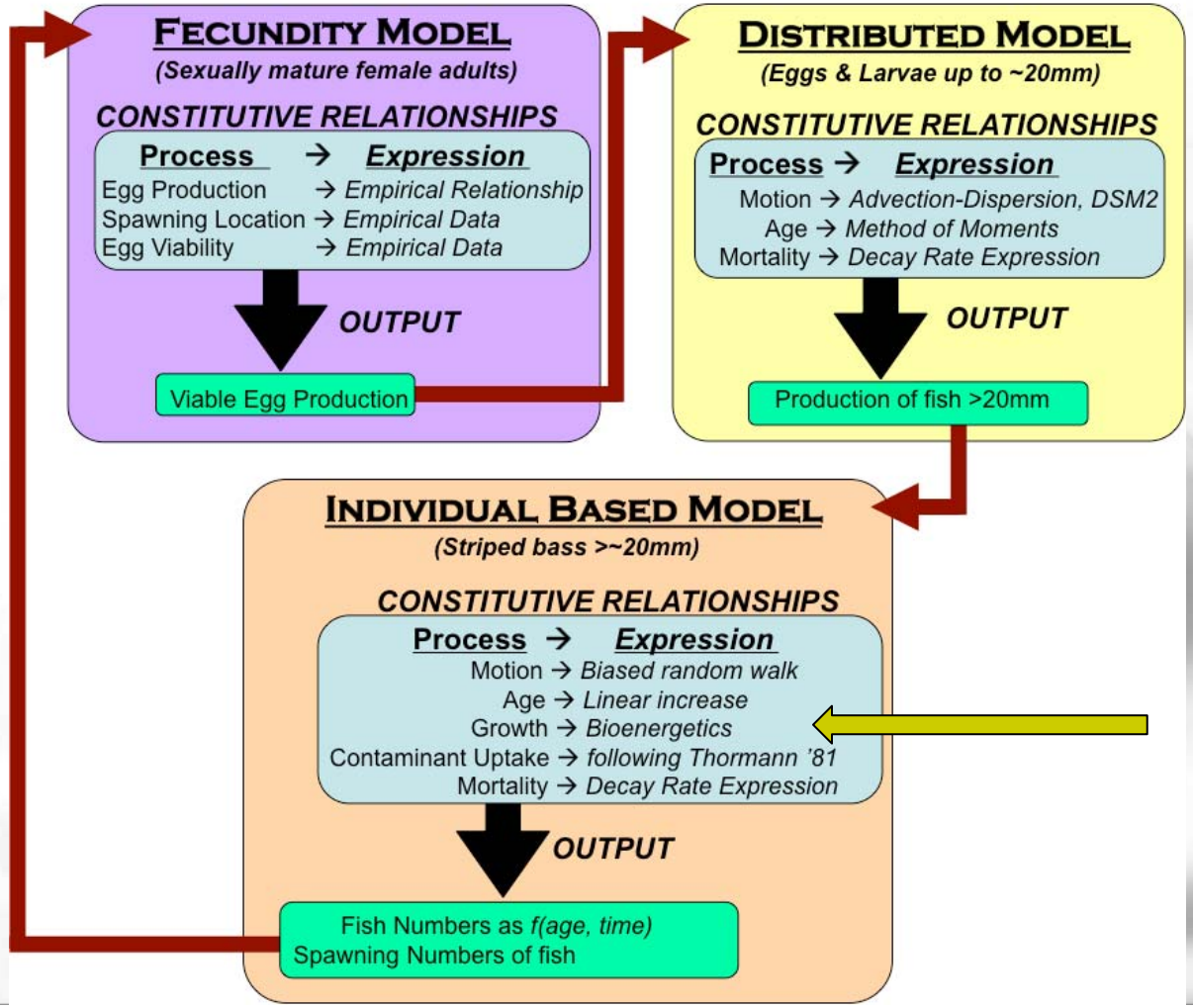

Body Burden (pg/g)
9200
8200
7200
6200
5200
4200
3200
2200
1200
200


Population
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
Mar-90
May-90
Jul-90
Sep-90
Nov-90
Jan-91
Mar-91
May-91
Date

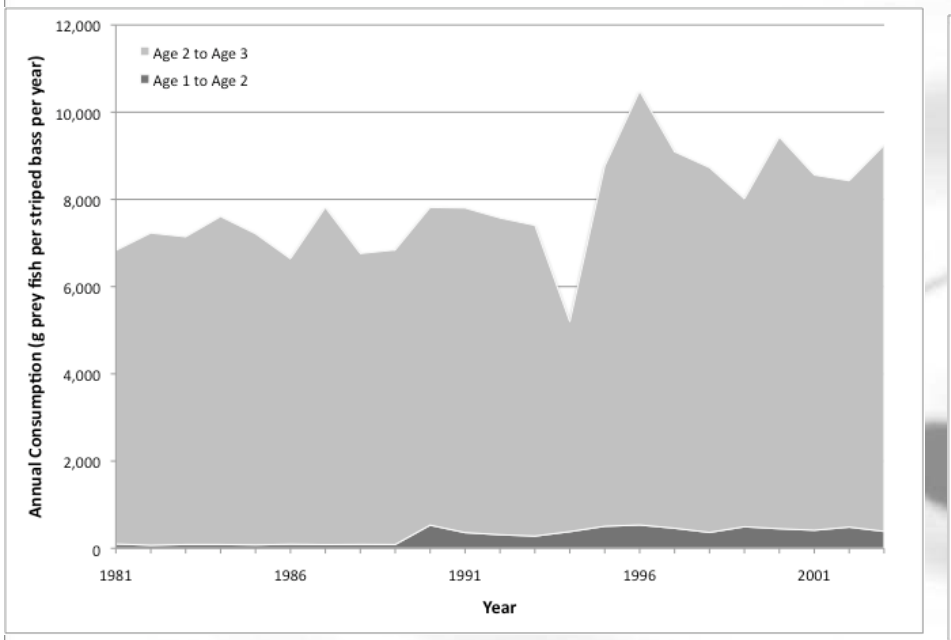
Purpose of Study

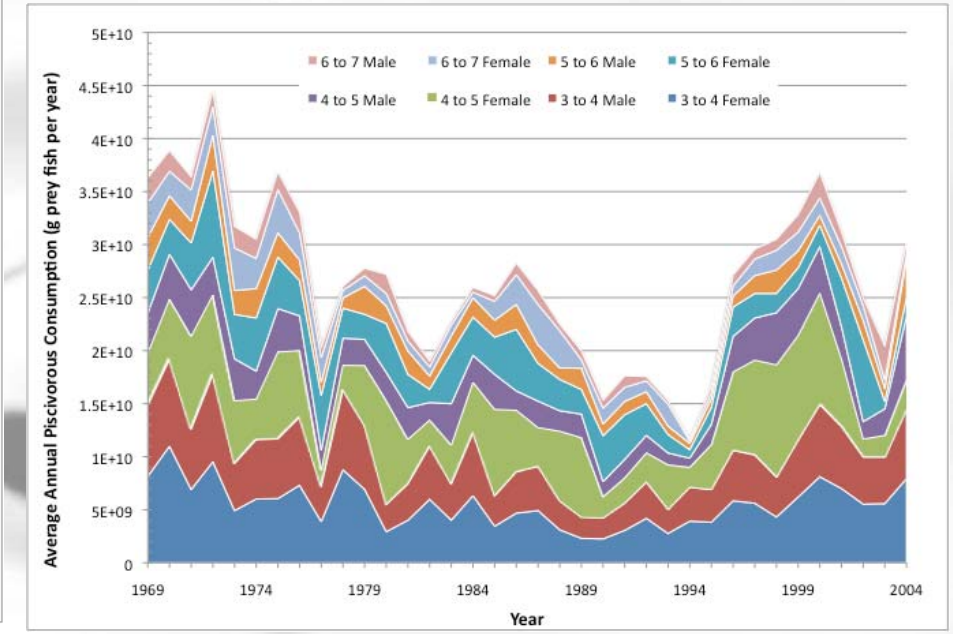
- Develop a population life-cycle model of striped bass
- Apply model to discern the relative significance of selected stressors on the decline of population numbers
- Extend life-cycle model into a generalized modeling framework applicable to other fish species in the Bay-Delta

Does the model work? Does it produce useful reliable information for estuarine management?



Is Striped Bass Piscivorous Prey Consumption Important in Recovery Planning Efforts?





What level of physical modeling accuracy is really warranted given biological data and knowledge gaps?

- Data driven model construction versus philosophical
- Effective modeling approach and therefore not predictive but relative for effects analysis.
  - Model that captures essential cause/effect relationships
- Quantifying the level of accuracy
  - Variances of the distributions of the parameters independently estimated

Data Availability: Distributed and Fecundity Models

- <u>Distributed Model</u>
  - ✓ DSM2 Hydrodynamics
    - Movement
  - ✓ Egg and larvae survey data
  - ✓ Water Temperature
    - Time to maturation
  - ✓ Mortality Rate

- <u>Fecundity Model</u>
  - ✓ Fecundity = *f* (Length)
  - ✓ Spawning locations
  - ☐ Egg Viability
    - i.e. contaminant burden

Data Availability: Individual Based Model

Movement:

- ✓ Salinity
- ✓ Depth
- ✓ Temperature
- ✓ Prey Availability

Growth:

- ✓ Striped bass specific parameters
- ✓ Temperature
- ✓ Weight
- ✓ Diet

Contaminant Uptake (PCBs):

- ✓ Prey consumption
- ✓ Respiration/elimination constants
- ✓ [Aqueous] & [sediment]
- ✓ Contaminant body burdens of field collected fish
- ☐ [Prey]

Mortality Rates:

- ✓ Natural vs. fishing
- ☐ Age and sex specific

Quality Assurance/Certification

- Monte Carlo Inverse Modeling to obtain likelihood distributions of fitted parameters given distribution of inputs for each model component.

Verification/Uncertainty/Simulation

Define distributions for inputs (D_1, D_2,…, D_n)

Generate sample values from distributions ($\mathbf{x}_1$, $\mathbf{x}_2$,…, $\mathbf{x}_n$)

Apply sample values to models to produce results ([$\mathbf{x}_i$, y($\mathbf{x}_i$)], i= 1, 2,…,n).

- Forward Monte Carlo Modeling
  - Use varying 'known' independently estimated parameters
  - Use varying fitted (Inverse MC)
  - Construct distributions of population numbers

Support

- Funding for this work has been provided by the Department of Water Resources through the Interagency Ecological Program

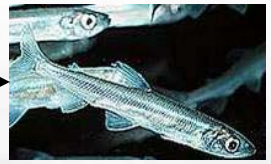
Possible Future Directions

Watershed Hydrology

Operations of Man-made Structures, Decisions/Regulations about CVP/SWP water system (i.e. operation of dams and pumps; court rulings, agreements with ag. and M&I water users)

DELTA WATER OPERATIONS

Delta Hydrodynamics,
Tidal effects,
Operation of barriers and gates
Sea level Rise, Levi break
Scenarios



Historic Inflows from watersheds
or
CLIMATE CHANGE MODEL
combined with Hydrology model

CALSIM II

Hydraulic models

Fish model(s)

Hydraulic models

Fish model(s)

Historic Inflows

Questions?

Individual Based Model: Growth

- Each time-step fish grows according to the bioenergetics model:

$$W_t = W_{t-1} + \left(\frac{1}{e_s} \sum_{j=1}^{n} \alpha_j e_{p,j} \right) (pC_{\max} - R - SDA - F - U) - S_p$$

  - ***Where,***
    - W = weight
    - α_j = percentage consumption of prey j
    - e_s, e_p = energy densities of striped bass and prey j, respectively
    - pC_{max} = realized consumption, *f(food avail, w, temp)*
    - R = Respiration, *f(w, temp)*
    - SDA = Specific dynamic action , $f(pC_{max}, F)$
    - F = egestion, $f(pC_{max})$
    - U = excretion , $f(pC_{max}, F)$
    - S_p = spawning weight loss

Individual Based Model: Data Sources for Growth Model

- Bioenergetics constants obtained from literature
  - Hartman 1995
  - Energy densities (Hartman 1995, Steimle 1985)
- Temperature obtained from field data
  - IEP, USGS, DWR
- Diets defined from gut analysis (field/literature)
  - Bryant 2007, Slater, Hartman 1995
- Percentage of maximum consumption (*p*) calibrated to match growth data
  - DFG tagging data (adults age 3-7)

Individual Based Model: Contaminant Uptake

- Uptake of total contaminants is guided by *(following Thormann 1981)*:

$$\beta_t = \beta_{t-1} + \alpha_1 \eta [PCB]_a dt + \alpha \sum_{j=1}^{n} C_j W_{t-1} [PCB]_p - \mathrm{N}\beta_{t-1}$$

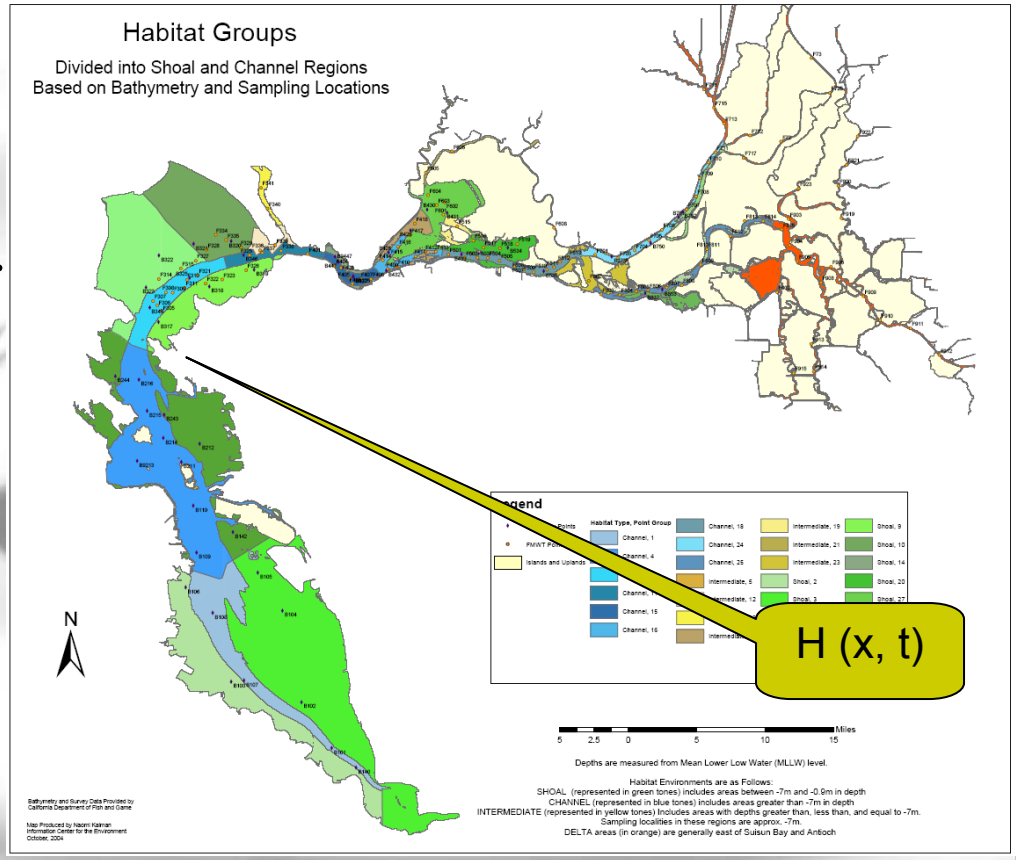
β_t = Total PCB's (*μg PCB's)*
α_1 = Aqueous assimilation efficiency , *following Thormann 1981*
η = Fish respiration rate *($L\ d^{-1}$), currently assumed (literature)*
$[PCB]_a$ = Aqueous concentration of PCB's (*μg PCB's L^{-1})*
α = Dietary assimilation efficiency, *currently assumed*
C_j = Consumption of prey type *j* (*$g_{prey}\ g_{bass}^{-1}$), from growth model*
W = Striped bass weight *(g_{bass}), from growth model*
$[PCB]_{p,j}$ = Concentration of PCB's in prey type *j* (*μg PCB's g_{prey}^{-1})*
N = Desorption or elimination rate *(d^{-1}), from Pizza 1983*

- Body burden (*BB*):

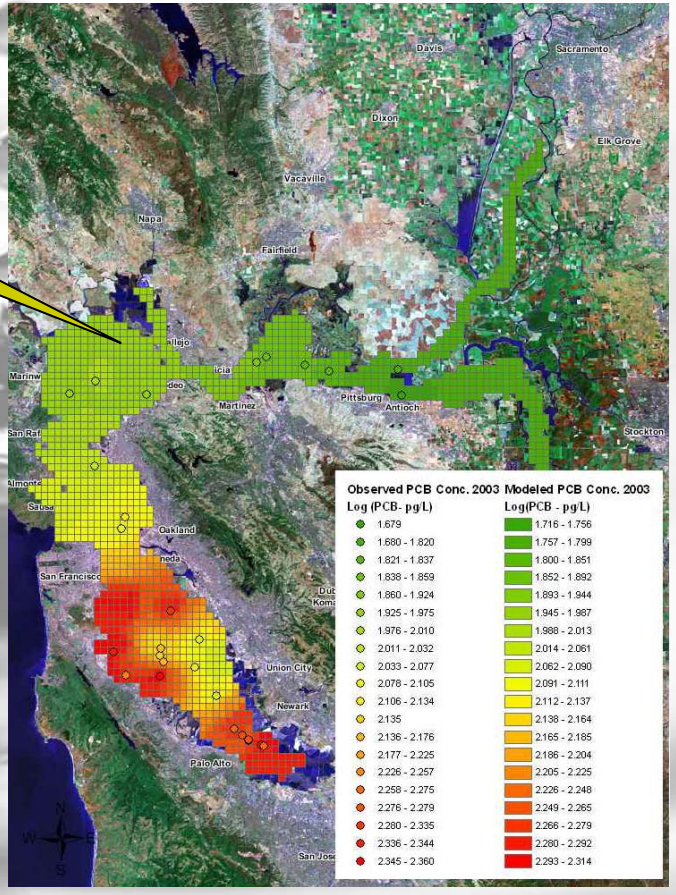
$$BB = \frac{\beta_t}{W_t}$$

Individual Based Model: Data Sources for Movement Model

- Bias based upon:
  - Literature
    - Feyrer 2007
  - Salinity
    - SFEI, IEP, USGS, K. Rose et al.
  - Depth
    - SFEI EcoAtlas
  - Prey availability
    - BDAT
  - Temperature
    - DWR, IEP, USGS



Individual Based Model: Data Sources for Contaminant Uptake

- PCB aqueous and sediment concentrations
  - PCB aqueous and sediment concentrations
    - From SFEI
  - Dietary sources
    - Proportionally related to sediment concentrations

C (x, t)