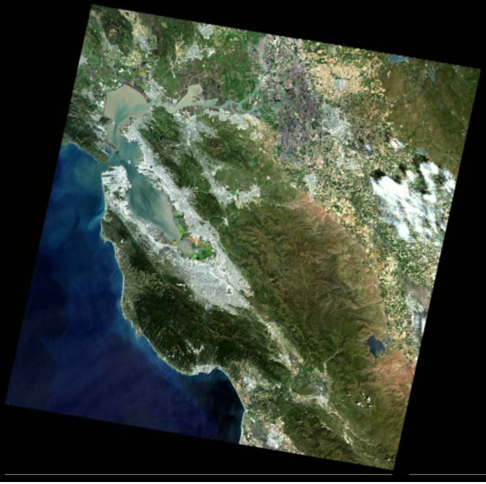
An ecosystem model for testing potential causes of the San Francisco Estuary pelagic organisms decline



Howard Townsend, Marissa Bauer, Larry Brown, Fred Feyrer,
NCEAS-POD working group

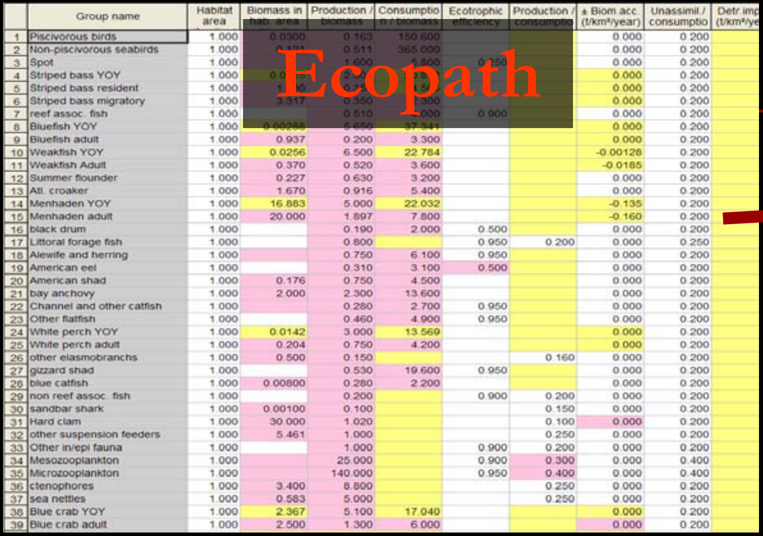
Problem Statement

- Abundance indices of several pelagic fishes in the upper San Francisco Estuary (delta smelt, age-0 striped bass, longfin smelt, and threadfin shad) had remained unusually low since early 2000s
- Seek to examine simultaneously the effects of multiple potential drivers on one or more fishes and place these declines in the broader context of estuarine degradation
- Modeling monotonic declines of a species using correlative approaches can be difficult as other factors with monotonic declines should correlate well.

Our Approach

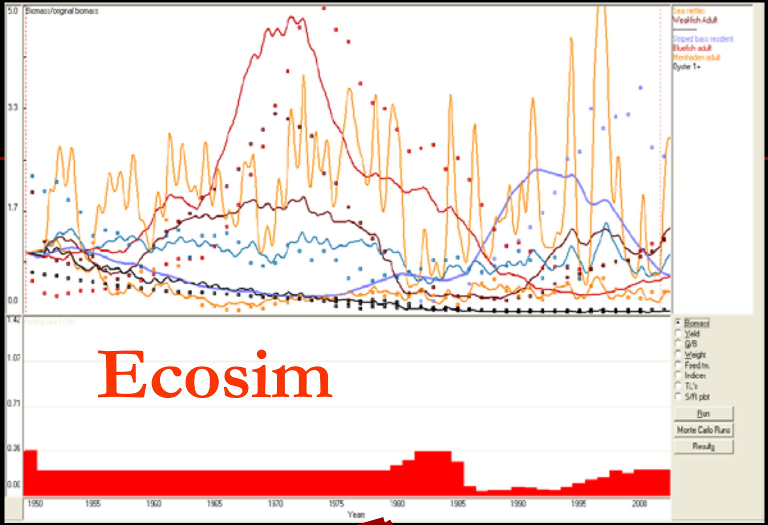
- Instead of using correlative approaches, use simulation modeling
- Instead of solely modeling populations in decline, also model populations that were increasing
- Use our knowledge of the ecosystem (esp. food web and habitat) to explore potential hypotheses to explain the decline
- Use a modular building-block approach
  - Understand energetic flows in system (Ecopath)
  - Explore hypotheses about the system using simulation (Ecosim)
  - Build spatially-explicit model using lesson learned from exploratory phase (Ecospace)
  - Incorporate hydrodynamics for a Management Strategy Evaluation tool (coupled model)

Ecosystem Modeling: Ecopath with Ecosim (EwE)

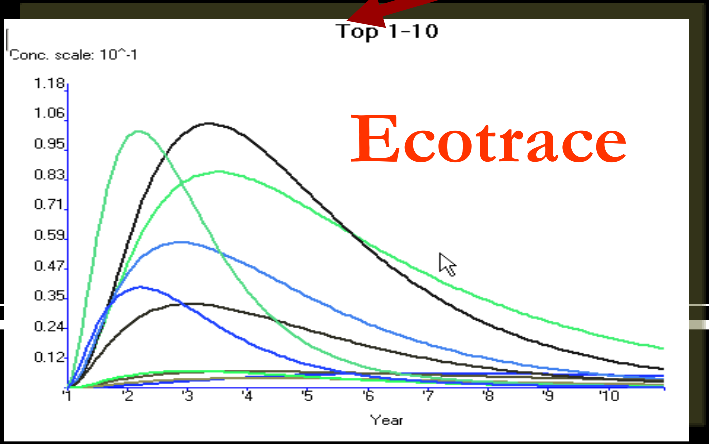


	Group name	Habitat area	Biomass in hab. area	Production / biomass	Consumption / biomass	Ecotrophic efficiency	Production / consumptio	± Biom.acc. (t/km²/year)	Unassimil / consumptio	Detr. imp (t/km²/ye
1	Piscivorous birds	1.000	0.0300	0.163	150.600			0.000	0.200	
2	Non-piscivorous seabirds	1.000	[illegible]	0.511	365.000			0.000	0.200	
3	Spot	1.000	[illegible]	1.600	5.800	0.250		0.000	0.200	
4	Striped bass YOY	1.000	[illegible]	[illegible]	[illegible]			0.000	0.200	
5	Striped bass resident	1.000	[illegible]	[illegible]	[illegible]			0.000	0.200	
6	Striped bass migratory	1.000	3.317	0.350	[illegible]			0.000	0.200	
7	reef assoc. fish	1.000		0.510	[illegible]	0.900		0.000	0.200	
8	Bluefish YOY	1.000	0.00268	6.650	37.341			0.000	0.200	
9	Bluefish adult	1.000	0.937	0.200	3.300			0.000	0.200	
10	Weakfish YOY	1.000	0.0256	6.500	22.784			-0.00128	0.200	
11	Weakfish Adult	1.000	0.370	0.520	3.600			-0.0185	0.200	
12	Summer flounder	1.000	0.227	0.630	3.200			0.000	0.200	
13	Atl. croaker	1.000	1.670	0.916	5.400			0.000	0.200	
14	Menhaden YOY	1.000	16.883	5.000	22.032			-0.135	0.200	
15	Menhaden adult	1.000	20.000	1.897	7.800			-0.160	0.200	
16	black drum	1.000		0.190	2.000	0.500		0.000	0.200	
17	Littoral forage fish	1.000		0.800		0.950	0.200	0.000	0.250	
18	Alewife and herring	1.000		0.750	6.100	0.950		0.000	0.200	
19	American eel	1.000		0.310	3.100	0.500		0.000	0.200	
20	American shad	1.000	0.176	0.750	4.500			0.000	0.200	
21	bay anchovy	1.000	2.000	2.300	13.600			0.000	0.200	
22	Channel and other catfish	1.000		0.280	2.700	0.950		0.000	0.200	
23	Other flatfish	1.000		0.460	4.900	0.950		0.000	0.200	
24	White perch YOY	1.000	0.0142	3.000	13.569			0.000	0.200	
25	White perch adult	1.000	0.204	0.750	4.200			0.000	0.200	
26	other elasmobranchs	1.000	0.500	0.150			0.160	0.000	0.200	
27	gizzard shad	1.000		0.530	19.600	0.950		0.000	0.200	
28	blue catfish	1.000	0.00800	0.280	2.200			0.000	0.200	
29	non reef assoc. fish	1.000		0.200		0.900	0.200	0.000	0.200	
30	sandbar shark	1.000	0.00100	0.100			0.150	0.000	0.200	
31	Hard clam	1.000	30.000	1.020			0.100	0.000	0.200	
32	other suspension feeders	1.000	5.461	1.000			0.250	0.000	0.200	
33	Other in/epi fauna	1.000		1.000		0.900	0.200	0.000	0.200	
34	Mesozooplankton	1.000		25.000		0.900	0.300	0.000	0.400	
35	Microzooplankton	1.000		140.000		0.950	0.400	0.000	0.400	
36	ctenophores	1.000	3.400	8.800			0.250	0.000	0.200	
37	sea nettles	1.000	0.583	5.000			0.250	0.000	0.200	
38	Blue crab YOY	1.000	2.367	5.100	17.040			0.000	0.200	
39	Blue crab adult	1.000	2.500	1.300	6.000			0.000	0.200	

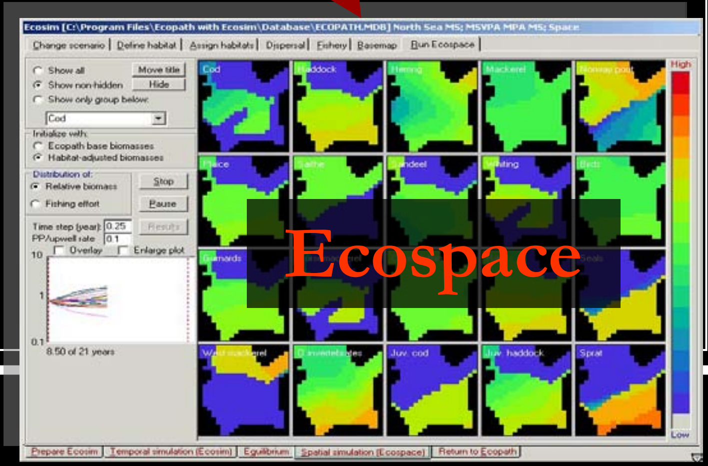
Ecopath



Ecosim



Ecotrace


Ecosim [C:\Program Files\Ecopath with Ecosim\Database\ECOPATH.MDB] North Sea MS; MSVPA MPA MS; Space

Time step (year): 0.25
PP/upwell rate: 0.1
8.50 of 21 years

Ecospace

NMFS, Bering Sea, GoAlaska
Prince William Sound
UBC
DFO
Four Fish. Commissions
UoWisconsin
NOAA, Chesapeake Bay
San Francisco Estuary.
Trop. Tuna Comm.
NCEAS
S Atlantic Fish.Comm.
Mote lab
La Paz, Mexico
G.o Mexico
West Florida
Mote Lab.
Yucatan reefs
Jamaica, BVI, . . .
Colombia
Trinidad
Venezuela
Charles Darwin
Research Station,
Galapagos

Abrolhos, Brazil
Sao Paulo, Brazil
Tongoy Gulf, Chile
Concepcion, Chile
Argentina

Greenland
Fisheries Inst.

Azores
F.I.

Faroe Fisheries Inst
IMR, Bergen
Baltic Sea RP, GEF
DIFRES,
Charlottenlund
CEFAS, Lowestoft
Black Sea, Turkey
Venice
Santander
Fish. Inst, Lisboa
Six West African
Countries

Namibia
Cape Town

★ training
courses /
workshops

Ecopath Mass Balance

$$B_i * \left(\frac{P}{B}\right)_i * EE_i - \sum_{j=1}^{n} B_j * \left(\frac{Q}{B}\right)_j * DC_{ji} - Y_i * E_i - * BA_i = 0$$

B= Biomass,
P/B= Production per Biomass,
Q/B=Consumption Per Biomass,
DC= Diet Consumption,
EE= Ecotrophic Efficiency,

Y=Yield (removals), E= Emigration, BA=Biomass Accumulation

Ecosim

- A time-dynamic simulation tool for hypothesis exploration and studying management policy options

- Ecosim builds on Ecopath

- Typically,
  - Use Ecosim to estimate vulnerability parameters by fitting to time series data,
  - Then use Ecosim to project implications of policy and management decisions

Ecosim Master Equation

$$\frac{dB_i}{dt} = g\sum_{j=1}^{n} Q_{ji} - \sum_{j=1}^{n} Q_{ij} + I_i - \left(M_i + F_i + e_i\right) B_i$$

B_i biomass of trophic group i

g_i growth efficiency

Q_{ji} consumption of prey (j)

Q_{ij} consumption by predators (j)

I_i immigration rate

M_i other mortality rate

F_i instantaneous rate of fishing mortality

e_i emigration rate

Ecosim: Time series data

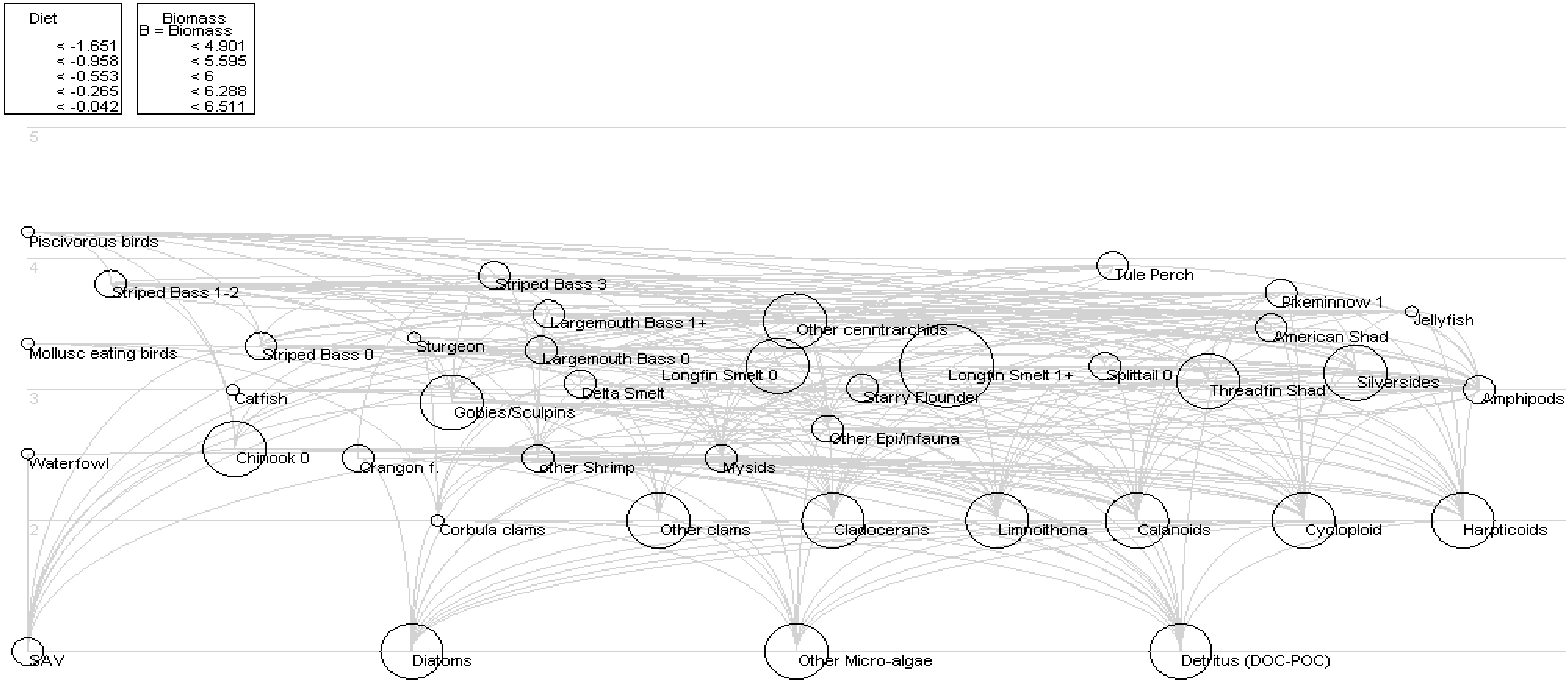
Drivers

- Mortality rates
- Fleet effort
- Biomass (force)
- Time forcing data (e.g., prim. prod., salinity)

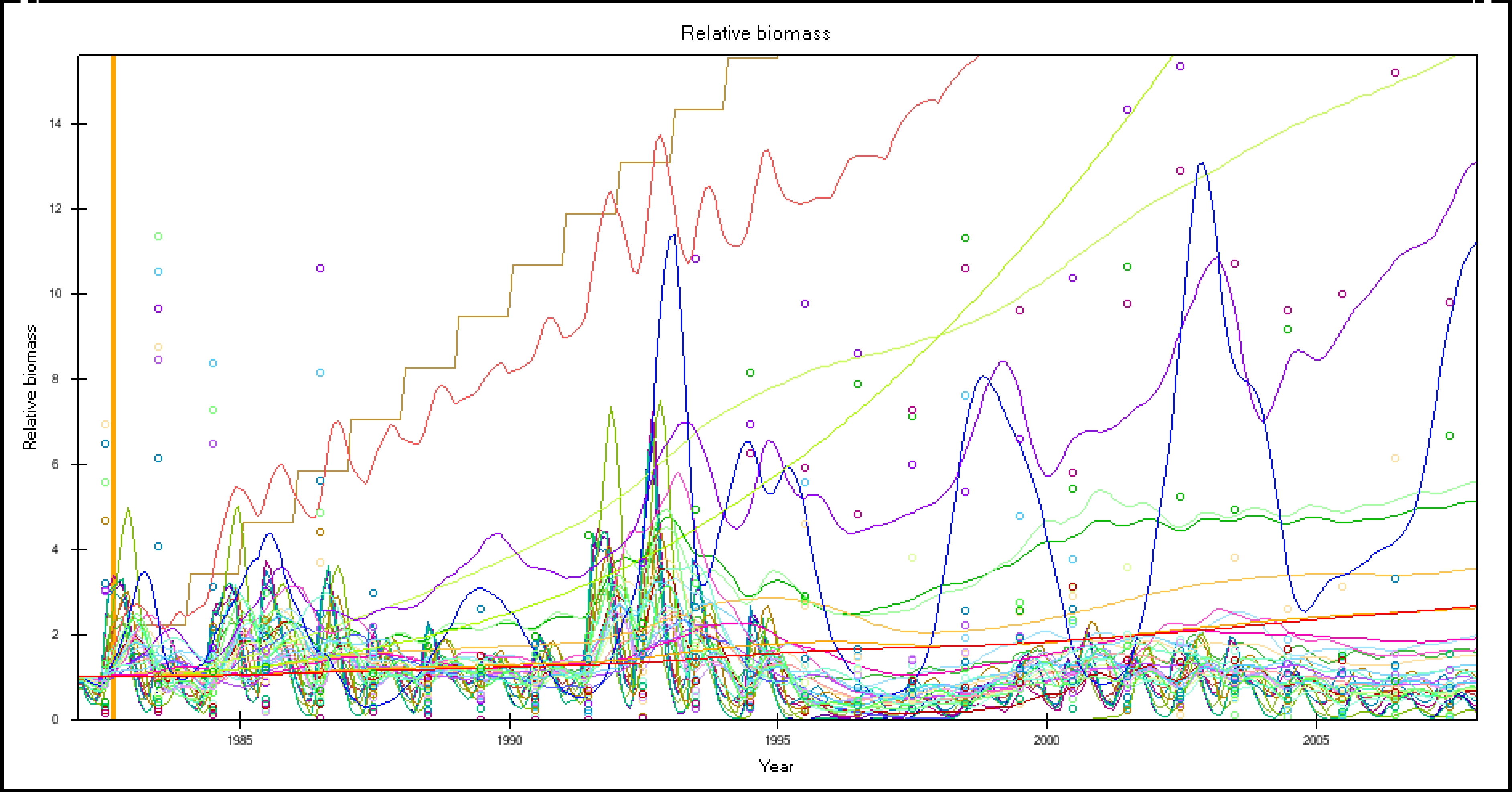
Evaluation

- Biomass (relative, absolute)
- Total mortality rates
- Catches/Removals
- Average weights
- Diets

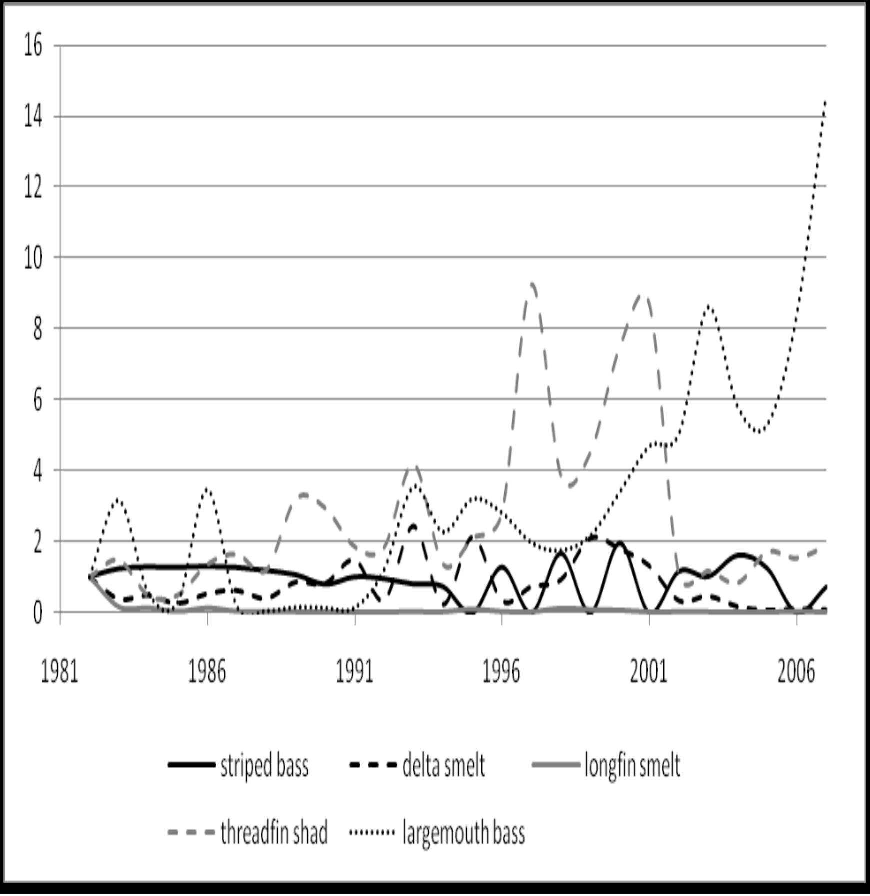
Ecopath: Mass balanced snapshot of SFE in early 1980s



Ecosim: Simulation of the POD species since early 1980s

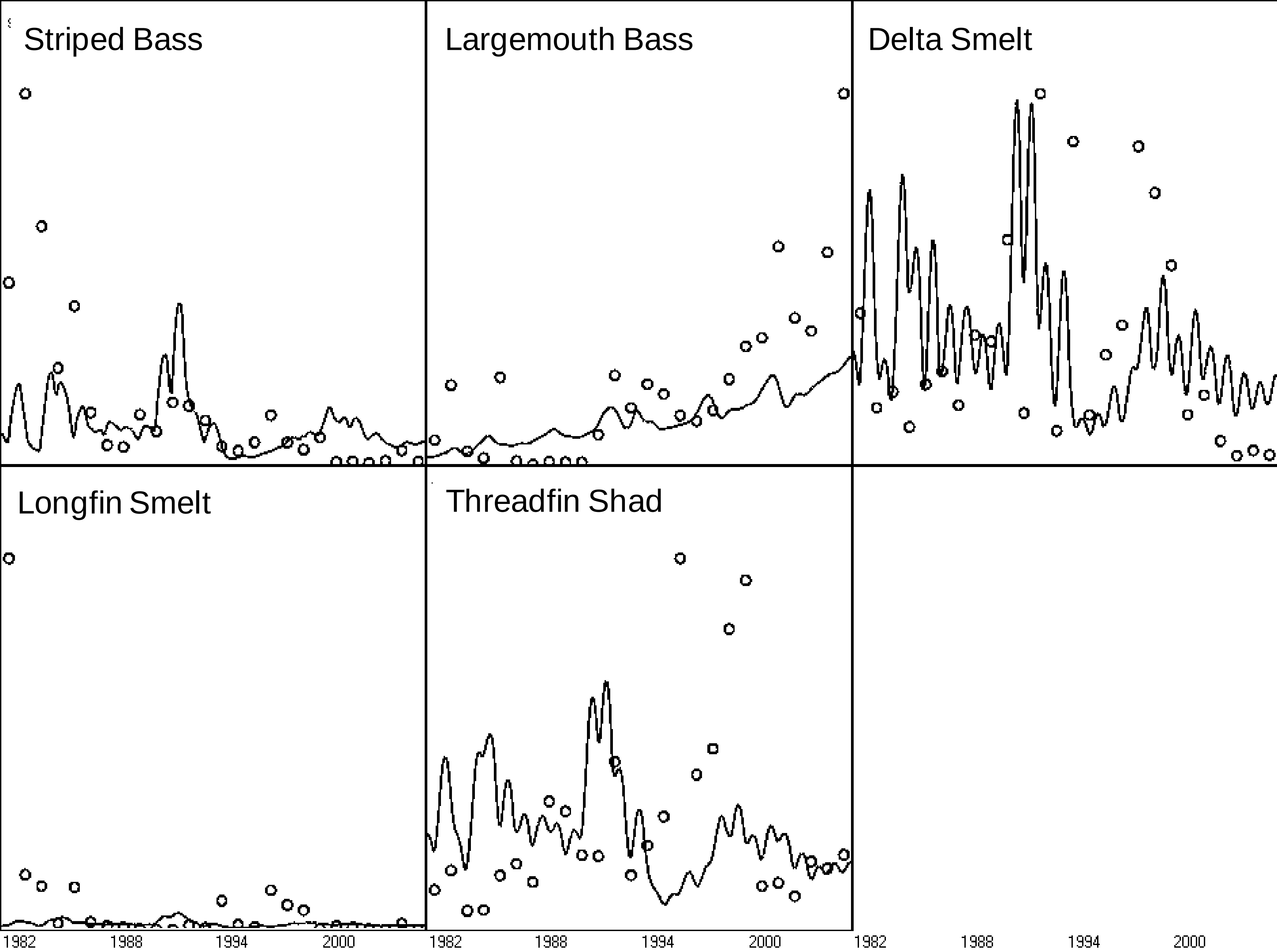


Ecosim: Hypotheses explored



- Decreased primary productivity/ Chlorophyll-a.
- Invasive species
  - Corbula Clams,
  - Limnoithona, and
  - Submerged aquatic vegetation – SAV)

	Invasives-Food Web				
Model effects	Chl-a	Corbula	Limnothoina	SAV	
Type of function/ Model ID	Forcing Function	Forced Biomass	Forced Biomass	Forced Biomass	Sum of Squares
A	X	X			226.3
B	X				217.3
C		X			224.9
D	X		X		213.1
E	X			X	161.7
F	X	X	X	X	210.6
G	X	X	X		224.7
H	X		X	X	181.4
I	X	X		X	212.7
Q					187.2
R	X	X	X	X	214.5


Striped Bass
Largemouth Bass
Delta Smelt
Longfin Smelt
Threadfin Shad
1982
1988
1994
2000
1982
1988
1994
2000
1982
1988
1994
2000

Conclusions

- Best fit comes from forcing primary production and SAV, suggesting an exogenous factor driving the system (i.e., not necessarily Limnothoina or Corbula)
- HOWEVER using a “Top-Down” model
  - also estimates of invasives could be improved
- We can re-work Ecopath for a “Bottom-Up” model to see if initial conditions have an effect on conclusions
- We can build spatially explicit model that does not rely on forcing functions

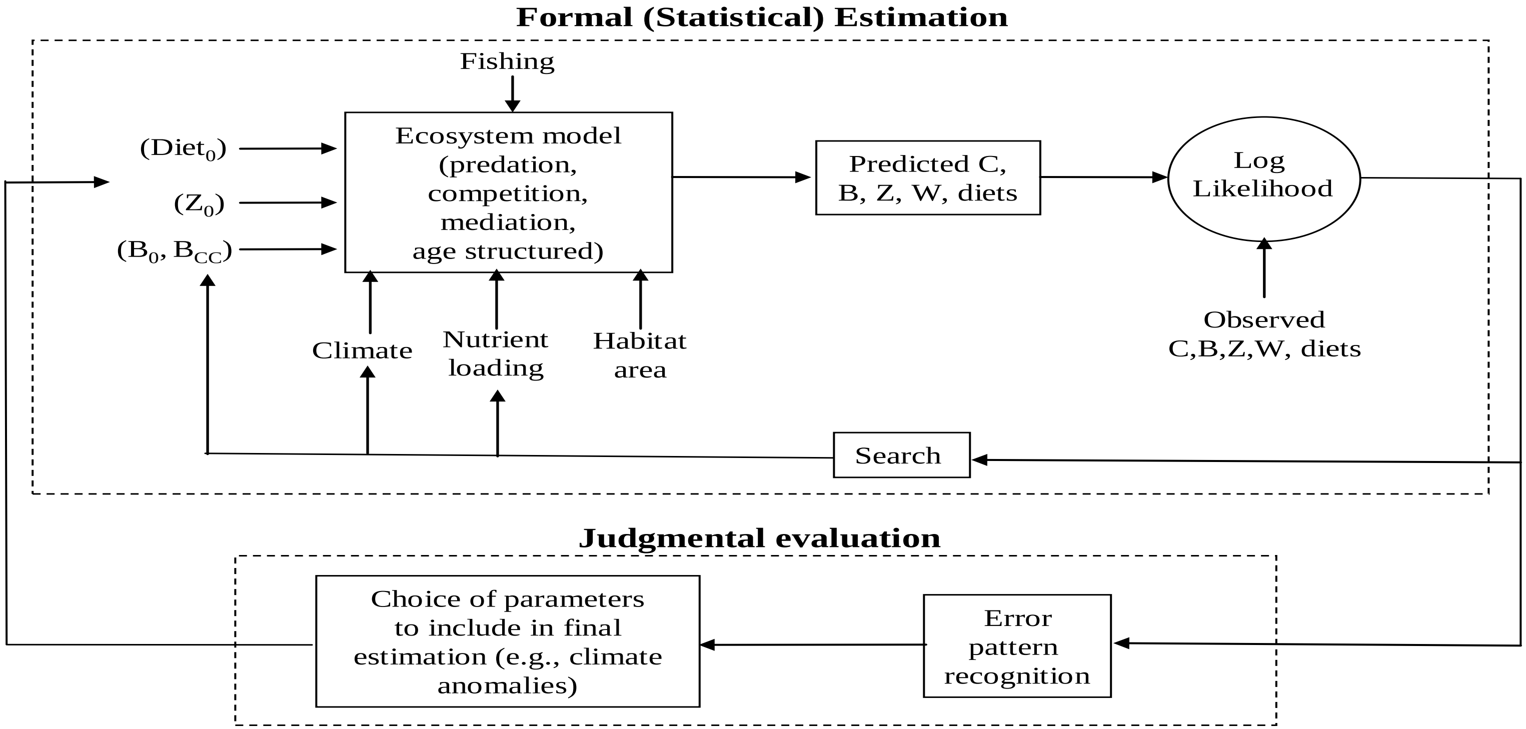
Parting point to consider

“Ecosystem models… will frequently be the best sources of such [resource management] information. In its absence, managers and decision-makers will have no choice but to fall back on their own mental models which may frequently be subjective, untested and incomplete, a situation which is clearly to be avoided.”

- The ecosystem approach to fisheries. Best practices in ecosystem modelling: modelling ecosystem interactions for informing an ecosystem approach to fisheries. No. 4 Suppl.2.1. Rome, FAO. 200. 44p.

Extra slides

Ecosim: Fitting to data



Formal (Statistical) Estimation

Fishing

(Diet_0)

(Z_0)

(B_0, B_{CC})

Ecosystem model
(predation,
competition,
mediation,
age structured)

Predicted C,
B, Z, W, diets

Log
Likelihood

Climate

Nutrient
loading

Habitat
area

Observed
C,B,Z,W, diets

Search

Judgmental evaluation

Choice of parameters
to include in final
estimation (e.g., climate
anomalies)

Error
pattern
recognition

Ecosim: Forcing and Mediation Functions

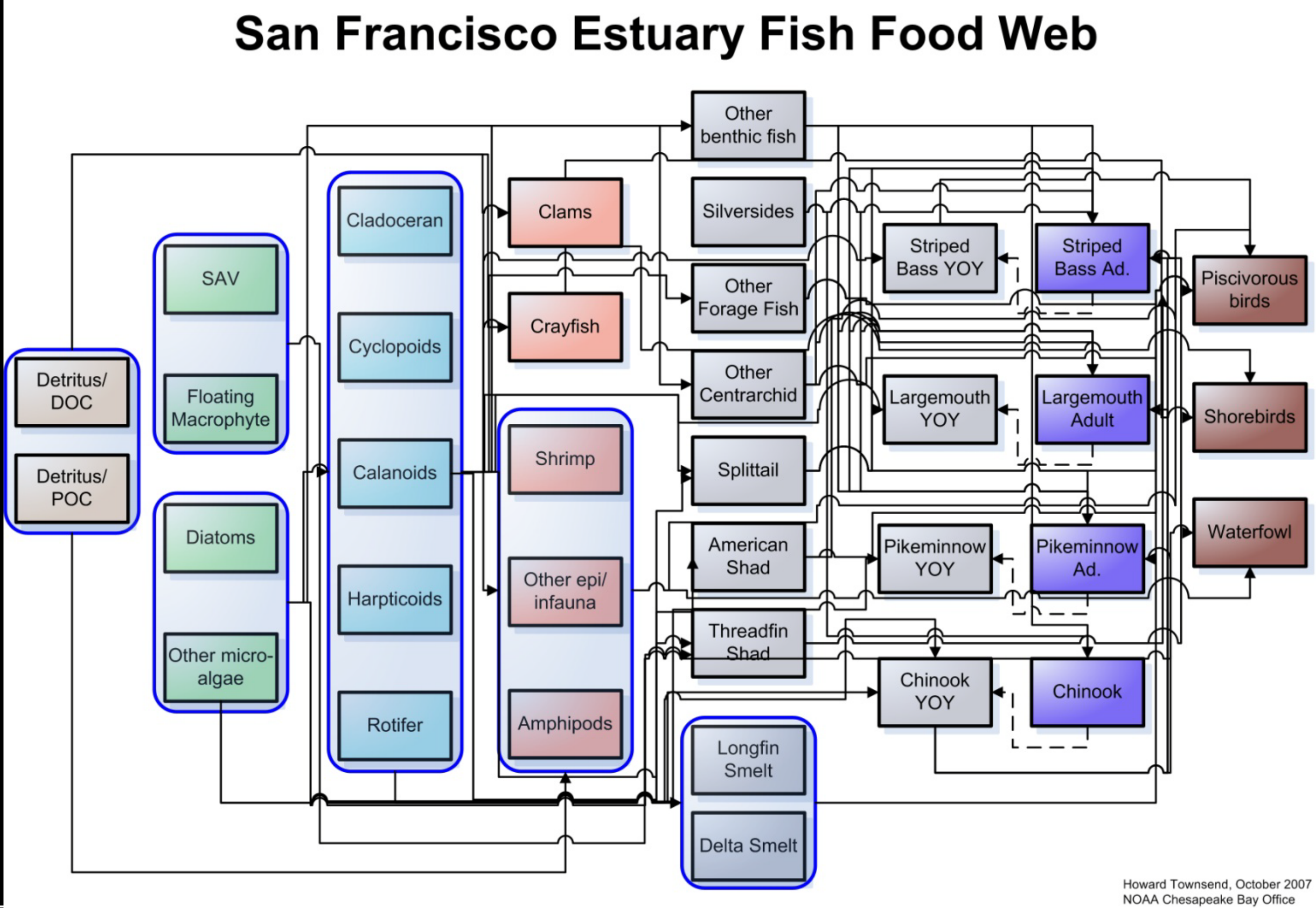
$$Q_{ij} = \frac{a_{ij} v_{ij} B_i B_j T_i T_j S_{ij} \dfrac{M_{ij}}{D_j}}{v_{ij} + v_{ij} T_i M_{ij} + a_{ij} M_{ij} B_j S_{ij} \dfrac{T_j}{D_j}}$$

Ecosim: Forcing and Mediation Functions

$$D_j = \frac{h_j T_j}{1 + \sum_k a_{kj} B_k T_k M_{kj}}$$

aij is the rate of effective search for i by j, Ti represents prey relative feeding time, Tj the predator relative feeding time, Sij the user-defined seasonal or long term forcing effects, Mij the mediation forcing effects, and Dj represents effects of handling time as a limit to consumption rate

Initial conceptual model of SFE Fisheries Ecosystem



Why Model?

- Usually not feasible to monitor all performance indicators directly, but performance indicators can be extrapolated from measurable variables.
- Management plans rest on implicit assumptions about causal relationships between plans and desired outcomes. Models necessitate formalization of the assumptions and provide structure for organizing relationships.
- Models enable projection. Projected changes in indicators help to identify needs for adjusting management plans and policy decisions.
- The application of equations that capture essential aspects of systems or processes often lead to the discovery of unknown properties of the systems or processes in question, just through standard mechanical algebraic or other mathematical manipulations

“It is useful to test prospective management strategies against ecosystem models: if they don't work on simple models why should they work in reality” - K*eith Sainsbury , ICES/SCOR Conference, Montpellier March 1999*