Institutionalized Model-making
IMM

State-space Structuring of Stakeholder-based

Collaborative Environmental and Natural Resource Systems Modeling

for

Team-building, Database Organization, Systems Analysis, Scientific & Management Decision-making, and Outreach

~

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IMM

Three features . . .

1. Process vs. product

Modeling (including collaborative modeling) can be distinguished as

Process oriented	vs.	Product oriented
"Model-Making"		"Modeling"

Premise: The process side is underappreciated as having product-independent value in its own right

My Message

Modeling Protocol

Compartment (stock & flow) models

Iteration
modification

Initiation/Specification
purpose, need, scope, goals

Conceptualization
compartments, connections, currency, controls

Formulation/Mathematization
system equations, functional forms

Identification
calibration/quantification

Simulation /Experimentation
Validation, verification

Utilization/Application
understanding, prediction, decision-making

Model-making
PROCESS
expert domain

Modeling
PRODUCT
modeler domain

science, applications,
& management
domains

Three features . . .

2. Formal structuring

The modeling process can be structured and formatted by formal theory

State-space system theory is the form employed in IMM

Three features . . .

3. Institutionalization

Properly institutionalized, the modeling process and its follow-on products can become permanent assets of user institutions, fostering a "bottom-up" basis for integrative science and management

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Summary:

1. Process first, products later
2. Formal structuring by system theory
3. Institutional permanence

My Message

IMM

Foreseen benefits . . .

Team and culture building

Structures people interactions

Emphasizes the modeling process first, products later

Captures and organizes the knowledge state-of-the-art

Identifies areas of ignorance

Codifies knowns & unk

Motivates and formats databases

Counters the maxim, "D a h

Enables

Guides res management directions and priorities

Structures support ($$$) directions and priorities

Informs management decision-making

Aids communication among constituencies

Holds the place for continuing (perpetual) development

.

.

.

Overarching goal ...

Team- & culture-building to holism

My Message

IMM

Further premise:

Formalizing this …

Initiation/Specification
purpose, need, scope, goals

Conceptualization
compartments, connections, currency, controls

PROCESS
expert domain

Iteration
modification

Formulation/Mathematization
system equations, functional forms

Identification
calibration/quantification

Simulation /Experimentation
Validation, verification

Utilization/Application
understanding, prediction, decision-making

facilitates this

PRODUCT
modeler and science & management domains

My Message

IMM

1971—a semin…

I have since studied all the mathematical system theories and settled on Zadeh's state-space theory for ecological purposes

1. Spring sabbattical — Michigan …
   Department of … Program
   Course in state-space system theory
   Instructor: James A. Resh

2. NSF summer institute — U. of Oklahoma Biological Station, Lake Texoma

   ~40 college biology teachers, 8 weeks as conceptual model-makers, ecologically modeling a cove adjacent to the station; field work and computer usage were featured

Start: I'm lost. What are we trying to do here?

Who's this guy with the matrices?

3. Smithsonian I… Reef, Belize

   ~40 of the world's le… coral reef experts; living in wind-blown thatched huts; sustained by snorkeling, diving, and rum cokes; spending 2 weeks as model-makers, making a conceptual model of the whole atoll ecosystem

My History

IMM

ca. 1975—1980

4. UNDP program — ADRIA—The Yugoslav Adriatic Coastal Ecosystem

In multiple week-long workshops over the ~5 year period, > 100 scientists of marine, fisheries, etc. laboratories and universiti[illegible] ...ptual models ... [illegible] ...ere, and ... this ... of these models was ever [illegible] for further development or use ... the participating laboratories

End: I now know what an ecosystem is

...wledge assembly

Hvala liepo, Dr. Patten. Sretno

...group interactions

5. @ UGA — Graduate teaching

Since these experiences, all my graduate courses have featured team-based modeling, simulation , and systems analysis.

My History

ca. 1975—1985

6. NSF LTER program — **Integrated Studies of the Okefenokee Swamp Ecosystem**

modeling / ensuing

Student researchers made multiple conceptual, and a few operational, models of different subsystems and processes in Okefenokee. It became impossible, however, to establish ongoing and model-making as NSF wanted to achieve uniformity across its sites, and no others were doing work with a strong modeling orientation. My stubborn commitment to modeling, and an struggle with NSF, caused loss of funding in 1986. The LTER sites, a prime target for IMM in the ecological world, are fragmented in their work still today— one of the program's most persistent criticisms. Culture-building by IMM is sorely needed in this domain

7. Incorporation — **Ecology Simulations, Inc.**

We ran a few contracts. There was no market. Google won't find ESI for you today, but we are still on standby.

ca. 1990's—2001

8. This is Dick Sage …

Adirondack Ecological Center, Newcomb, NY

I collaborated with him 1-on-1 for eight years building "everything known about the Adirondack White-tailed deer" into a huge (~100 pp. of code) ecosystem-based Stella simulation model for this species

I succeeded in converting this straight-talking wildlifer-forester into a hemmer-hawer who could no longer give a straight answer to anything. He knew too much, and how it fit together. Dick's model-making experiences had transformed him from initial critic and skeptic into the world's first "systems-thinking wildlifer-forester"

On a weekend in early August, 2001 I finally closed the model around on itself and generated (without changing a single one of the several hundred parameter values Dick had computed and supplied) the target number of 15-20 deer/mi^2 on the Huntington Wildlife Forest (AEC)

IMM

ca. 1990's—2001

Dick died two days later after collapsing on Whiteface Mountain leading a class field trip with Bill Porter. They were coming to meet me for a tour of a bog at Paul Smith's VIC

He never knew we had finally graduated from modeling "process" to "product"

It wouldn't have mattered. For him the jury was already in on the value of a process he had once referred to as "a bunch of [expletive deleted]"

To date, no institution or wildlife management agency has claimed the model for further development and use. Nor would they. There is not yet a culture for this—that is still to be built, and hopefully this conference might become one of the steps in that very needed direction.

My History

State-Space Determinism

Lofti A. Zadeh

z = input vector

x = state vector

y = output vector

Z = input space

X = state space

Y = output space

$\phi : Z \times X \longrightarrow X$ state transition function

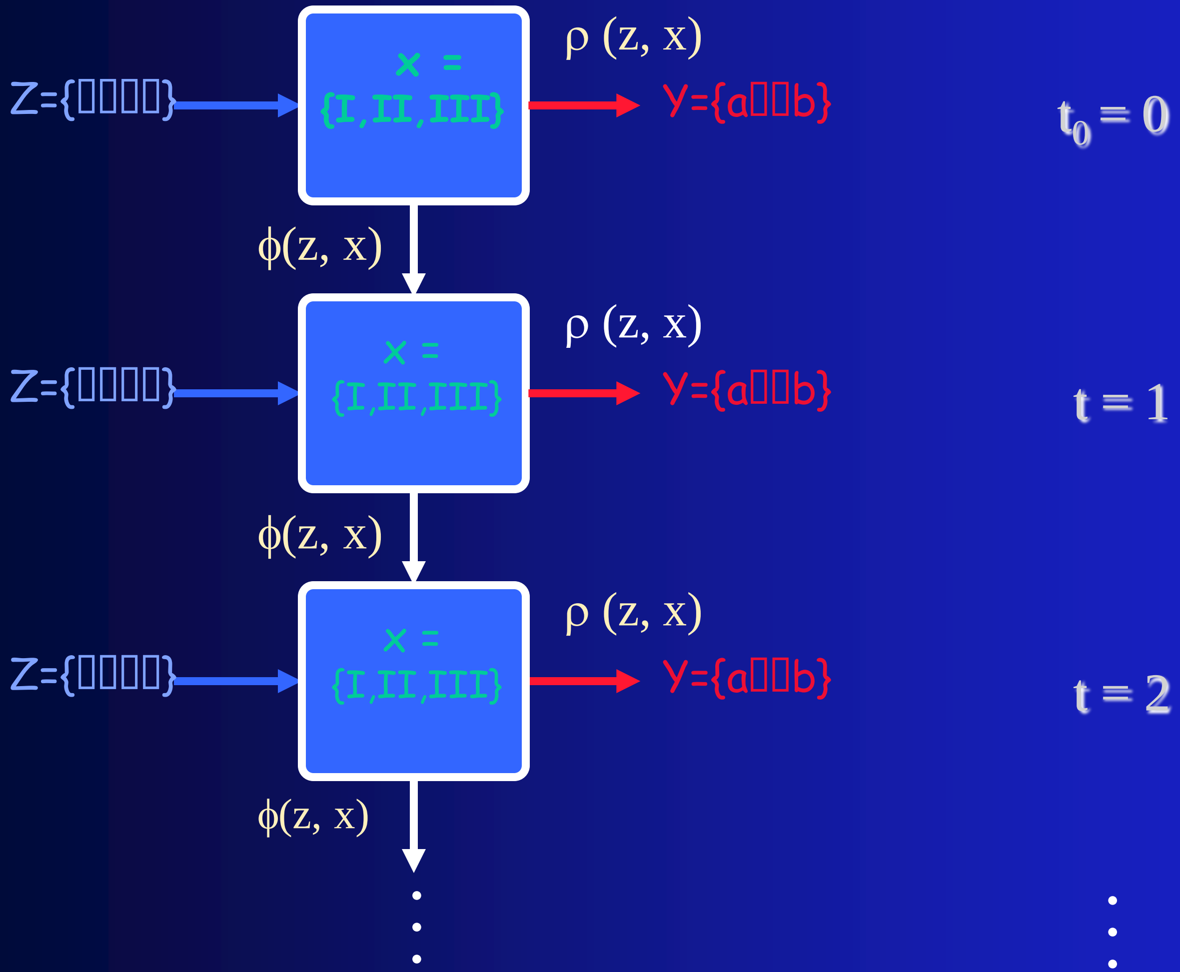
$x = \phi(z, x)$

$\rho : Z \times X \longrightarrow Y$ response (output) function

$y = \rho(z, x)$

How State-Space Systems Work

Example: 3 states (x), 2 inputs (z), 2 outputs (y)

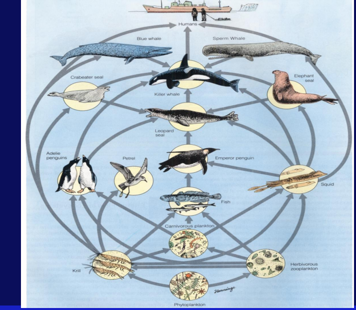


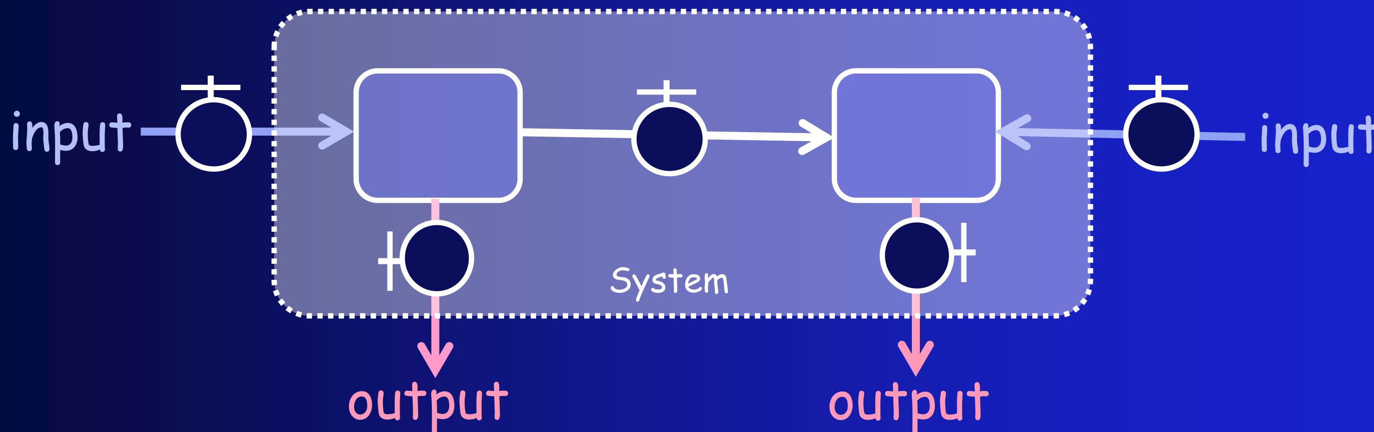
State-Space Dynamics

IMM

“4 C's ” model construction

Digraph format





The "4 C's"

- Compartments
- Connections
- Currency
- Controls

IMM methods involve , , ,
- parsing & defining
- decribing & documenting
- estimating & measuring

these model categories

Model-Making

IMM

How State-Space Systems Work

The state transition function is usually expressed in differential form . . .

state vector — flow matrix — unit vector — input vector — output vector

$$\phi': d\mathbf{x}/dt = F1 + \mathbf{z} = F^{T}1 + \mathbf{y}$$

- $\mathbf{x}$: state vector
- F: flow matrix
- 1: unit vector
- $\mathbf{z}$: input vector
- $\mathbf{y}$: output vector

$F1 + \mathbf{z}$: OUTPUT ENVIRON generating form (input driven)

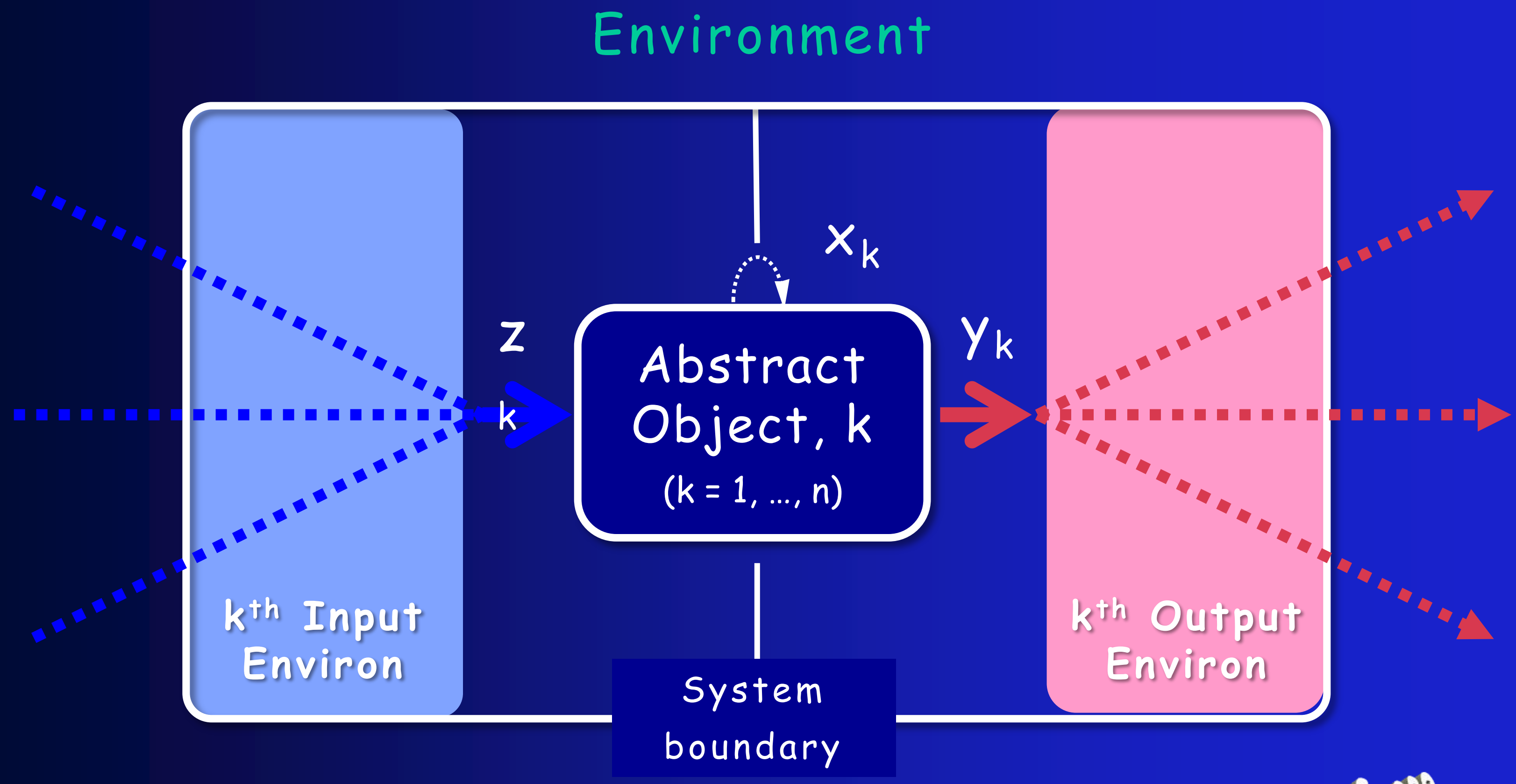
$F^{T}1 + \mathbf{y}$: INPUT ENVIRON generating form (ouput referenced)

Environ?

State-Space Dynamics

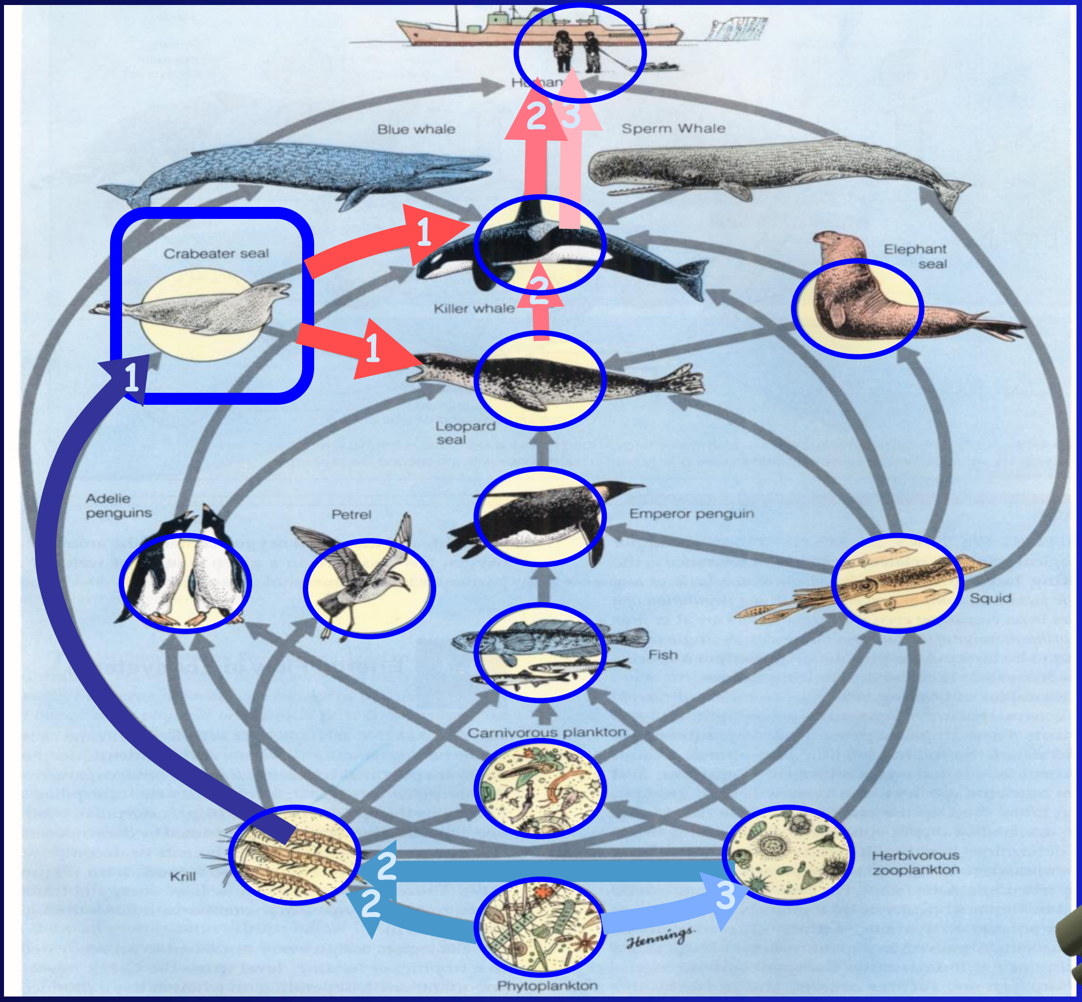
Environs

The measurable intrasystem environments of all system components



State-Space Environs

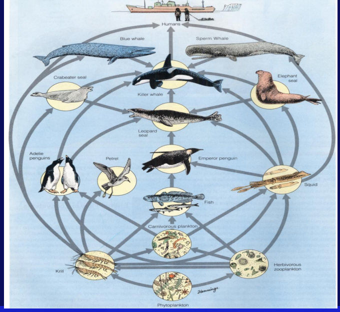
Illustration

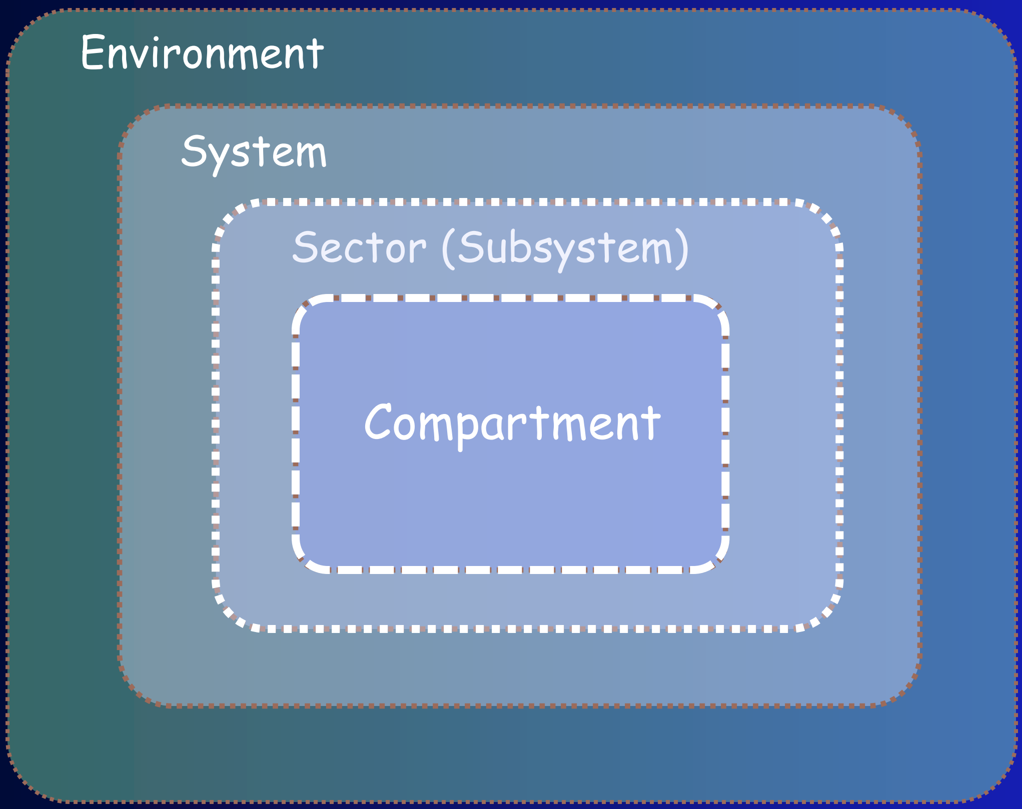


Miller 1992. Living in the Environment. Wadsworth, p. 94

Hierarchical Categories

Four levels for working purposes

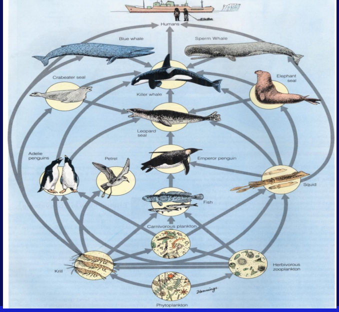




Compartments are focal

Teams form around sectors

State-Space Formatting



$$\phi': dx/dt = F1 + z = F^T1 + y$$

$$F_{n \times n} = (f_{ij})$$ quantitative flow matrix

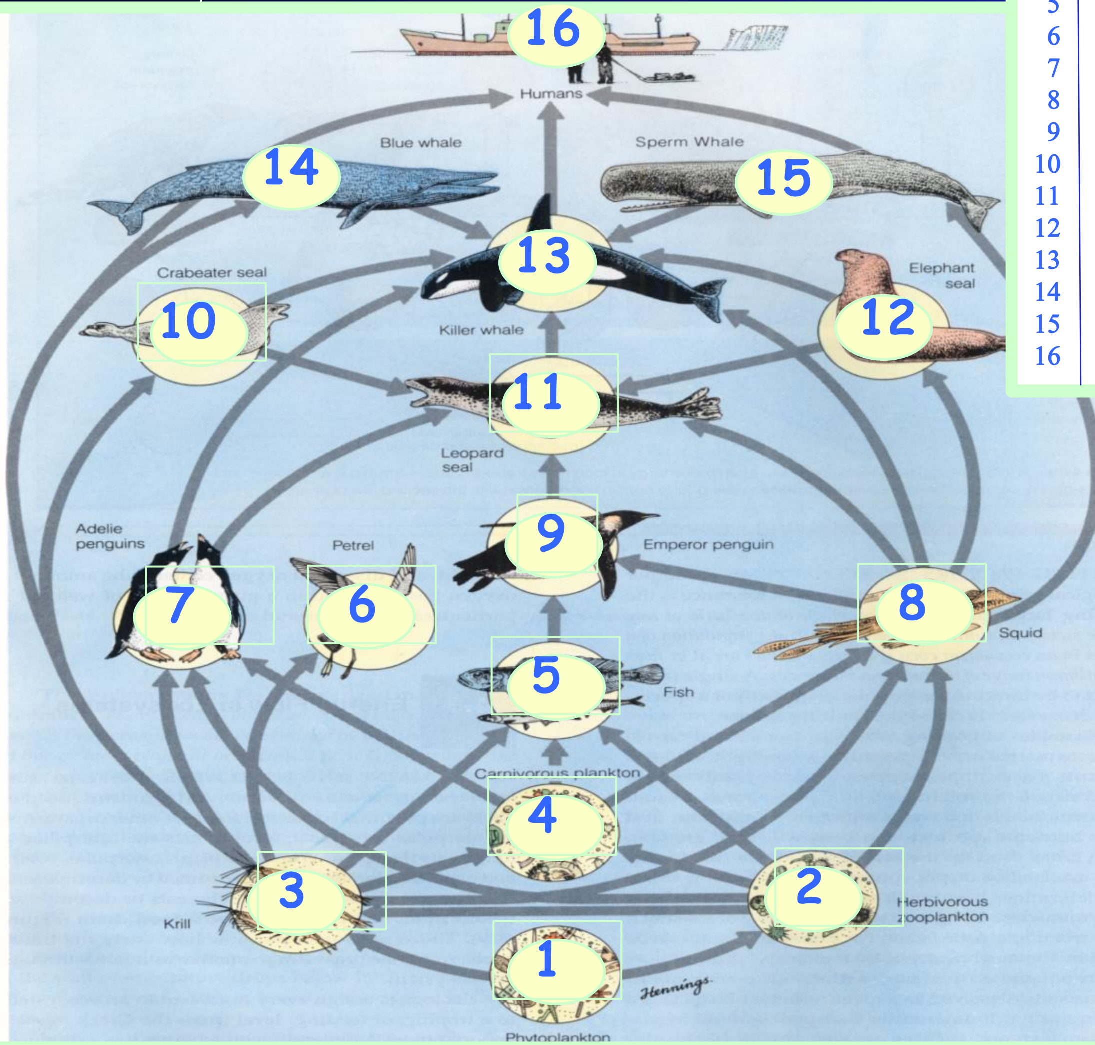
$$A = (a_{ij})$$ qualitative *adjacency matrix*

$a_{ij} = 1$ if $f_{ij} > 0$
$a_{ij} = 0$ if $f_{ij} = 0$

The qualitative adjacency matrix, *isomorphic* to the quantitative flow matrix, is at the core of IMM state-space structuring

IMM Structuring

Digraph → Adjacency Matrix Isomorphism



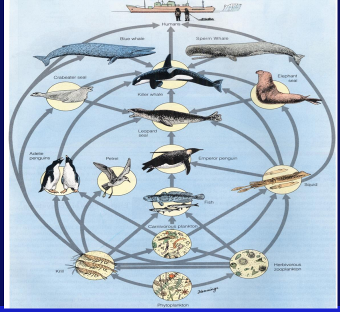
A =

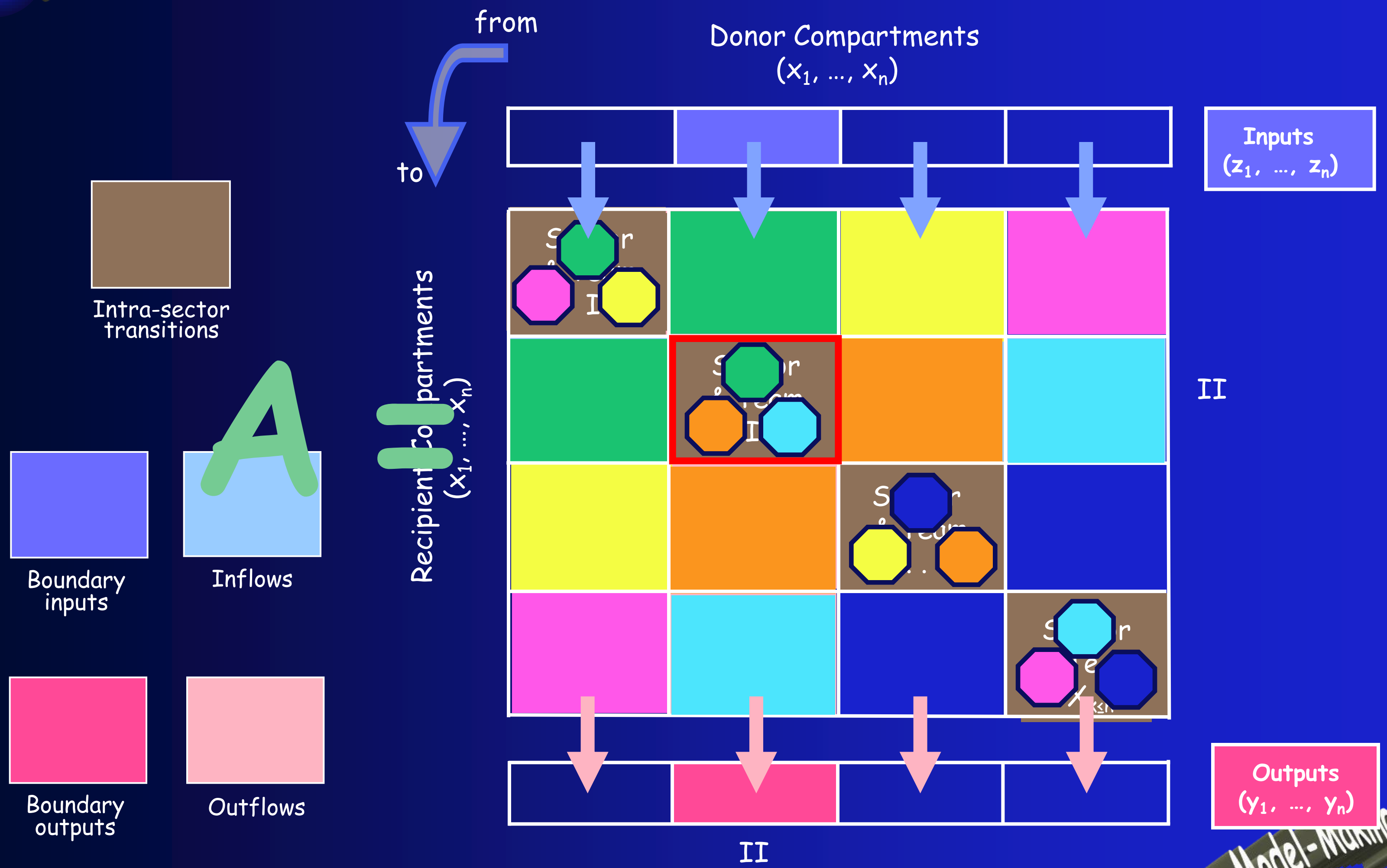
↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
8	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
10	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0
12	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	1	1	0	1	1	1	0	1	1	0
14	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	1	0	0	0	0	1	0	0	0	0	1	1	0	0

orientation: columns to rows

"4 C's " model construction

Adjacency matrix formatting for pairwise integration of compartment sectors





IMM

The ABCD's of Environ Analysis

Mathematical Methods

$$\phi' : dx/dt = F1 + z = F^T1 + y$$

boundary (m = 0) · direct (m = 1) · indirect (m > 1)

Qualitative:

Pathway Analysis

$A : I + (A) + (A)^2 + \dots$

$A^T : I + \dots + (A^T)^m + \dots + \infty$

Throughflow Analysis

$B : I + (I+B) + (I+B)^2 + (I+B)^3 + \dots + (I+B)^m + \dots = -B^{-1}$

$B' : I + (I+B') + (I+B')^2 + \dots = -B'^{-1}$

Storage Analysis

$C : \dots + (I+C\Delta t)^2 + (I+C\Delta t)^3 + \dots + (I+C\Delta t)^m + \dots = -C^{-1}$

$C' : \dots + (I+C'\Delta t) + (I+C'\Delta t)^2 + (I+C'\Delta t)^3 + \dots + (I+C'\Delta t)^m + \dots = -C'^{-1}$

Utility Analysis

$D = B' - B,\ U = \Sigma_m D^m = (I - D)^{-1},\ Y = U \cdot T$

The IMM qualitative process culminates with A

Isomporphic quantitative modeling products' follow

IMM Structuring

IMM

A Case Study

Environs

and the

U. S. Strategic Petroleum Reserve

ESI

ECOLOGY SIMULATIONS, INC.

Brine Disposal Environmental Impact Assessment
and
Quantification of Ecosystem Health
by
Network Environ Analysis (NEA) in the Strategic Petroleum Reserve

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Odum School of Ecology, University of Georgia

and

Ecology Simulations, Inc.

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ESI

ECOLOGY SIMULATIONS, INC.

INTRODUCTION

This study was scoped as a proof-of-concept project

It was funded around 1980 by the National Oceanic and Atmospheric Administration (NOAA)

It addresses the natural complexity of whole ecosystems by Network Environ Analysis (NEA), a methodology that implements environmental system theory

Its results and predictions have never been tested.

ESI

ECOLOGY SIMULATIONS, INC.

I. The Strategic Petroleum Reserve

SPR

THE STRATEGIC PETROLEUM RESERVE

Brief History & Current Status

Provides for emergency oil storage, most in salt domes along the Texas and Louisiana coasts

Established by Congress in 1975 (PL 94-163) after 1973-74 oil embargo

Original provisions 150 million bbl by end of 1978
500 million bbl by end of 1982
1978 amendment expansion to 1 billion bbl

Current capacity 727 million bbl (115,600,000 m^3)

February 2012 inventory 695.9 million bbl (110,640,000 m^3) = 36-day supply

Four sites near petrochemical refining and processing centers

Bryan Mound—Freeport, Texas; capacity 254 million bbl

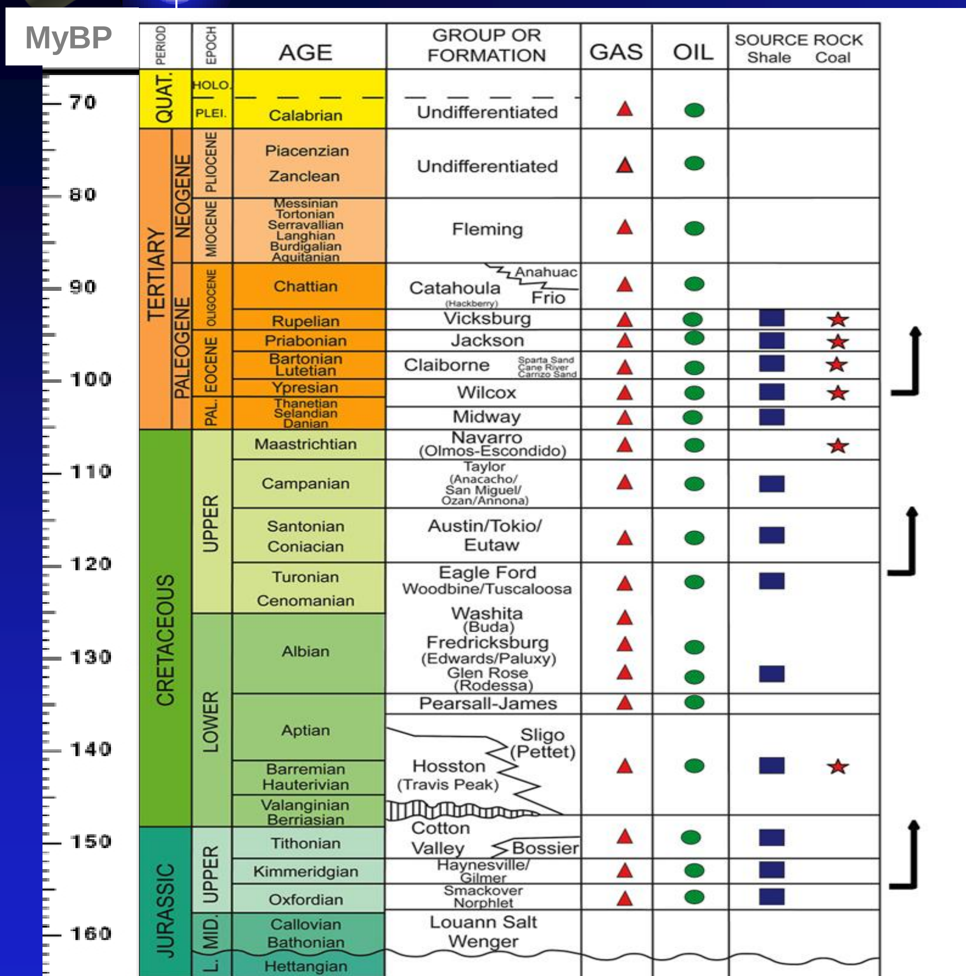
Big Hill—Winnie, Texas, capacity 160 million bbl

West Hackberry—Lake Charles, Louisiana, capacity 227 million bbl

Bayou Choctaw—Baton Rouge, Louisiana, capacity 76 million bbl

THE STRATEGIC PETROLEUM RESERVE

Salt-Dome Geology

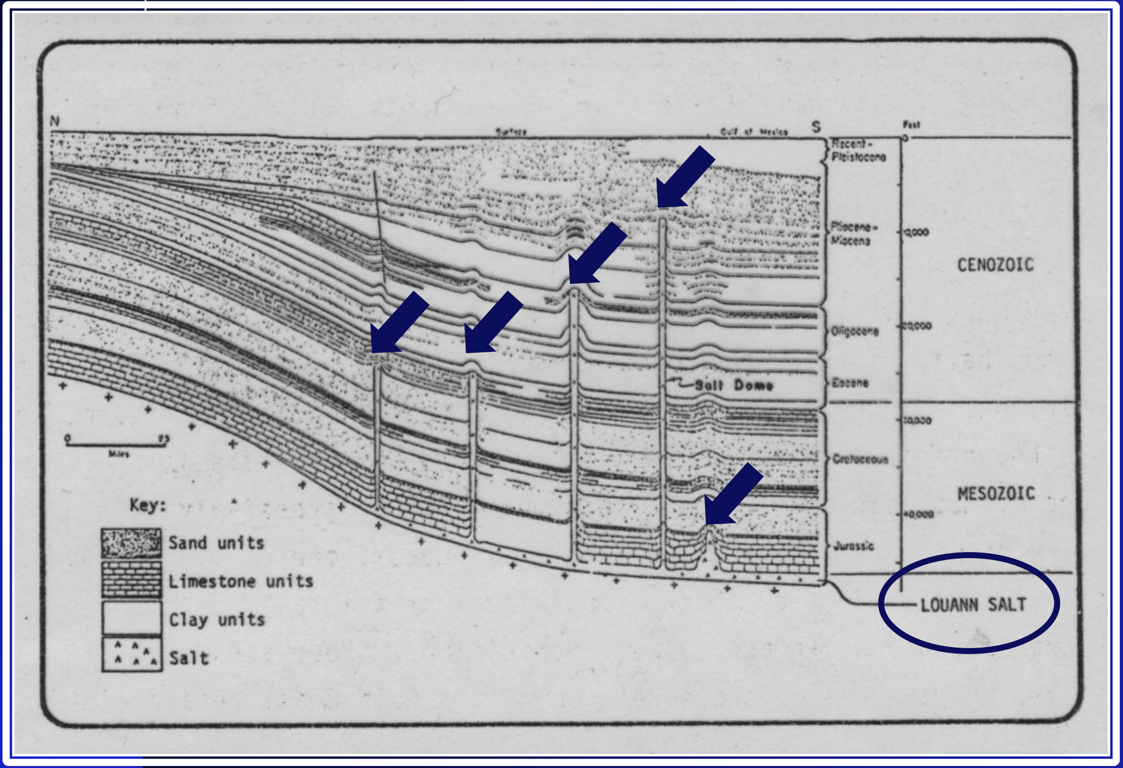


Stratigraphic section, northern Gulf of Mexico coastal plain

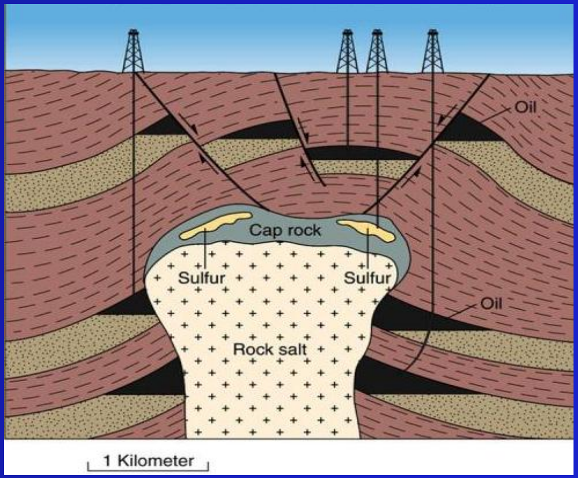
The Louann Salt Formation, source of the salt domes, was deposited in the middle Jurassic 160-million years BP

THE STRATEGIC PETROLEUM RESERVE

Salt-Dome Formation



Louann salt, less dense than overlying sedimentary strata, rises upward from beneath the sea floor and land surface to form the salt domes . . .



THE STRATEGIC PETROLEUM RESERVE

SPR

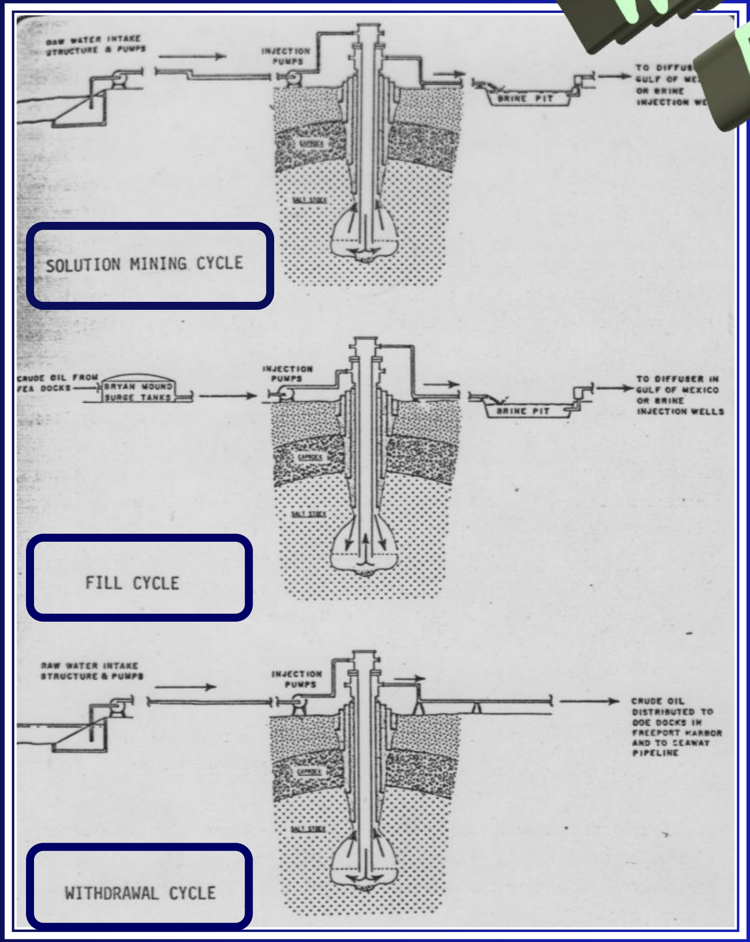
Salt-Dome Storage Caverns

Operation Cycles

Whole ecosystem
EIA problem

Each site contains a set of oil storage caverns solution-mined beneath the caprock surfaces

3 operating stages



#1 seawater pumped in, effluent brine out

#2 oil pumped in, brine pumped out

#3 seawater pumped in, displaced oil out

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II. Gulf Ecosystem "4 C's" Model

GEM

GULF ECOSYSTEM MODEL

Compartments

Table IX.1 Compartment codes and names.

Code	Name
N1	Pelagic Planktivores
N2	Benthoplanktivores
N3	Benthovores
N4	Type I Nektivores
N5	Type II Nektivores
N6	Type III Nektivores
N7	Type IV Nektivores
N8	Type I Mixed Feeders
N9	Type II Mixed Feeders
N10	Penaeid Shrimp
P1	Net Phytoplankton
P2	Nannophytoplankton
P3	Microzooplankton
P4	Microheterotrophs
P5	Mucus Net Feeders
P6	Grazing Zooplankton
P7	Primary Carnivorous Zooplankton
P8	Secondary Carnivorous Zooplankton
P9	Ichthyoplankton, Type I
P10	Ichthyoplankton, Type II
P11	Carnivorous Merobenthozooplankton
P12	Grazing Merobenthozooplankton
P13	Plankton Eggs and Lecithotrophic Meroplankton
B1	Benthic Eggs
B2	Benthic Algae and Protophytes
B3	Photosynthetic Bacteria
B4	Microbenthos
B5	Meiobenthos
B6	Infaunal Subsurface Deposit Feeding Macrobenthos
B7	Hard-Bodied Surface Deposit Feeding Macrobenthos
B8	Soft-Bodied Infaunal Surface Deposit Feeding Macrobenthos
B9	Soft-Bodied Epifaunal Surface Deposit Feeding Macrobenthos
B10	Soft-Bodied Infaunal Suspension Feeding Macrobenthos
B11	Hard-Boiled Infaunal Suspension Feeding Macrobenthos
B12	Epifaunal Suspension Feeding Macrobenthos
B13	Predators/Omnivores/Scavengers
C1	Fecal Material
C2	Organic Aggregates
C3	Fine Particulate Organic Carbon
C4	Pelagic Dissolved Organic Carbon
C5	Benthic Surface Particulate Organic Carbon
C6	Benthic Subsurface Particulate Organic Carbon
C7	Benthic Dissolved Organic Carbon

43 Compartments

Nekton Submodel (N) 10

N10, *Penaeus* spp. will be focal in impact analysis

3 species: Pink, White, Brown Shrimp

Plankton Submodel (P) 13

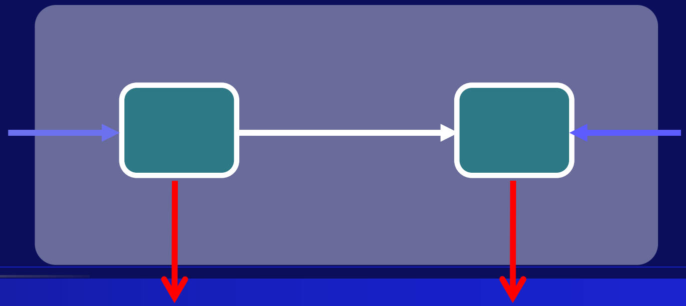
Benthos Submodel (B) 13

Organic Complex Submodel (C) 7

GULF ECOSYSTEM MODEL

Connections

Currency: Carbon



CARBON FLOW PROCESSES IN THE CONCEPTUAL GEM MODEL

Intercompartmental

12 Interior Processes

Reproduction	Development
Uptake of DOM	Molting
Ingestion	Mortality
Egestion	DOM production
Secretion	Physical agglomeration
Egg production	Physical breakage

GEM-Environment Exchange

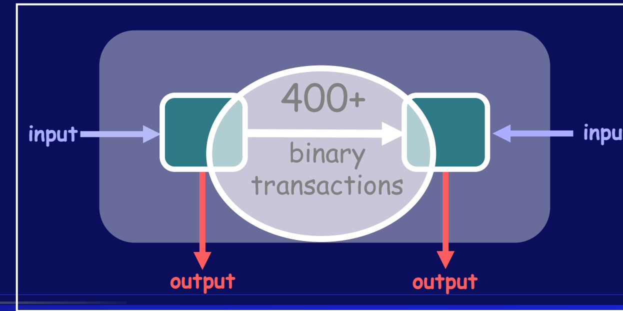
5 Boundary Processes

Migration	Physical transport
Primary production	Respiration

Harvest

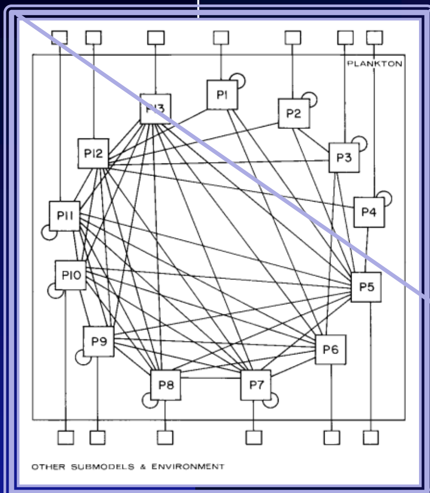
GULF ECOSYSTEM MODEL

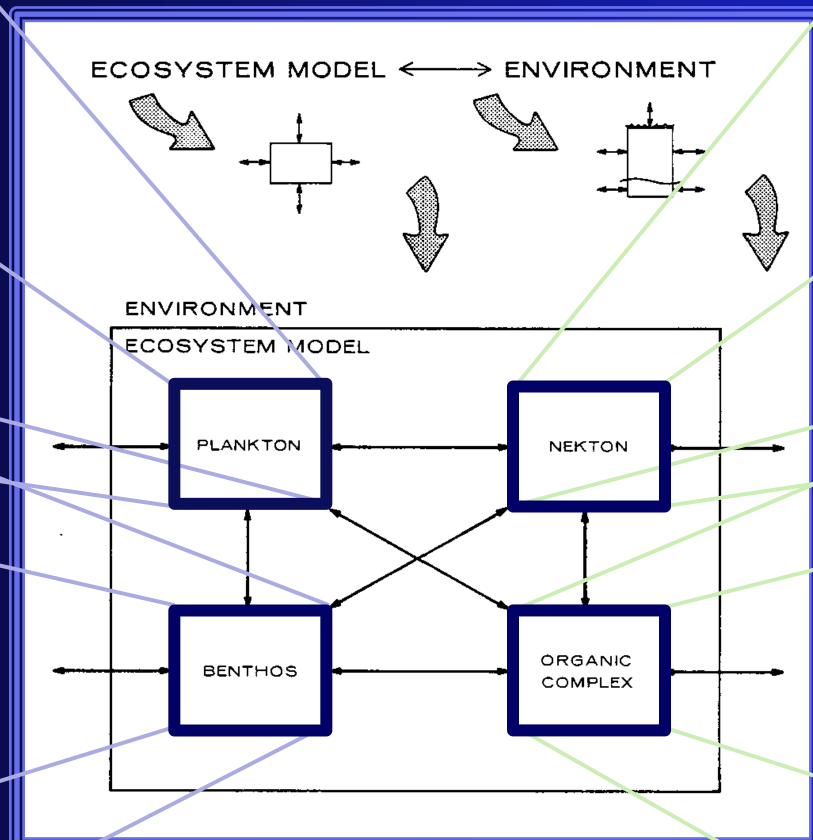
Connections

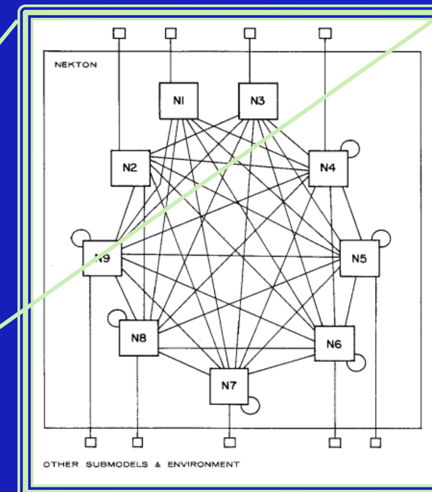


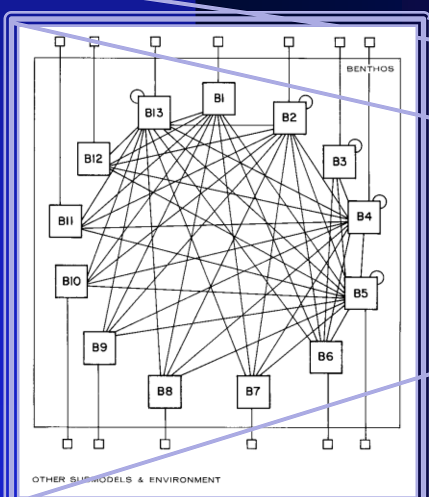
Sector (Team) 1
Plankton 13

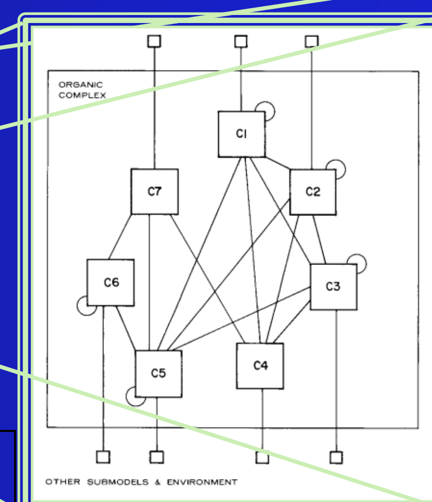
Sector (Team) 2
Nekton 10











Sector (Team) 3
Benthos 13

Sector Team 4)
Organic Complex 7

GULF ECOSYSTEM MODEL

Controls

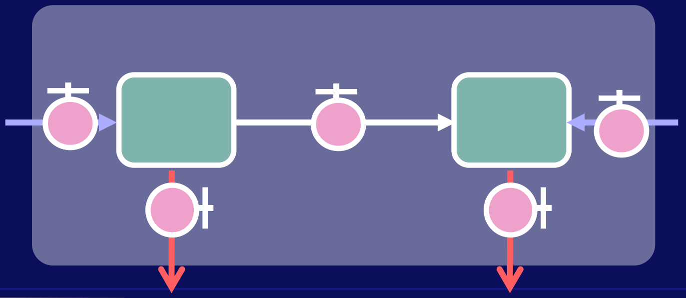


Table II.5.1 Factors controlling the carbon flow processes in the Gulf Ecosystem Model and their codes.

17 control factors

Control factor	Code
Temperature	T
Salinity	S
Dissolved oxygen	O
Available nitrogen	N
Available phosphorus	P
Water depth	D
Sediment characteristics	M
Time of day	H
Light characteristics	L
Julian day	J
Fishing pressure	F
Estuarine discharge	E
Turbidity	C
Bioturbation	B
Physical resuspension	R
Waves, storm fronts, etc.	W
Intrusion	I

outputs inputs

Response (Y) = R(Z, X, T, S, ...)

state variables (compartments)

control variables

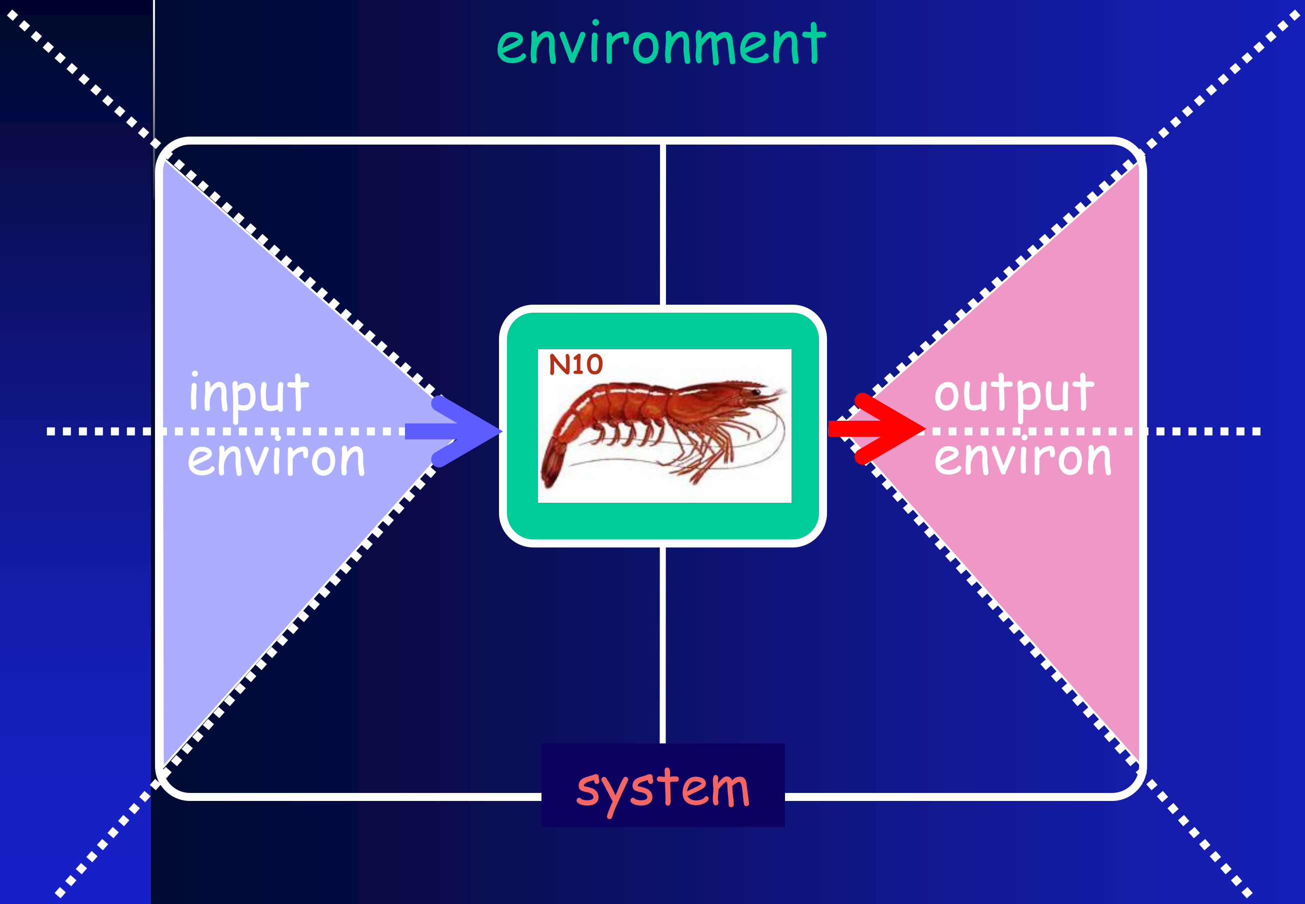
Temperature and Salinity were the main control variables formulated for the present brine disposal impact assessment

III. Brine Disposal Impact Assessment

EIA

NETWORK ENVIRON ANALYSIS

N10 Penaeid Shrimp (3 species)



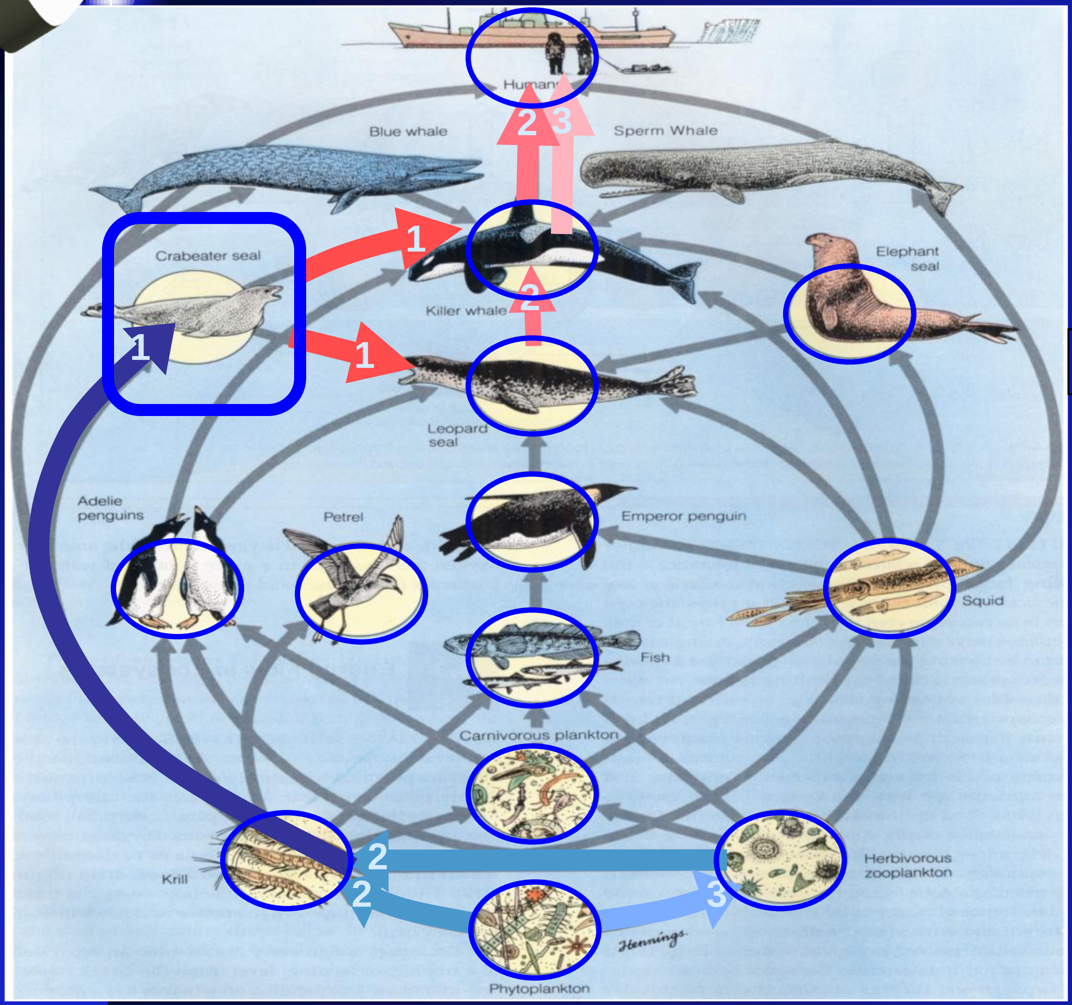
The subsequent environ-based brine disposal impact assessment will focus on the Penaeid environs, which are only 2 of the 43 × 2 = 86 environs in the GEM model, each with the same potential:

… for specific attention

… and management mitigation & control

BRINE IMPACTS ON GEM ENVIRONS

What the following GEM graphs will show . . .



Miller 1992. Living in the Environment. Wadsworth, p. 94

Percent deviations of selected model parameters to three perturbations from a reference salinity of ~35 $^{o}/_{oo}$:

34 $^{o}/_{oo}$, 38 $^{o}/_{oo}$, and 42 $^{o}/_{oo}$

1. Compartmental standing stocks

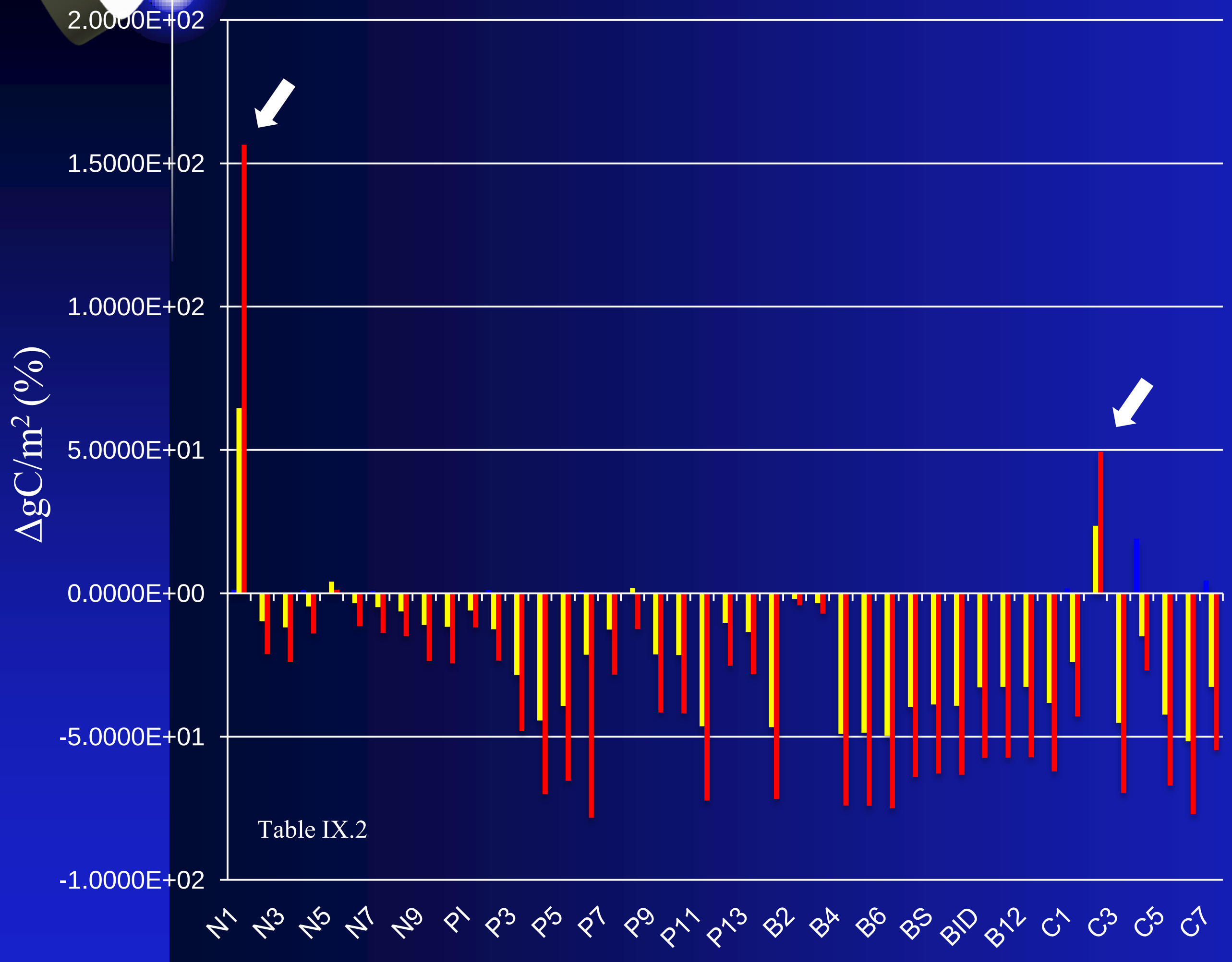
   ... and for the input and output environs of N10 Shrimp:

2. Intercompartmental C transfer rates
3. Compartmental C residence times
4. Compartmental C residence time variances

BRINE IMPACT ASSESSMENT

% Changes in Standing Stocks, ΔgC/m² (30 m water column)

KEY
- 20°C, 34 ‰
- 20°C, 38 ‰
- 20°C, 42 ‰



Except for some outliers, the compartments show progressive standing stock decreases with increasing hypersalinity

Pelagic Planktivores (N1) and Organic Aggregates (C2) increase

Conclusion

In general, the system loses biomass in proportion to the degree of hypersalinity

BRINE IMPACT ASSESSMENT

% Change in Carbon Transfer Frequencies

KEY
- 20°C, 34 °/oo
- 20°C, 38 °/oo
- 20°C, 42 °/oo

N10 Shrimp Input Environ

Table IX.18.

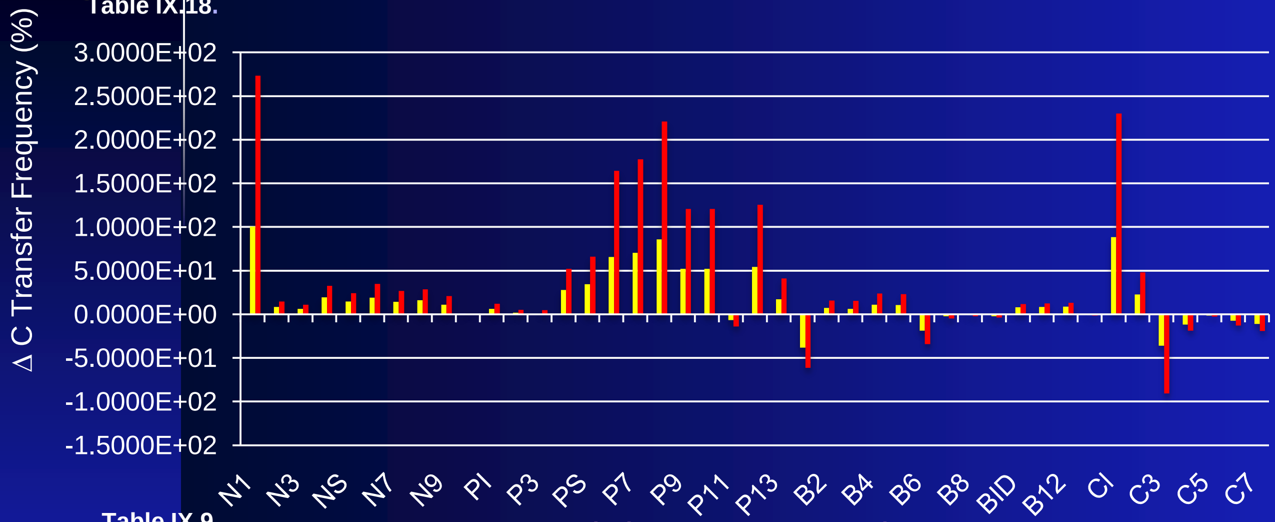
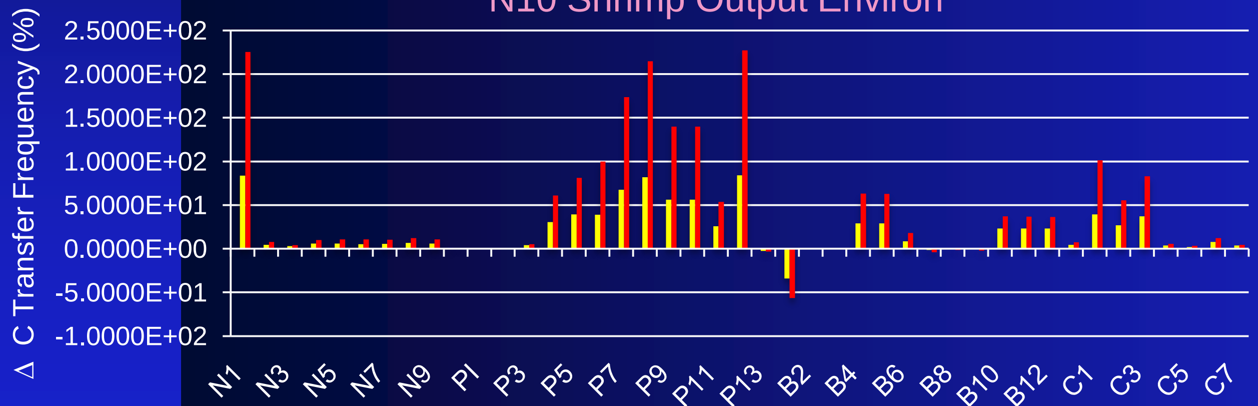


Table IX.9

N10 Shrimp Output Environ



Input environ: % change in mean number of times C in shrimp (N10) has entered prior compartments

Output environ: % change in mean number of times C in shrimp (N10) will enter future compartments

30 and 33 of the 46 compartments show greatly increased C turnover in the respective input and output environs

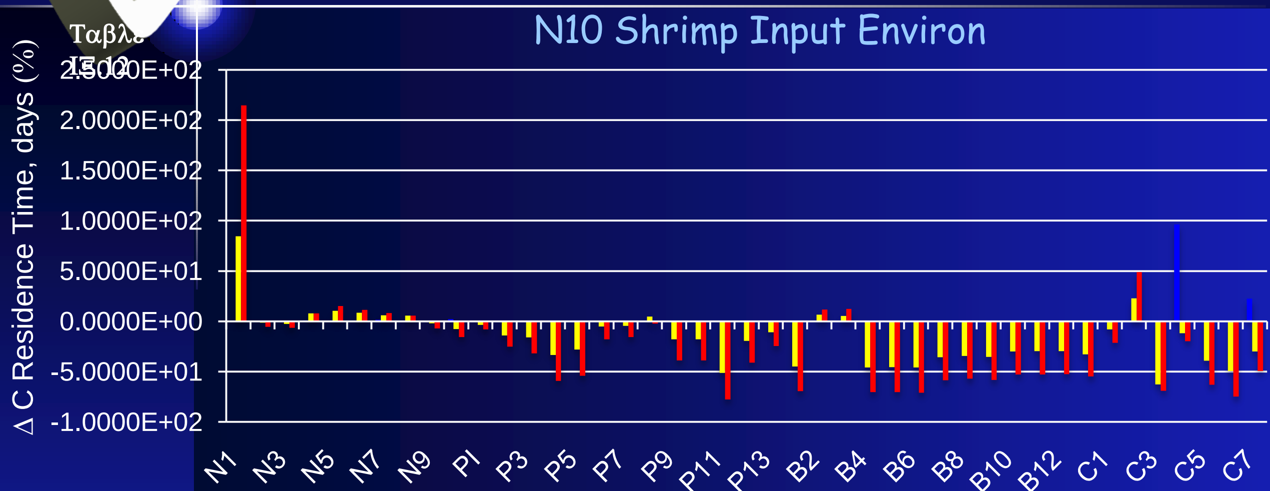
Conclusion

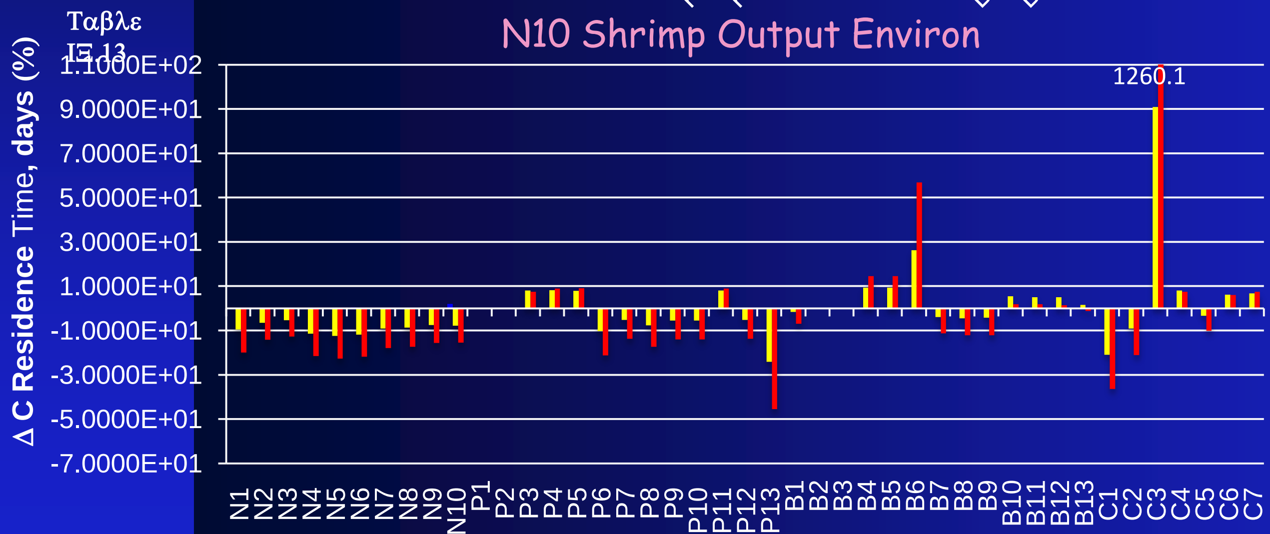
With exceptions, the Shrimp I/O subsystem runs generally faster in proportion to the hypersalinity

BRINE IMPACT ASSESSMENT

% Change in Residence Times

KEY
20°C, 34 ‰
20°C, 38 ‰
20°C, 42 ‰





Input environ: % change in past residence times in days that C in N10 has resided in each prior compartment since entrance

Output environ: % change in future residence times in days that C in N10 will reside in each subsequent compartment until exit

Residence times decrease in 33 and 25 compartments in the input and output environs, respectively, in proportion to hypersalinity—but distribution patterns differ

Conclusion

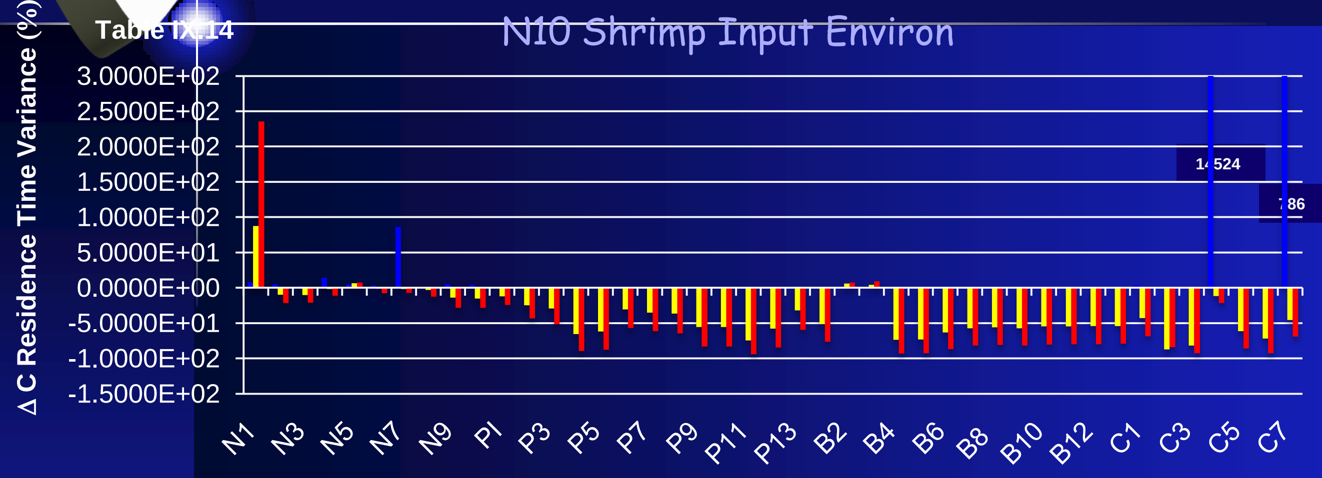
General reduction of C residence times reflects that the stressed Shrimp I/O subsystem runs proportionally faster under hypersalinity stress

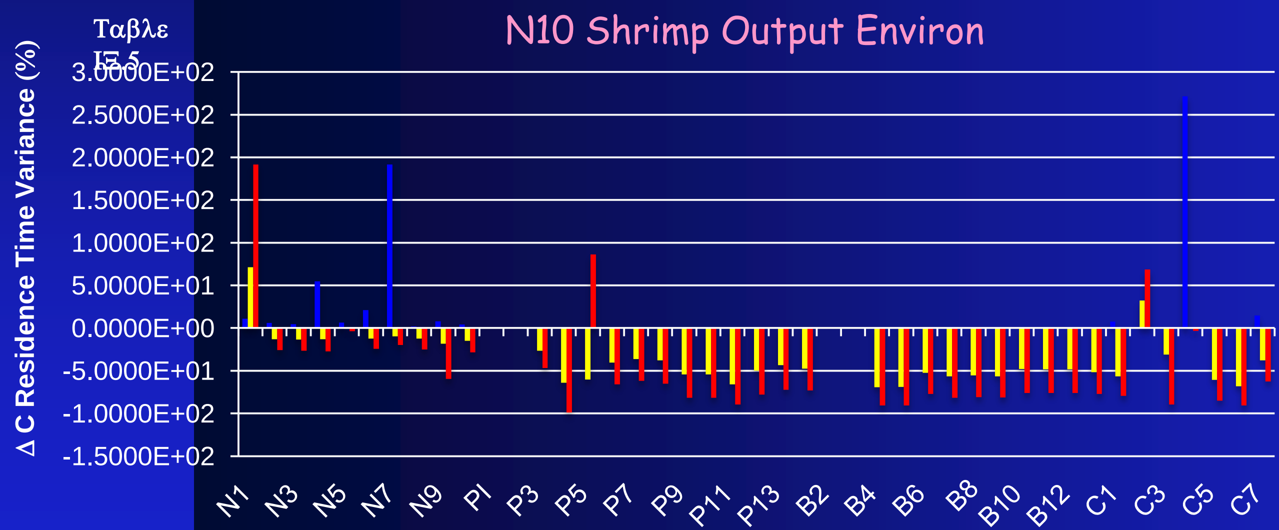
BRINE IMPACT ASSESSMENT

% Change in Residence Time Variances

KEΨ

- 20ºX, 34 º/oo
- 20ºX, 38 º/oo
- 20ºX, 42 º/oo





Input environ: % changes in past residence time variances

Output environ: % changes in future residence time variances

Except for the few outliers, most compartments in both environs show decreased variances in proportion to hypersalinity stress

Conclusion

The Shrimp I/O subsystem exhibits narrowed responses in proportion to hypersalinity, reflecting stenotopic dynamics and systemic dystrophy

IV. Implications for Ecosystem Health

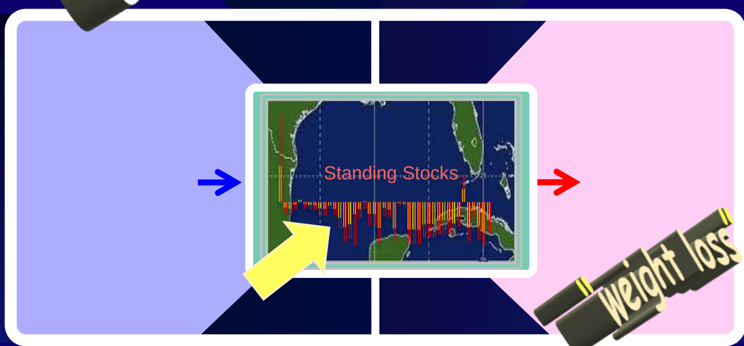
EcoH

EcoH

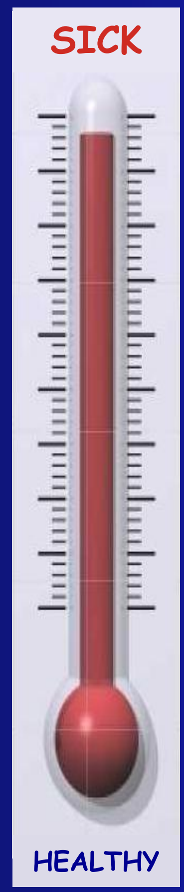
ECOSYSTEM HEALTH

Summary: Under hypersalinity perturbations com… and … exhibit proportional responses reflecting degree o… …ckness … …llness

Ecosystem illness where and to what degree is quantifiable by NEA

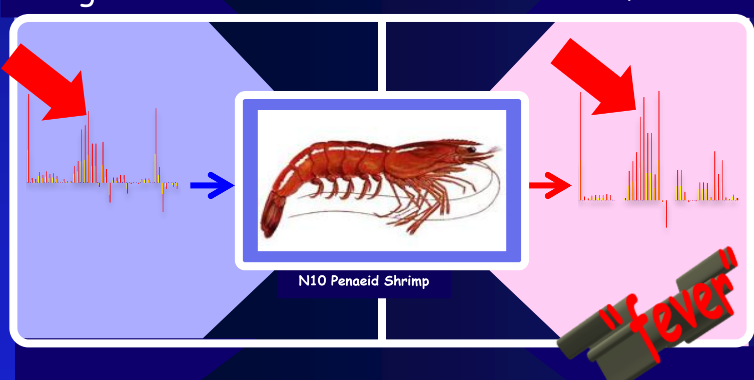


Compartments lose biomass

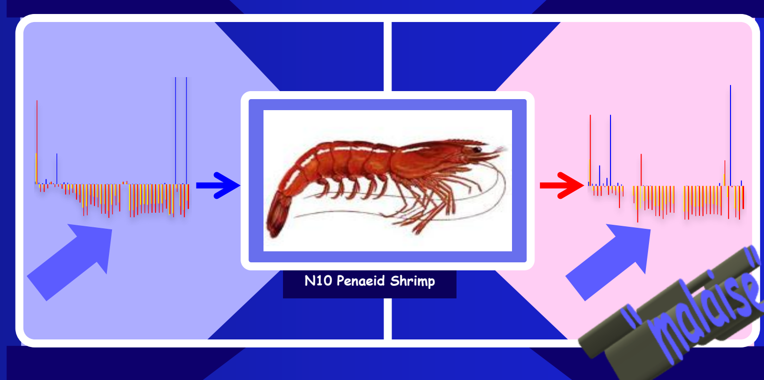


Smaller C residence times ⇒ I/O environs run faster

Higher C turnover ⇒ I/O environs run faster



Smaller C residence time variances ⇒ I/O environs run narrower



ESI

ECOLOGY SIMULATIONS, INC.

Details differ, but the same kinds of results are evidenced by the other 42 compartments and 84 environs in the GEM model

Malady is apportioned differentially to different ecosystem sectors enabling focused treatment of specific subsystems, species, and processes

Network Environ Analysis (NEA) offers a promising model-based, whole-ecosystem methodology for comprehensive Environmental Impact Assessment and Ecosystem Health Assessment with high precision diagnostic, treatment, and management potential

Because of its modeling complexities, demands for "big data", and lack of institutional markets capable of sustained commitment, it has never been tried.

Summing up . . .

1. In my career lifetime, in my field, there has been no mainstream market for IMM and related systems and modeling approaches. *Ecological modeling* remains a subfield, albeit robust, of the broader science

2. Times are changing now, however, and there is urgent need for complex systems approaches to the complex systems of nature confronting humanity, beginning with the ability to organize disparate multidisciplinary and lay human resources into coherent wholes in themselves that can meaningfully address the essential wholeness of natural systems

3. IMM is a complex systems protocol to create out of the minds of many a unified expert-systems vision that can carry over to and lead the development of technical complex systems approaches, particularly high-level modeling, and data and systems analyses (including Environ Analysis) that can serve as lenses through which to view and grapple with natural and human complexity

IMM

Summing up . . .

4. IMM reached the proof-of concept stage 35 years ago, in a few projects I have described, and in particular the GEM model for the *Strategic Petroleum Reserve.* There has never been, then or since, a culture to embrace more, not in my field. Active resistance and rejection have been more the norm, prompting my (unpopular) characterization of ecology's "retreat into simplicity" following the 1970's *IBP Analysis of Ecosystems* program's reach-beyond-grasp demonstration of the incredible complexity in ecosystems

5. A culture of holism, , and institutional change to accommodate it, are needed now to move things along. This does not exist, but in my experience is a natural, even assured, outcome of theory-structured team-building in workshops and other collaborative settings

6. Hopefully, this conference may prove a seminal event in moving things along.

Thank you