MIEA - Modelação Ecológica
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Modelação ecológica

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Modelação Ecológica

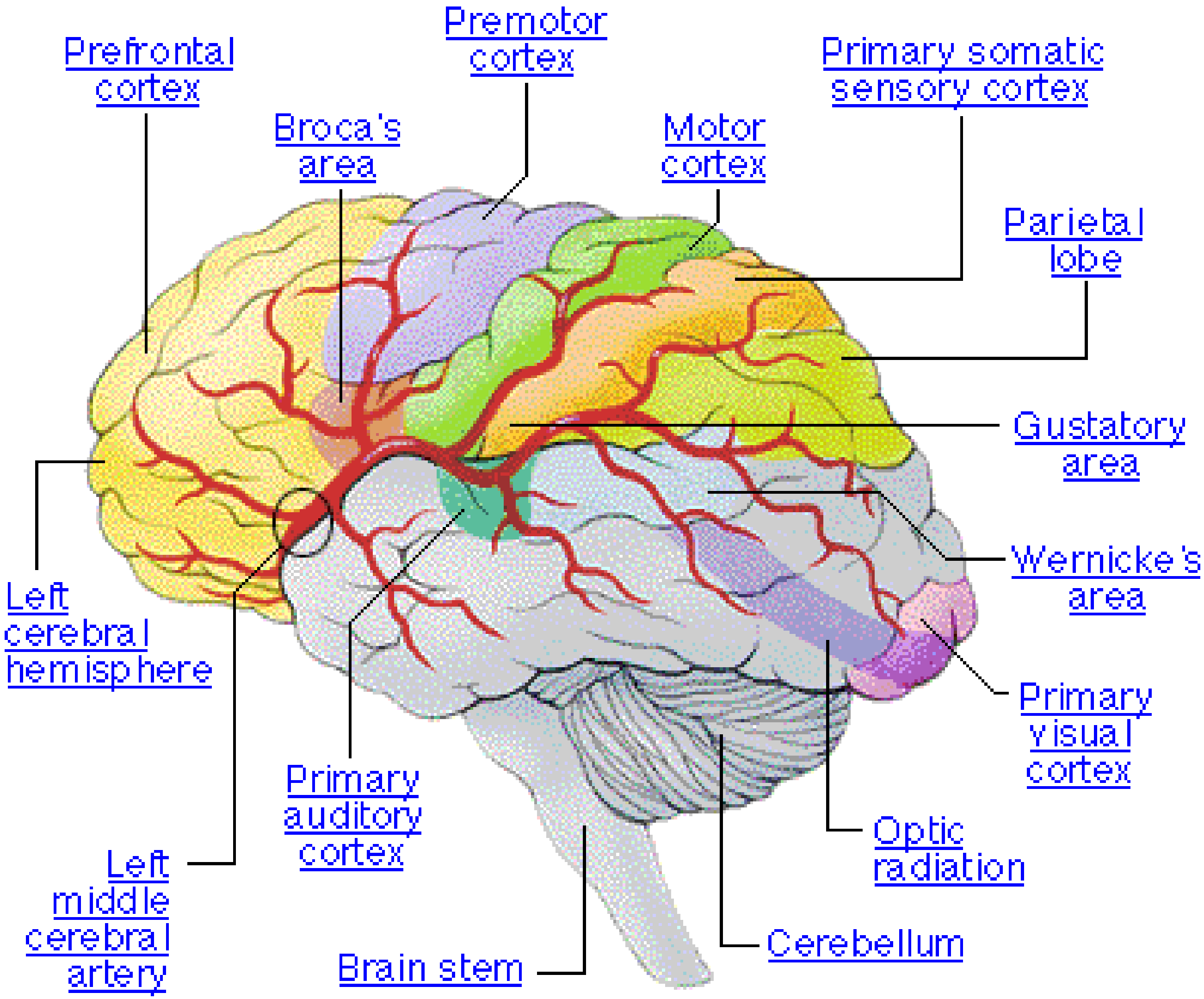
Abordagem diversificada

Temas

- Principios gerais de modelação
- Modelos ecológicos
- Sistemas de gestão integrada
- Desafios

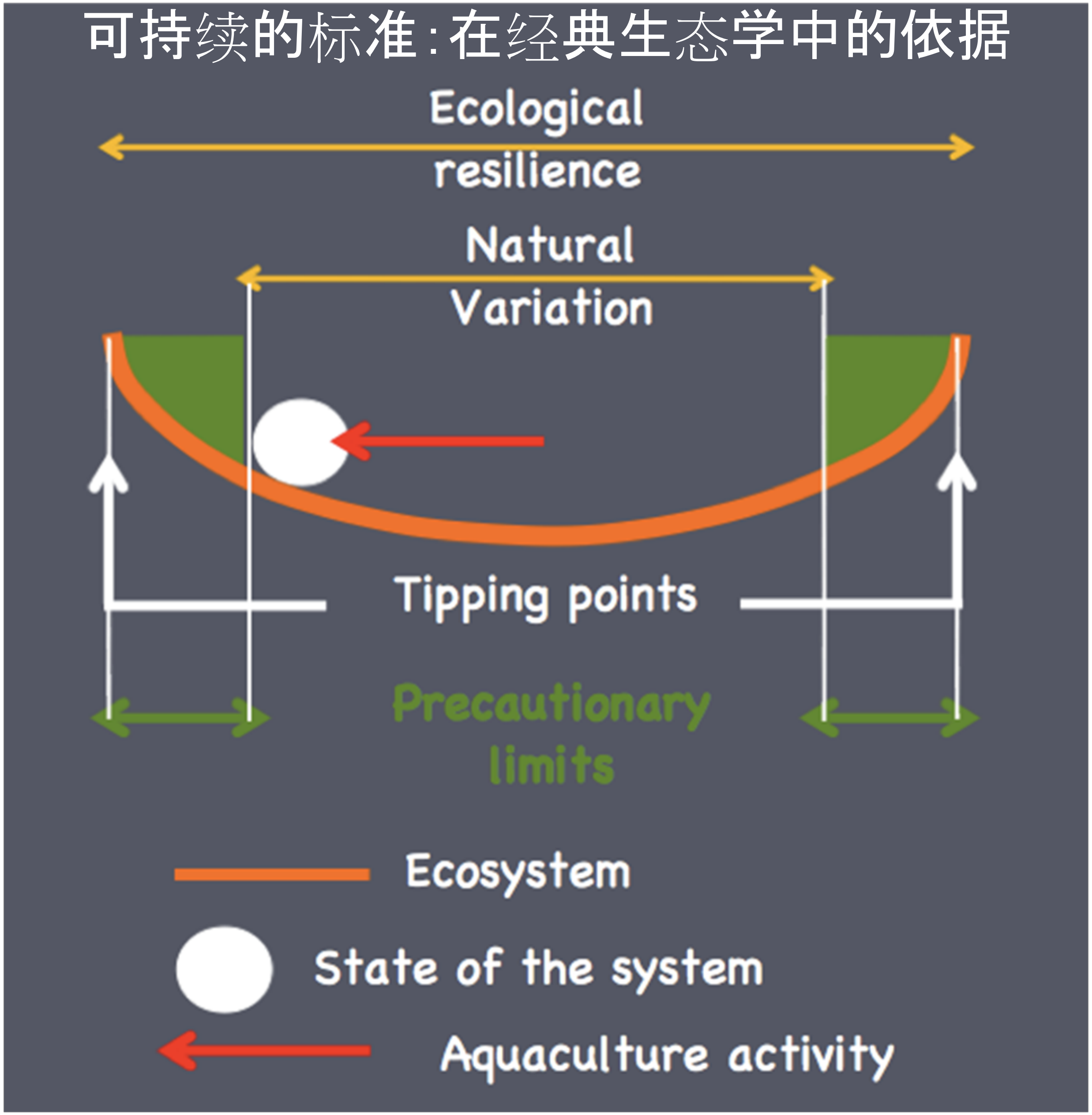
Não existe uma receita exacta

Here is the best model…



Turn your computer off. Turn your brain on

Sustainability criteria: foundation in classical ecology



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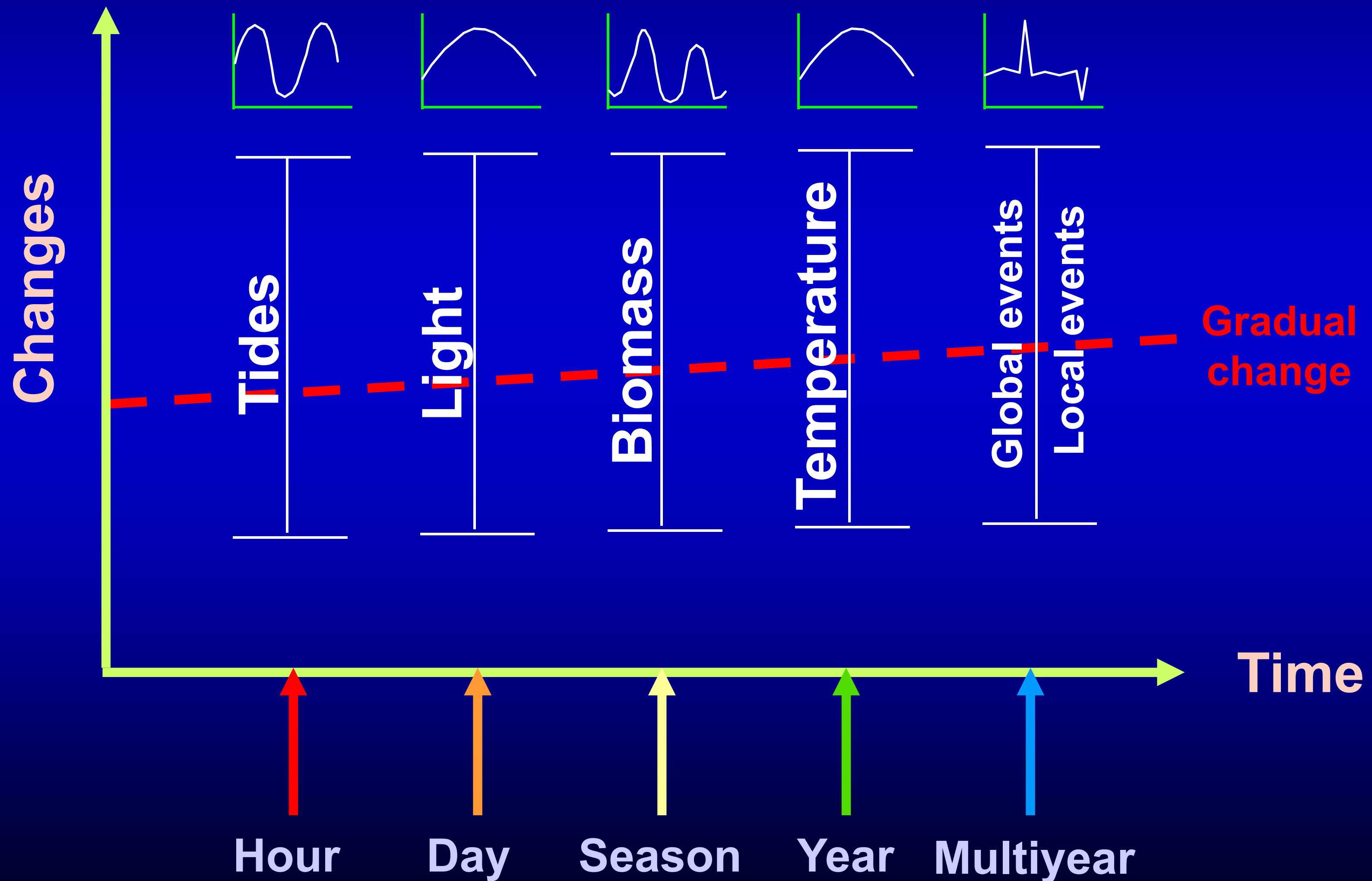
Changes in coastal systems



Model diversity

When we talk about models, 49.9999% of the world sees this!

The other half sees this...

Lab models

- Incubations for primary production or BOD

GIS Spatial models

- Marine spatial planning, chlorophyll spatial distribution

Mathematical models

- dC/dt = -kC (dynamic, time varying)

Physical models

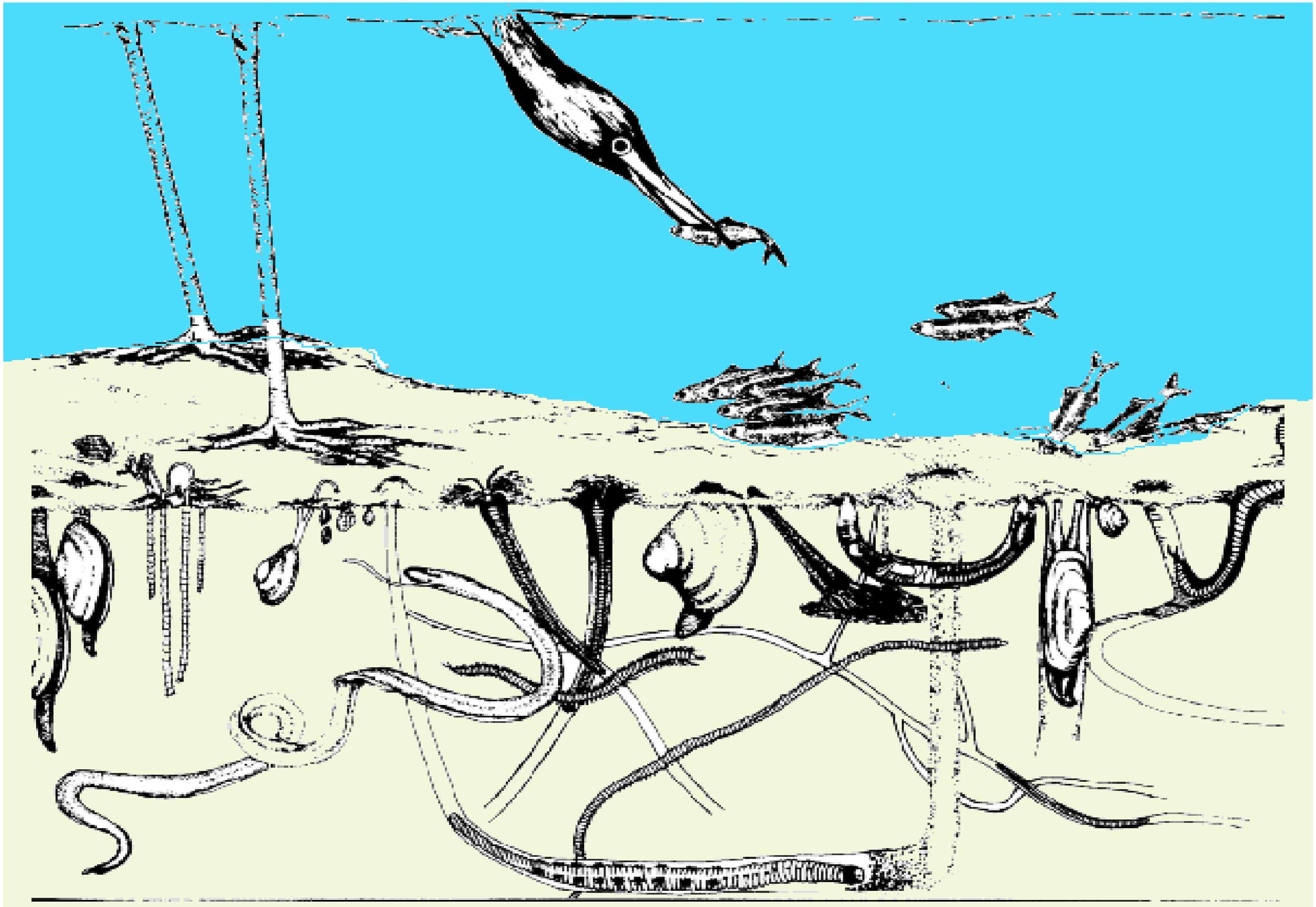
- Harbour scale models, toys

Other models

All models are wrong, but some are useful (George Box)

Ecological models are complex

even for simple systems...



How many state variables would you use in this system?

Why do we use models?

Measure state, perform experiments, simulate...

- Our conceptual understanding of ecosystems is often illustrated as a set of boxes (state) linked by arrows (processes)
- Processes such as primary production or grazing form the links between boxes (state), e.g. phytoplankton biomass, nutrient concentration
- Experimental approaches can help quantify these processes (e.g. P-I curves)
- This quantification can be used to mathematically “link” the boxes, and simulate ecological changes in time and space

No question, no model. A model is a tool, not an objective

Ecological Modelling – A tool

- Measurement of chlorophyll (satellite), suspended matter (sampling), area of mussel culture (GIS) etc;

- Modelling of shellfish growth allows the determination of rates such as net phytoplankton removal, nutrient excretion, production, which often cannot be directly measured.

State can be measured, processes can be modelled

Ecological Modelling - Objectives

Description and support

- Test and validate mental models
- Support sampling design
- Describe and hindcast
- Support data interpretation (e.g. laboratory models)

Forecasting

- Predict *general* behaviour of ecosystem
- Test and diagnose potential modifications
- Distinguish long-term signals from short-term variation

Make your model as simple as possible – but no simpler

Characteristics of models

Four defining elements

- Generality → Models should be portable
- Realism → Loss of realism is expected
- Accuracy → Loss of accuracy due to smoothing, difficulty in accommodating stochastic events, etc
- Simplicity → Reduce complexity whenever possible (Occam's razor)

Building a model is a trade-off among these four characteristics

Ecological Modelling

Different dimensions, different scales

Dimensions

- Statistical
- Zero-dimensional (time only)
- One-D (rivers, narrow estuaries)
- Two-D (non-stratified estuaries, coastal areas)
- Three-D (systems with pronounced horizontal and vertical gradients)

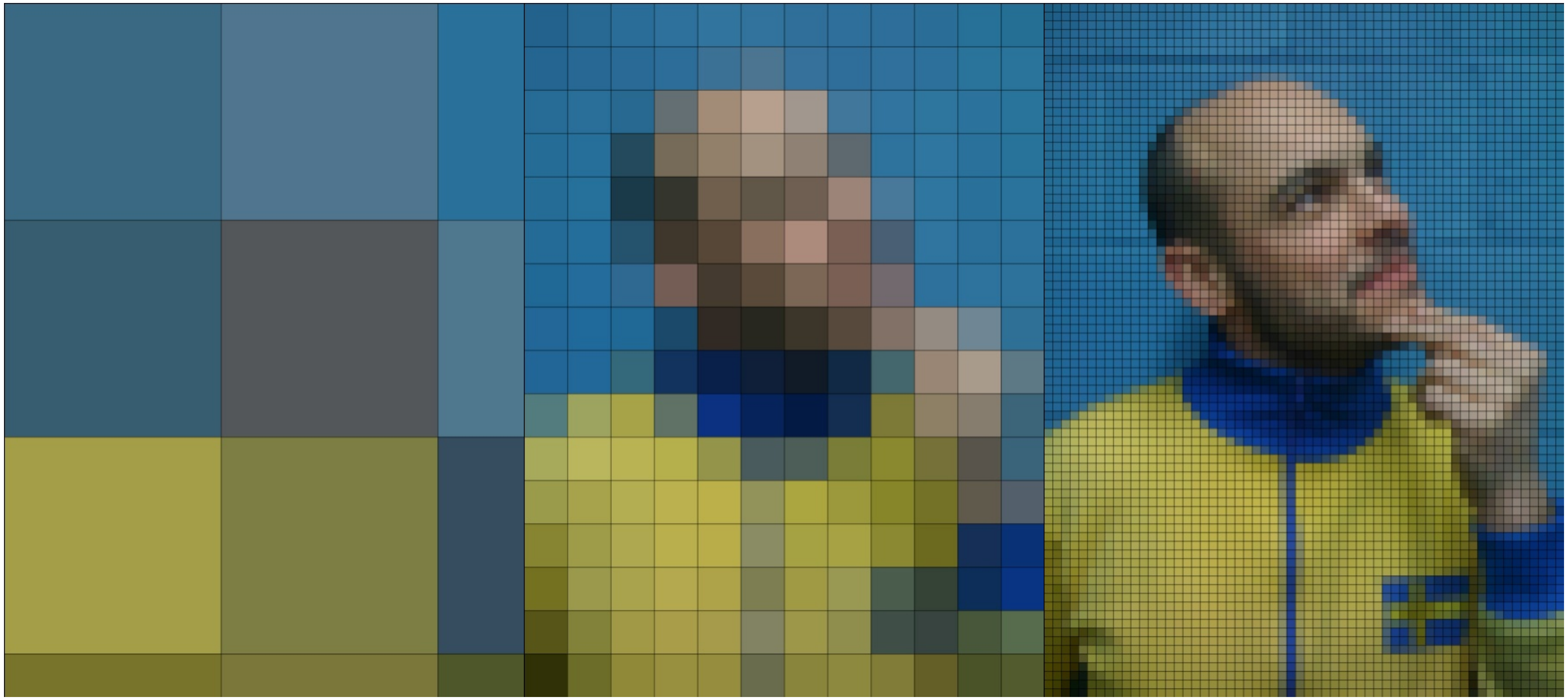
Time and space scales

- Hydrodynamics - Small cells, short timestep and time scale (tidal cycles, spring-neap cycles, localised case studies)
- Ecology - Larger boxes, longer timestep and time scale (seasonal cycles, annual patterns, multiannual variation)

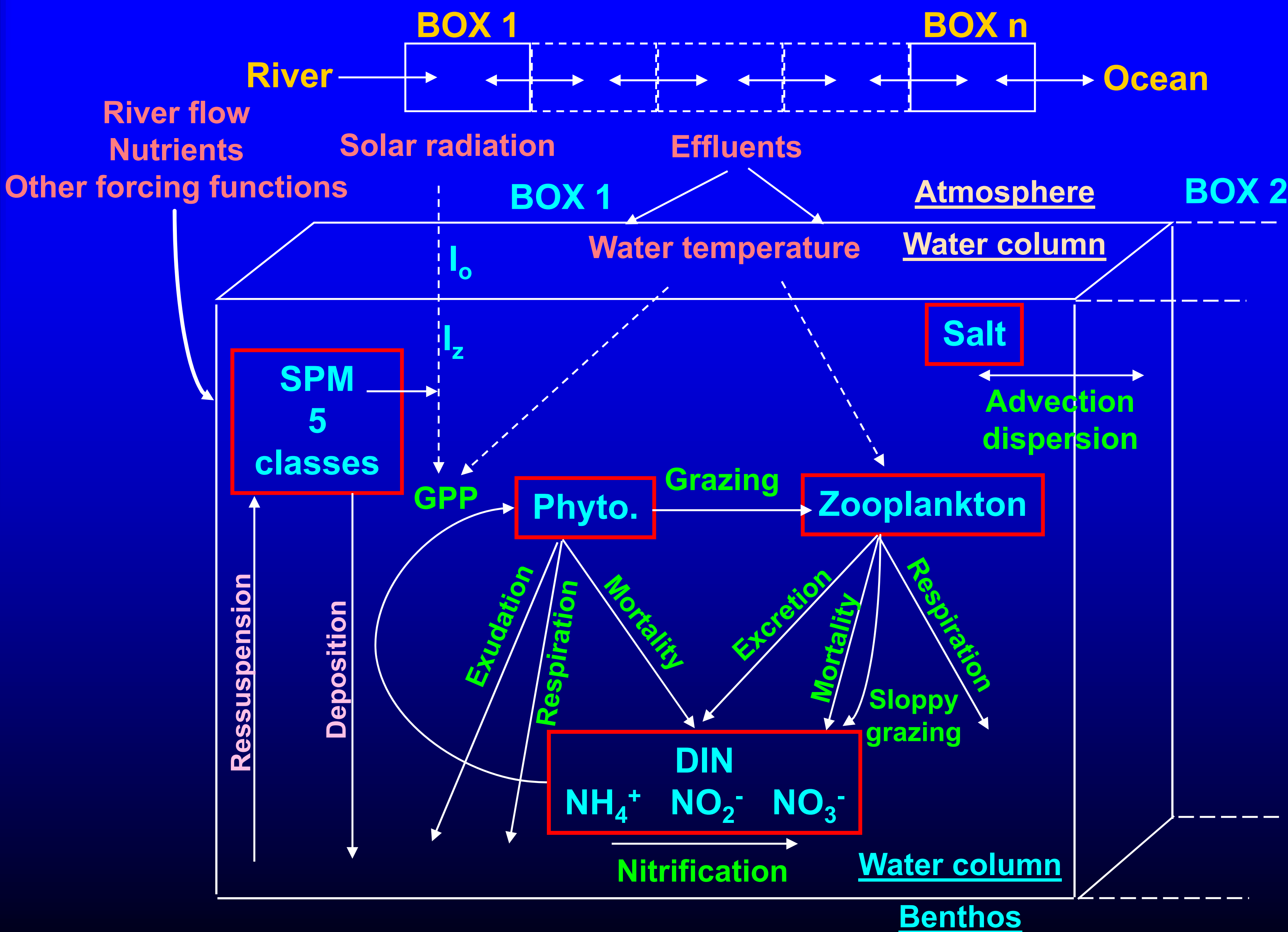
Most people don't solve the problem, they change the problem into something they know how to solve. This does not solve the problem

Ecological modelling in coastal environments:

At which spatial resolution do we need to represent an ecosystem?



General scheme of a simple ecological model



Ecological Modelling

Elements and requirements

Model elements

- State variables (nitrate, phytoplankton)
- Forcing functions (light, temperature)
- Processes (production, mineralization)
- Parameters (light extinction cofficient, half-saturation constants, grazing rate)

Model requirements

- Physical framework (box volumes, areas, etc)
- Boundary conditions (concentration values at model limits)
- Initial conditions (starting values for model)

Operational models (a.k.a. data assimilation)

- Re-initialised at appropriate time steps

Conceptual framework + Physical framework = Model

Ecological Models

Development stages

Model Conception

- Objectives of the model
- Components of the model (variables, forcing functions)
- Scope of the model (time and space)
- Limitations and closure

Model Implementation

- Problem decomposition, definition of appropriate sub-models
- Data handling and generation
- Model building (e.g. visual platform)
- Running and testing

Model Calibration

- Tuning parameters and functions using field data

Model Validation

- Testing against an independent dataset

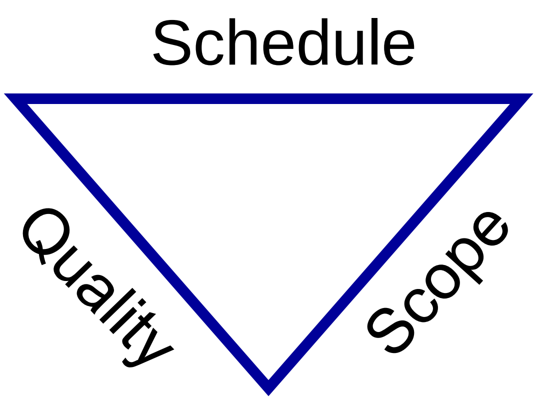
Re-use if possible, develop if necessary

Ecological Models

Technical aspects

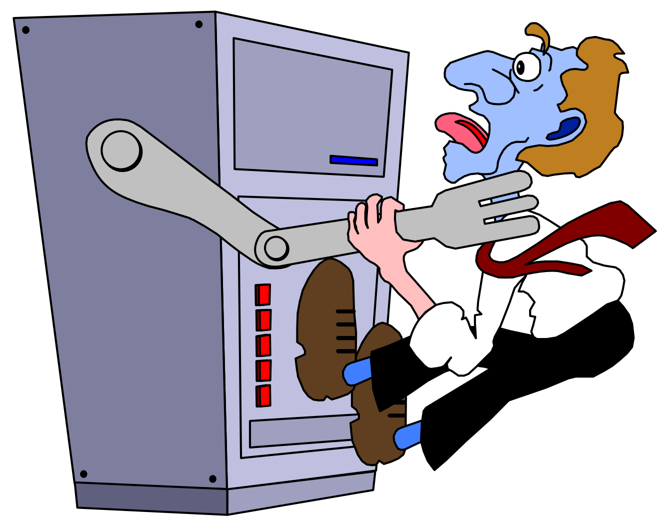
- <u>Development</u>
  Visual (e.g. PowerSim)
  “Hard-coded?”
  Hybrids (e.g. Matlab-based, EcoWin2000)

- Object-oriented modelling
- Links/use of “any” language
- Portability (ANSI code)



- <u>Model Coupling</u>
  Internal
  Protocol
  External

- Protocol coupling



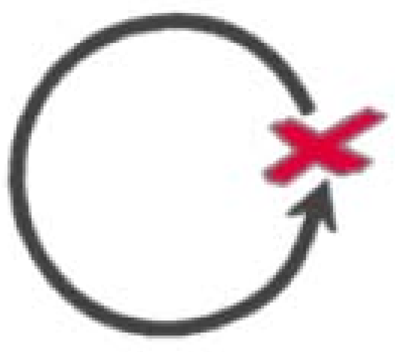
Há muitas maneiras de fazer bacalhau

Ecological Models

Spreadsheets and visual models

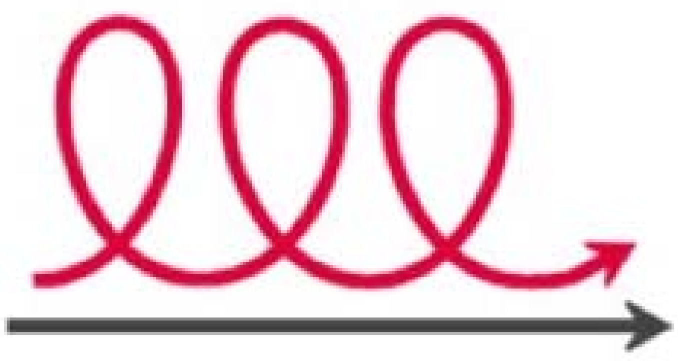
Spreadsheets

- Excel, Lotus123 etc
- Data in rows and columns, only formula for active cell is visible
- Feedback mechanisms are eliminated to avoid circular references



Visual models

- Powersim, Stella etc
- Data (including data links) represented using visual elements
- Feedback is explicitly considered as a major factor in systems analysis



Models are all about feedbacks

Ecological models

Brief case studies

What is the question?

- No question, no model. A model is a tool, not an objective
- Eutrophication in the Ria Formosa, Portugal
- Mussel growth in Killary Harbour, Ireland

Relevance: sustainable management of coastal systems

Ecological models

Brief case studies

What is the question?

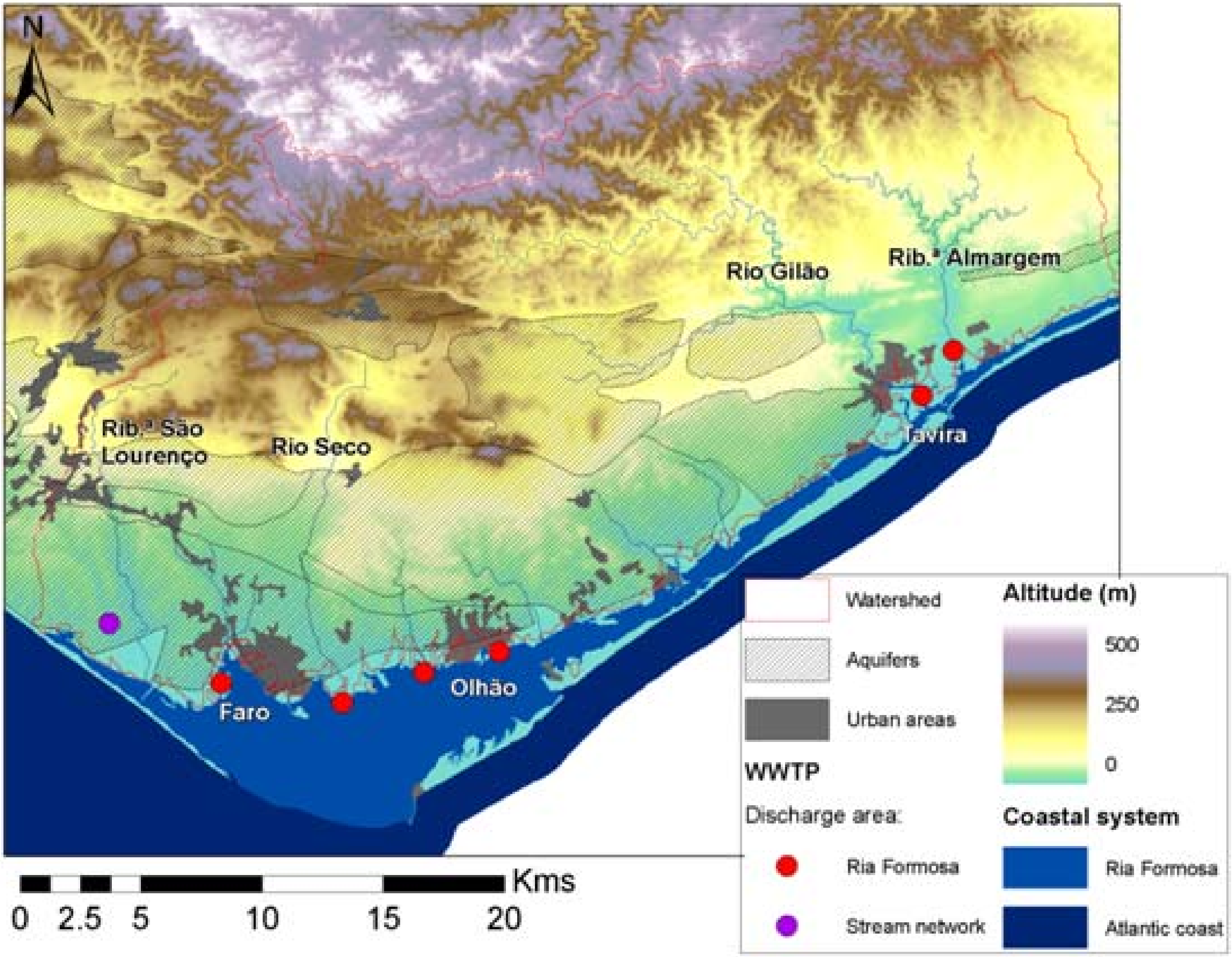
- What is the eutrophication status of the Ria Formosa?
- What management measures might be implemented?
- Use ecosystem-scale models to look at the effect of bivalves in the system
- Examine effects of nutrient loading on plankton and seaweeds
- Review management scenarios and legislative compliance

Relevance: water management, conservation, sustainability

A.M.Nobre, J.G.Ferreira, A.Newton, T.Simas, J.D.Icely, R.Neves, 2005. Management of coastal eutrophication: Integration of field data, ecosystem-scale simulations and screening models. Journal of Marine Systems, 56 (3/4), 375-390.

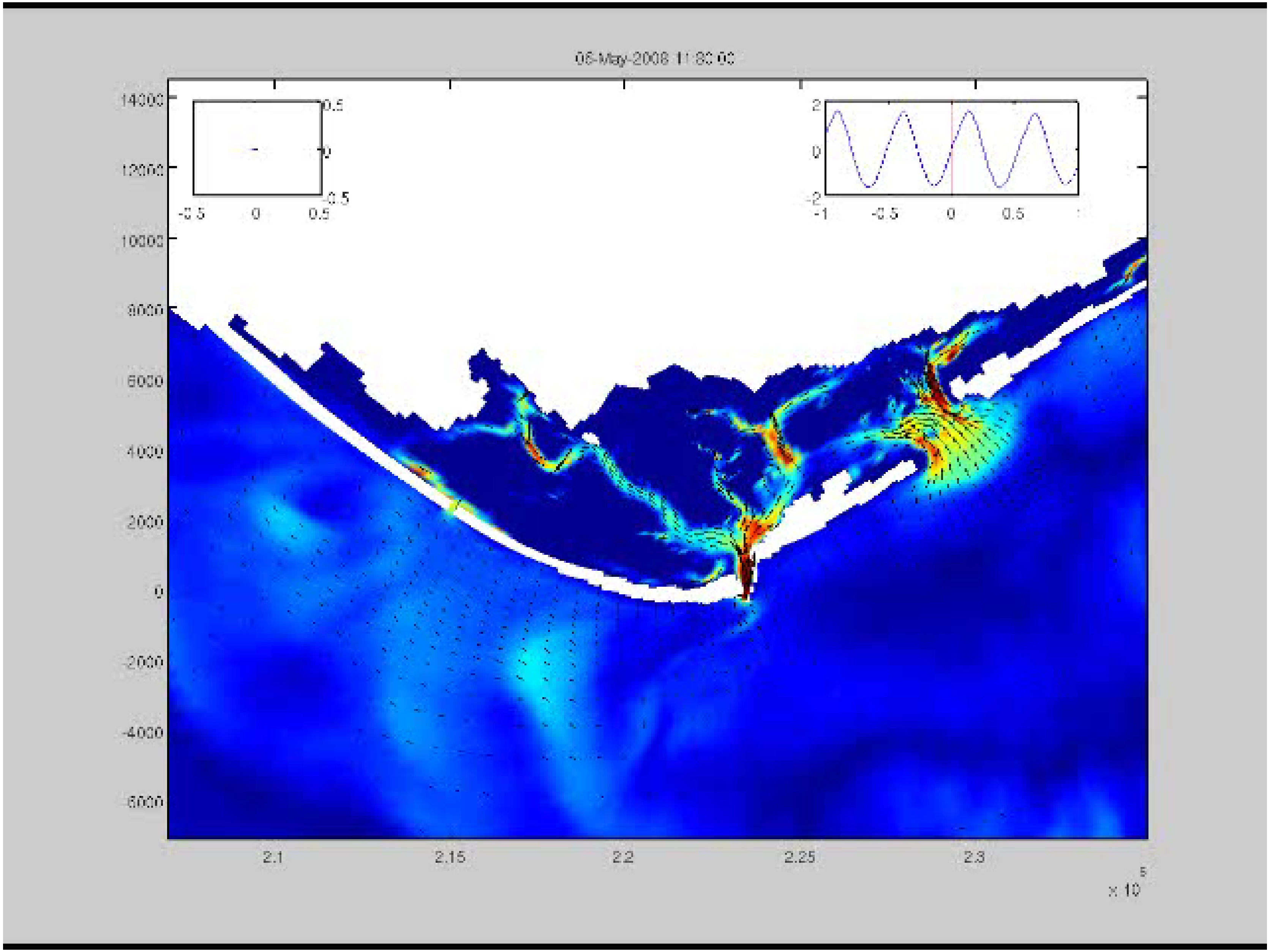
FORWARD study area – The Ria Formosa and its watershed

Framework for Ria Formosa Water Quality, Aquaculture, and Resource Development



Southeastern Portugal: 184 km^2, 1-3 m tidal range, 13-23 ºC, 36 psu.
Bivalve and finfish aquaculture, salt extraction, wild fisheries, MPA.

Connectivity: Offshore- Ria Formosa (circulation model)

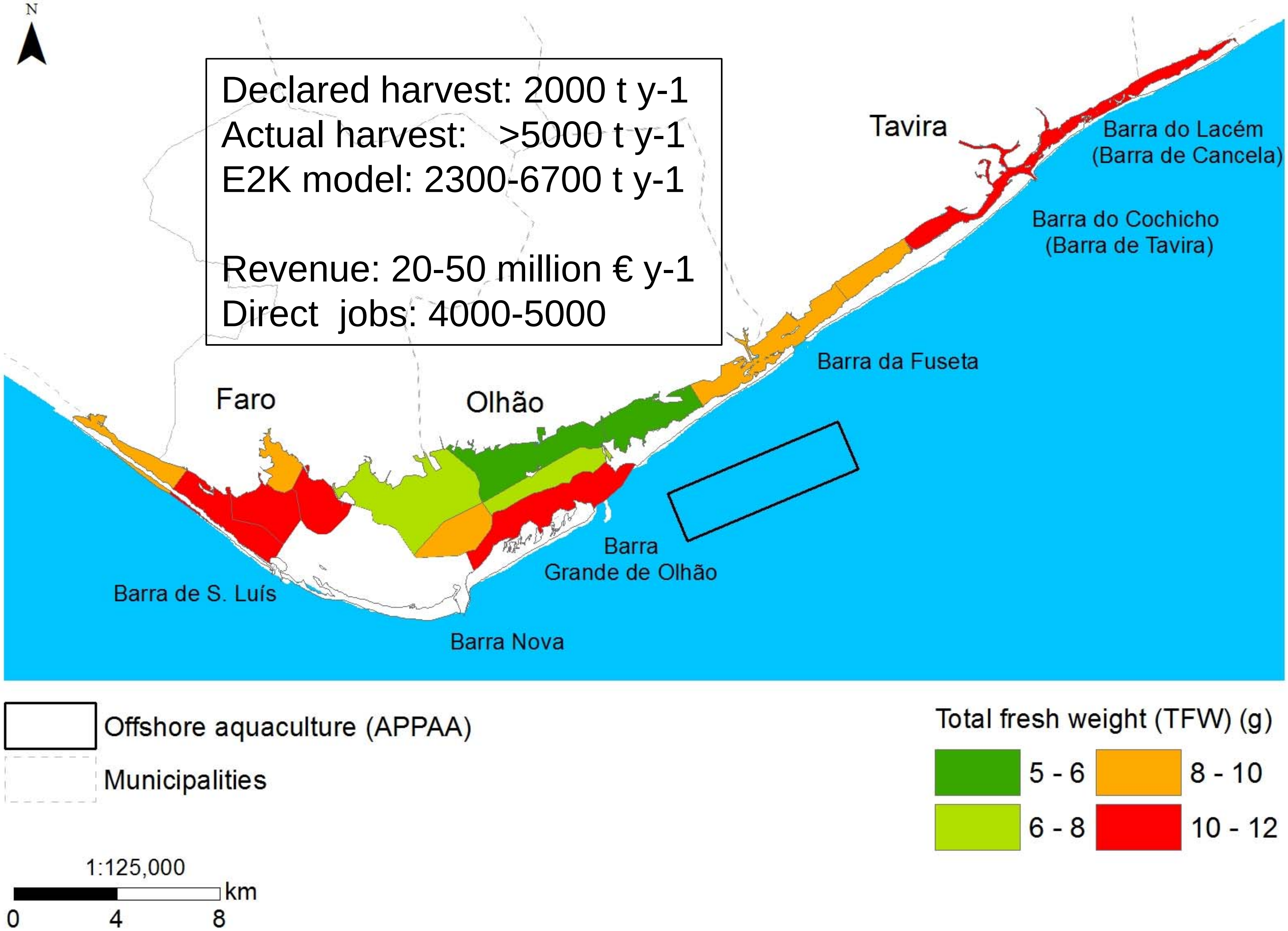


Tidal circulation in the Ria Formosa, Algarve. Water residence time of 1-2 days.

EcoWin2000 model – system-scale clam production

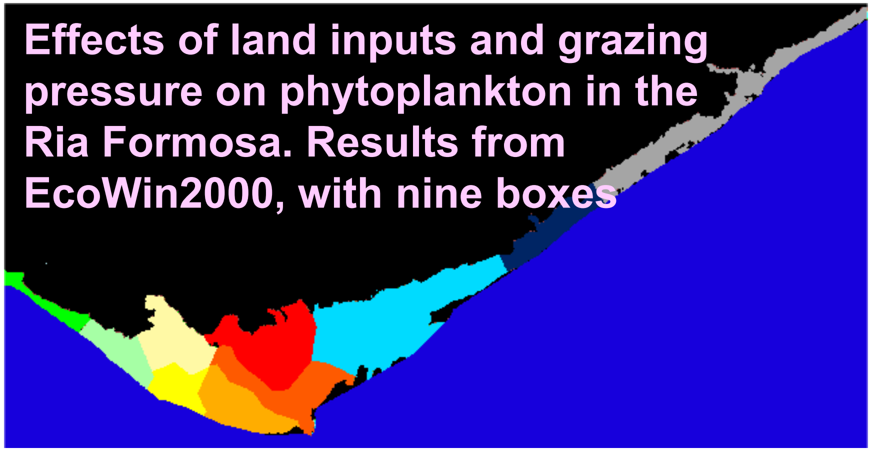
Declared harvest: 2000 t y-1
Actual harvest: >5000 t y-1
E2K model: 2300-6700 t y-1

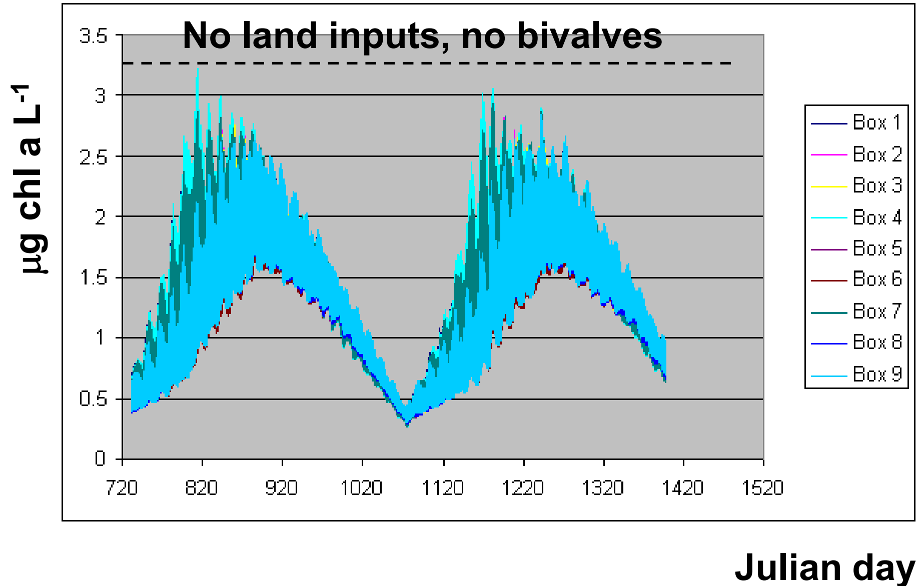
Revenue: 20-50 million € y-1
Direct jobs: 4000-5000

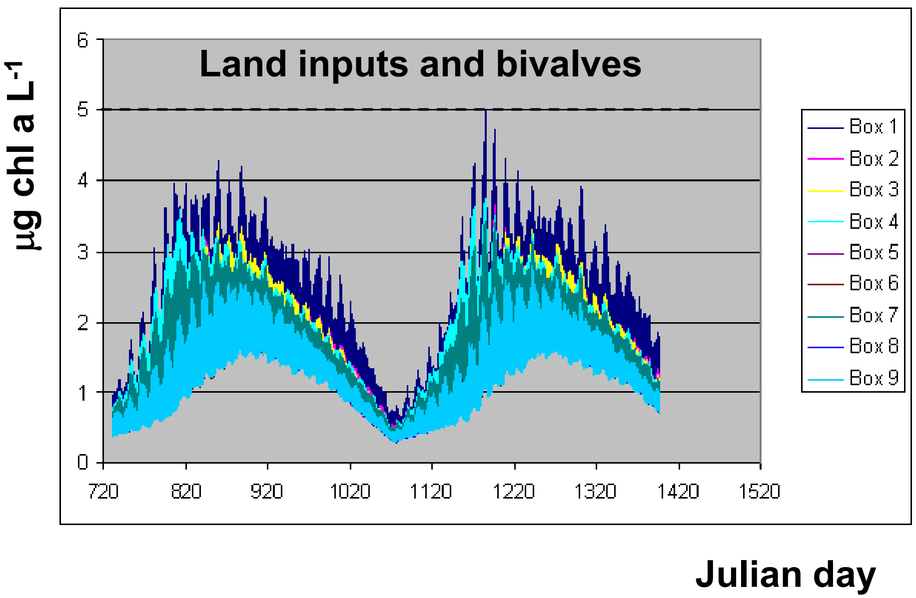


System-scale carrying capacity is spatially variable, depends on ocean connections.

EcoWin2000 model – nutrient loading and top-down control







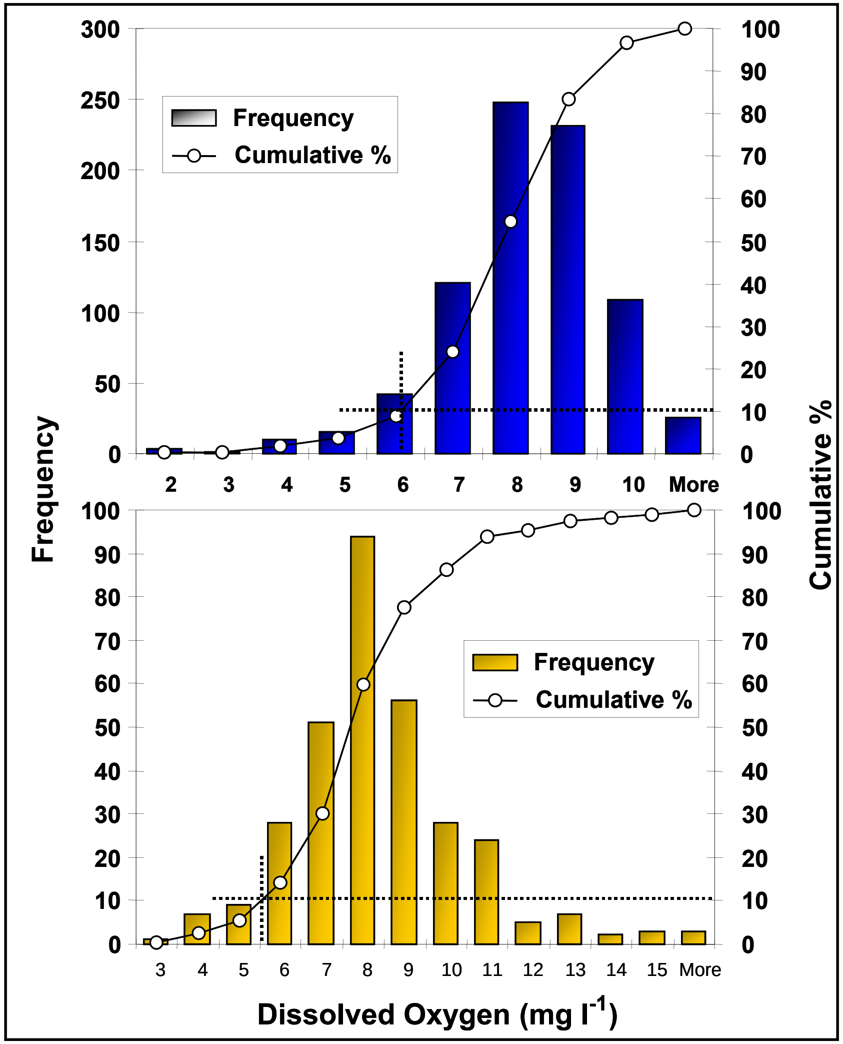
OAERRE project

Tett, P., Gilpin, L., Svendsen, H., Erlandsson, C.P., Larsson, U., Kratzer, S., Fouilland, E., Janzen, C., Lee, J., Grenz, C., Newton, A., Ferreira, J.G., Fernandes, T., Scory, S., 2003. Eutrophication and some European waters of restricted exchange. Continental Shelf Research, 23, 1635-1671

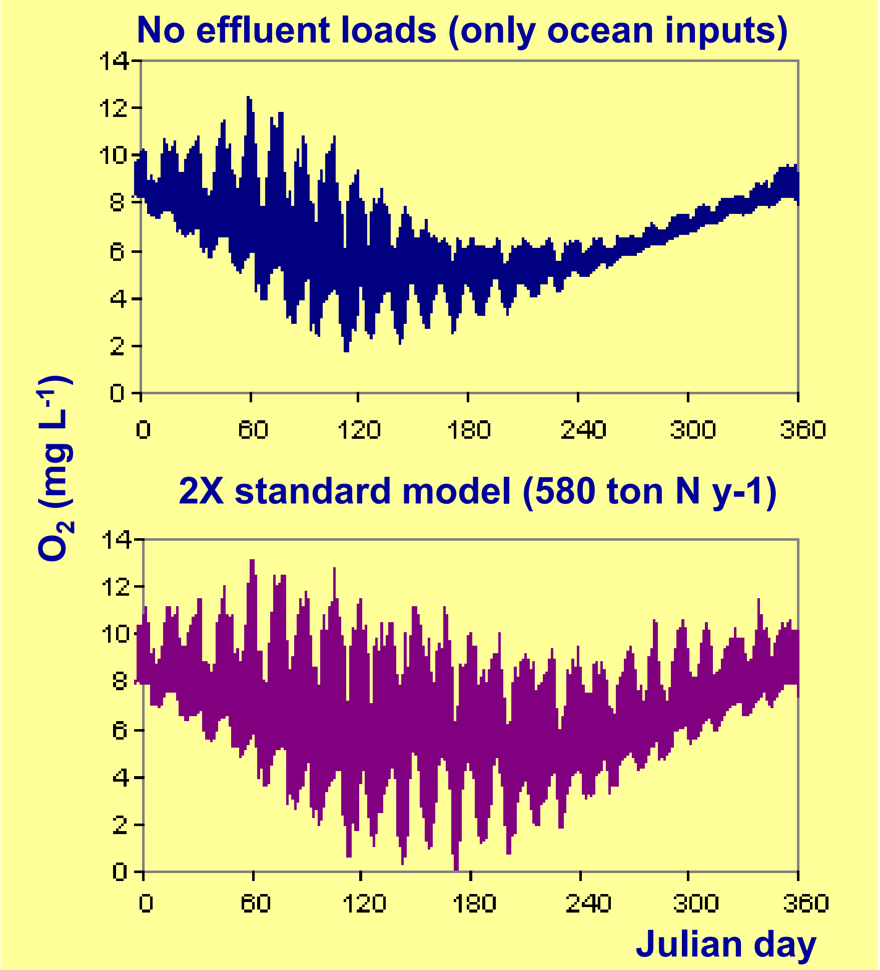
Top-down control of algae by bivalves cancels the effect of land inputs.

EcoWin2000 model – Dissolved oxygen in channels and tide pools

D.O in the channels

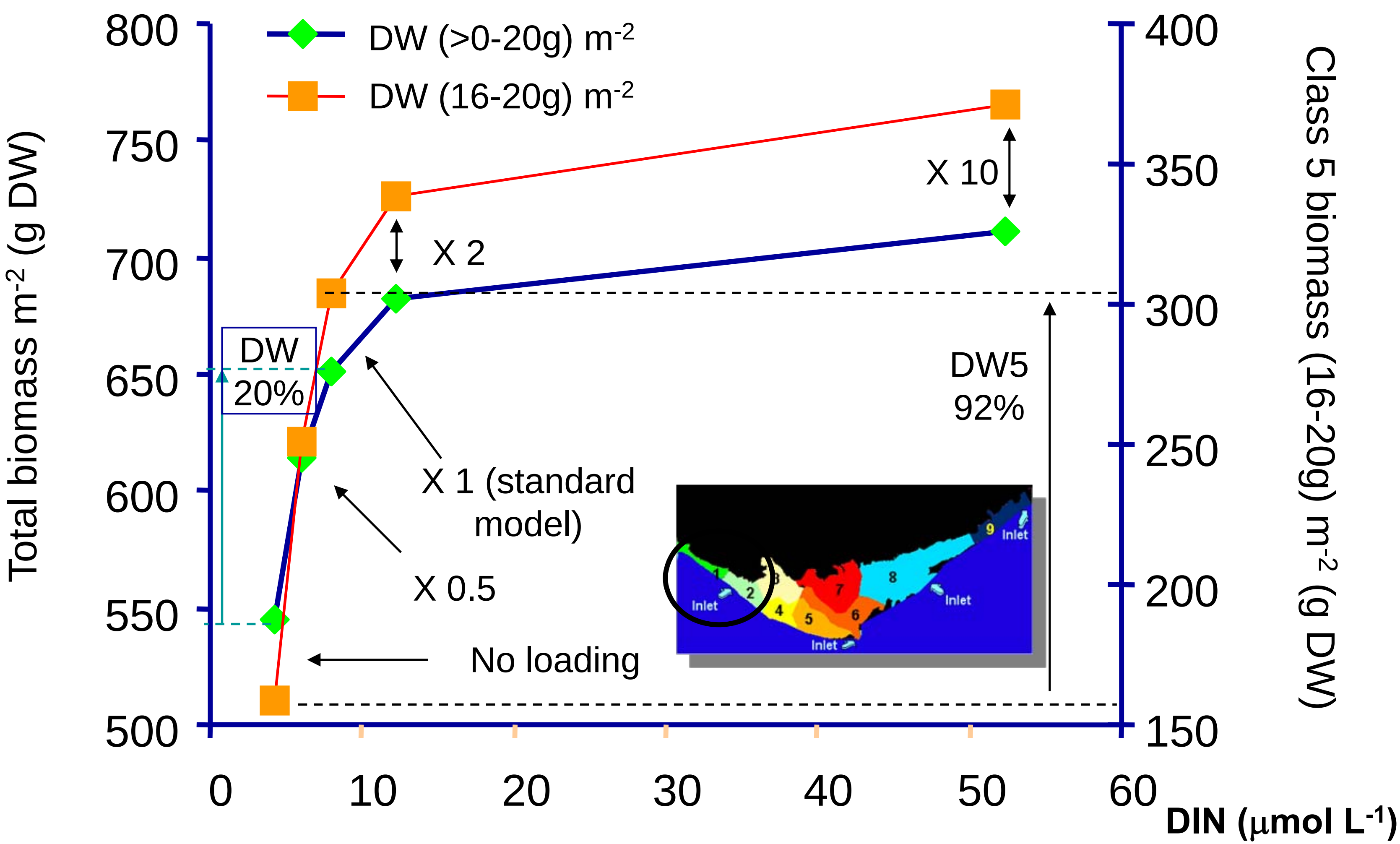


D.O in the tide pools



Modelling of the Ria Formosa 'misses' the effects of low DO in tide pools.

EcoWin2000 model – Growth of *Ulva*
Percentile 90 for different DIN loads



Total biomass increases much less than biomass of large algae that smother clams.

Ecological models

Integrated management

What is the question?

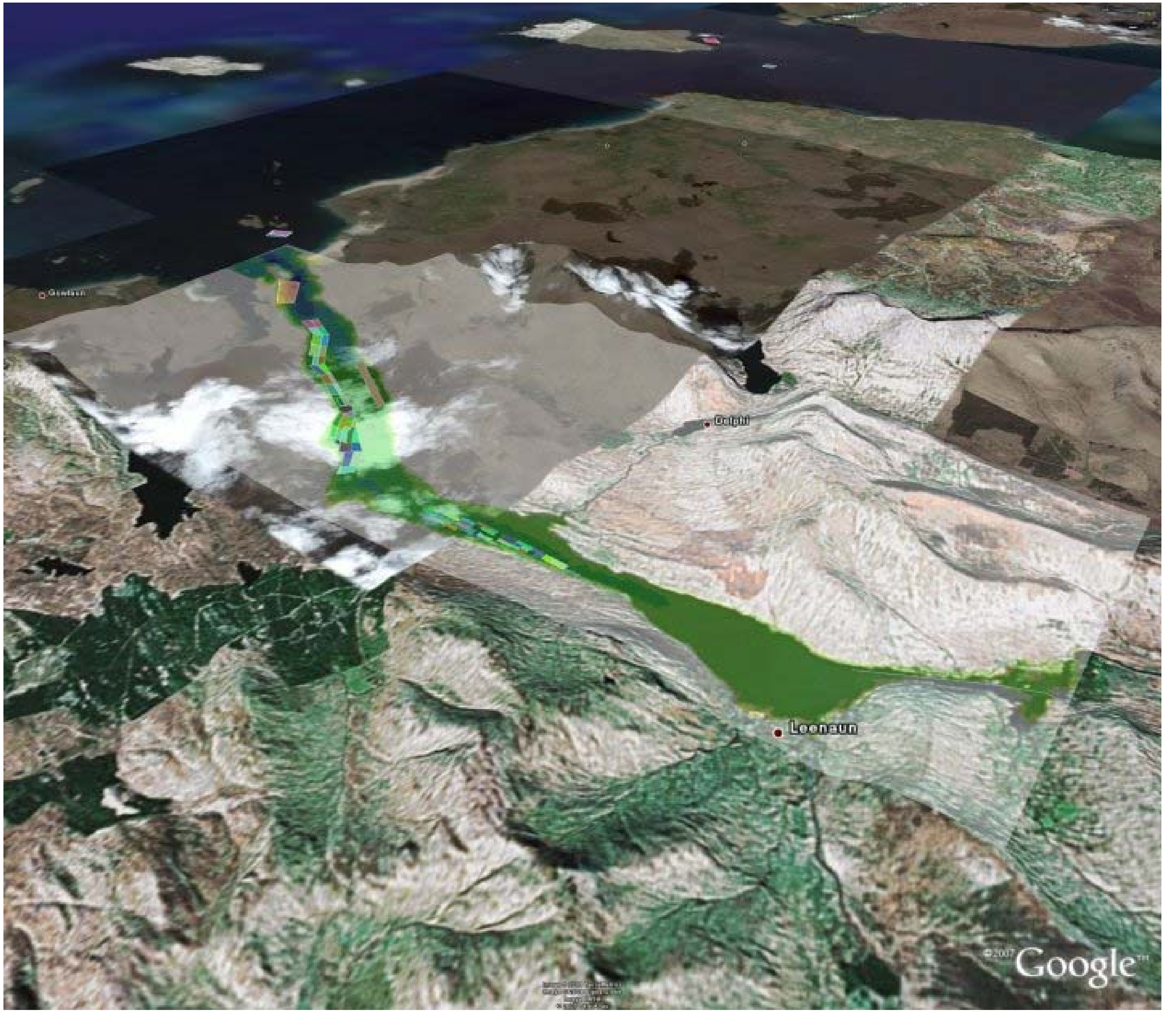
- How much mussel aquaculture is desirable in Killary Harbour, Ireland?
- Aquafarmers are worried about slow growth
- Regulators are worried about exceeding carrying capacity
- No one is sure what would be the best management measures. If the cultivation needs to be reduced, then where and by how much?
- Such decisions impact livelihoods, and can have social consequences

Relevance: sustainable aquaculture

Nunes et al., 2011. Towards an ecosystem approach to aquaculture: assessment of sustainable shellfish cultivation at different scales of space, time and complexity. Aquaculture. http://dx.doi.org/10.1016/j.aquaculture.2011.02.048

Killary Harbour

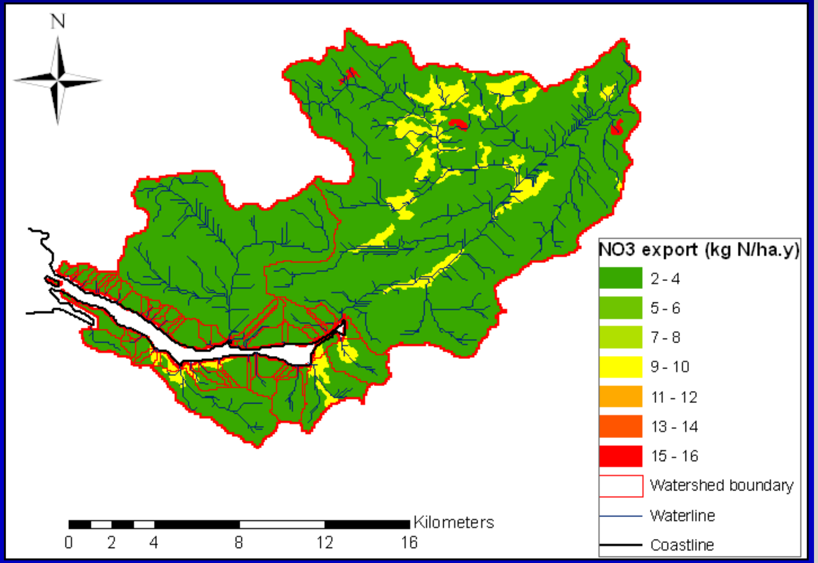
- NW Irish coast
- About 15 km long, 10 km^2
- Mussel rafts on the southern shore of the lower estuary
- Sparse population, more sheep than humans



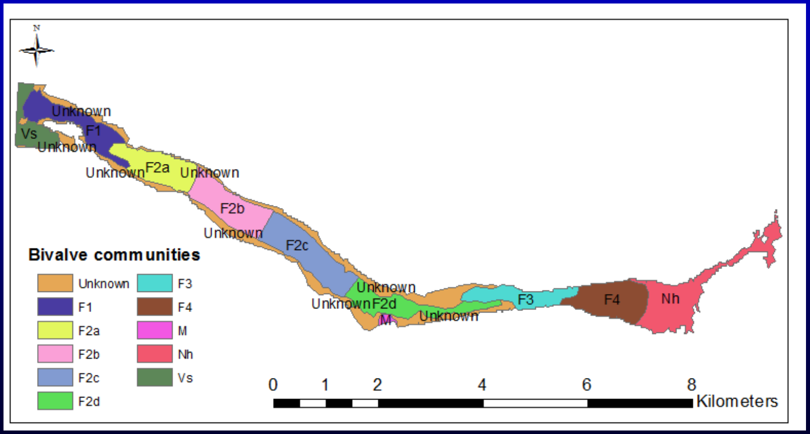
One of about sixty systems designated for aquaculture in Ireland

Catchment and biodiversity

- Catchment nutrient loads for N (NO_3 and NH_4) and P (DRP) estimated from landcover using export coefficients (Foy and Girvan, 2004)
  - Total N load: **74.8** ton.y^{-1}
- Natural bivalve communities surveys before aquaculture (Keegan and Mercer, 1986) and after limited aquaculture (Rodhouse and Roden, 1987)
  - Wild bivalve density: **3** to **6** ind.m^{-2}, significantly lower than in comparable coastal systems

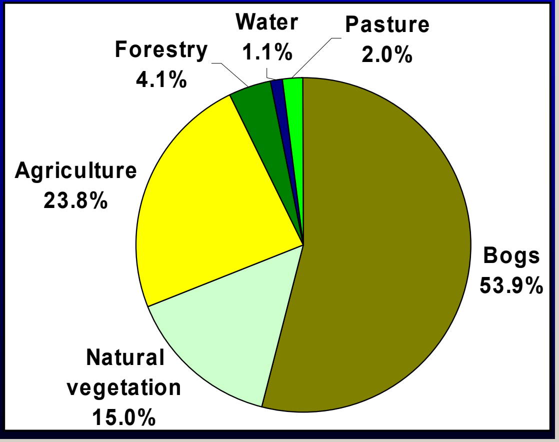


Map of nitrate sources

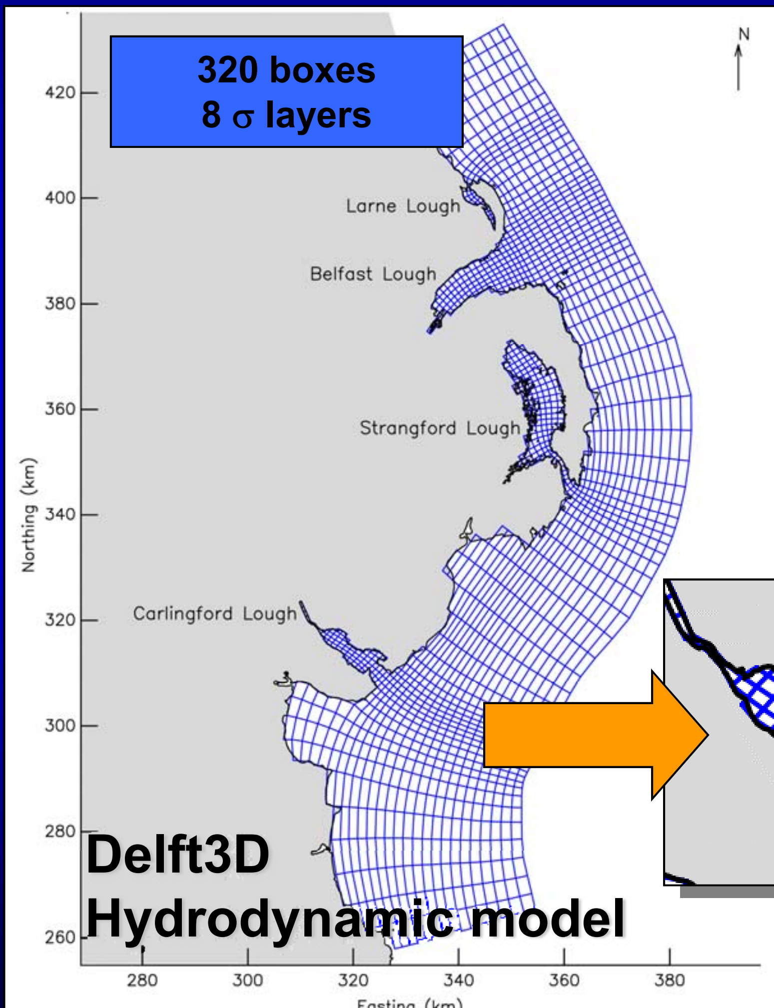


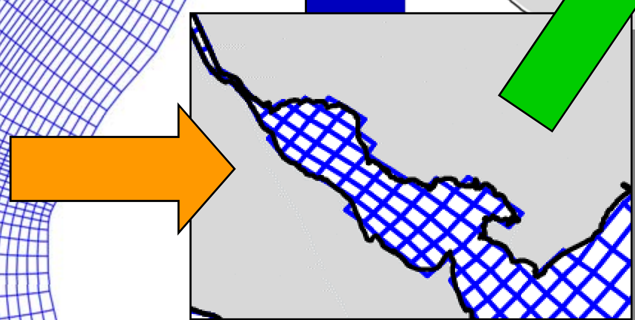
Map of bivalve communities

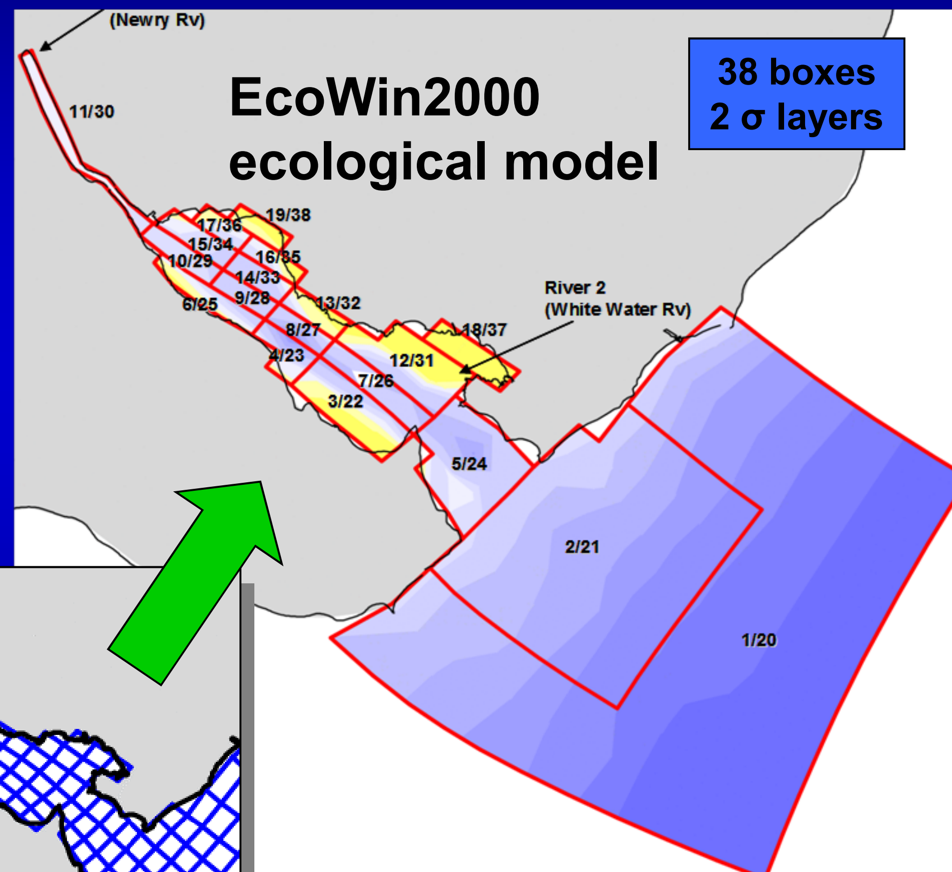
Catchment nitrate sources, by landcover type



Hydrodynamic coupling - Carlingford Lough



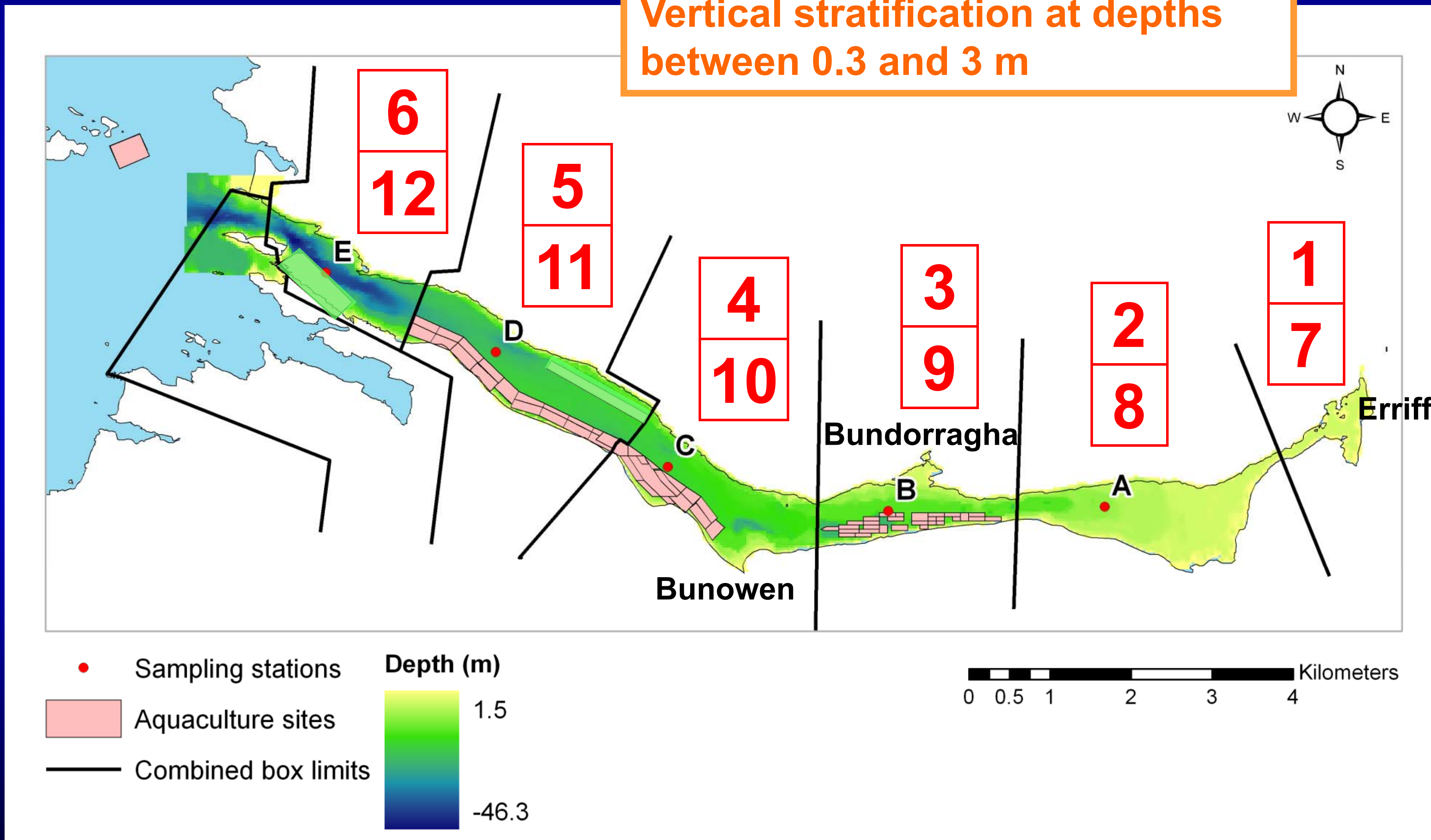




A much coarser grid is used in biogeochemical models than in hydrodynamic models.

EcoWin2000 3-D model: zone delimitation (model boxes)

Vertical stratification at depths between 0.3 and 3 m



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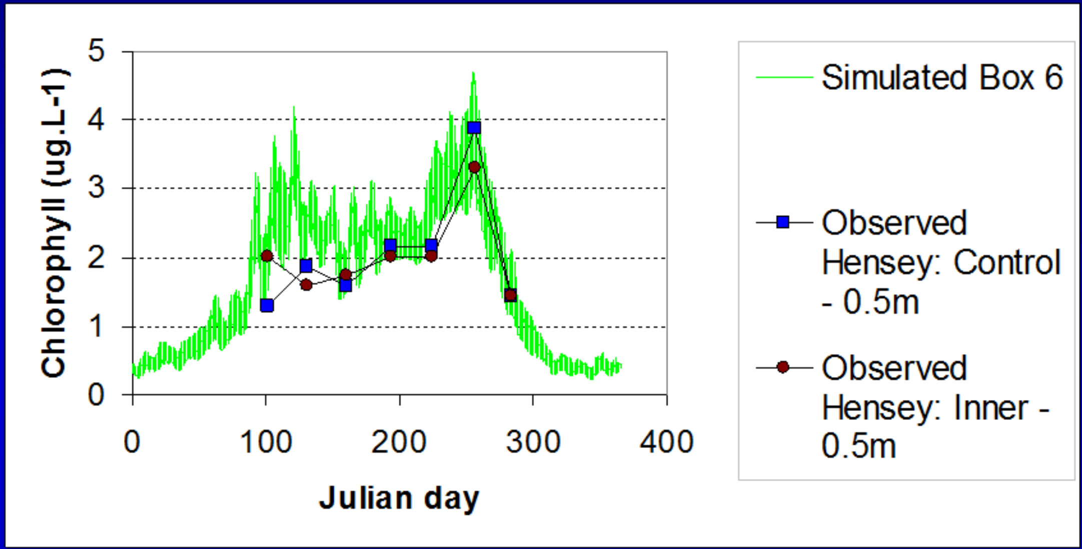
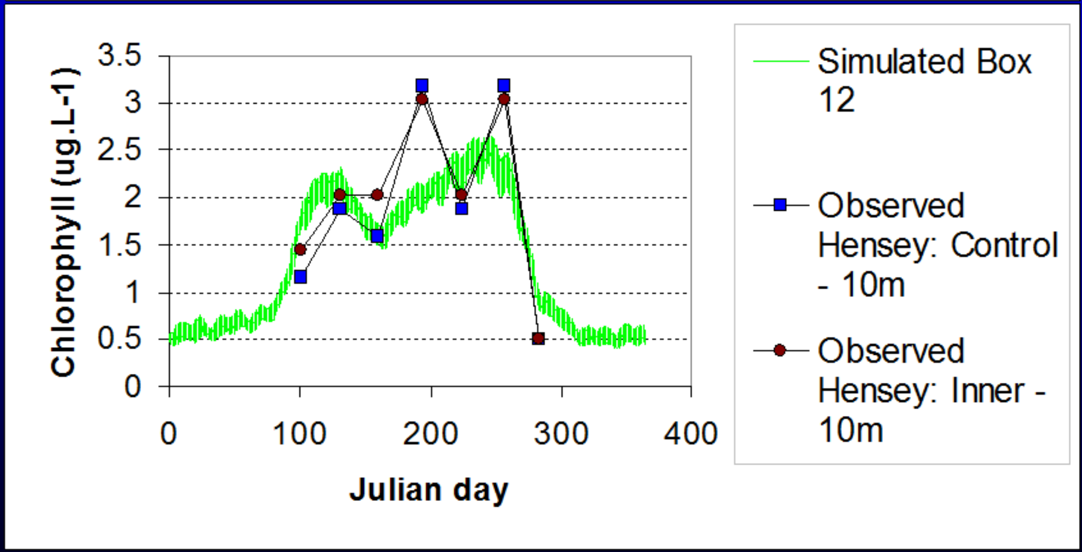
EcoWin2000: calibrating food resources





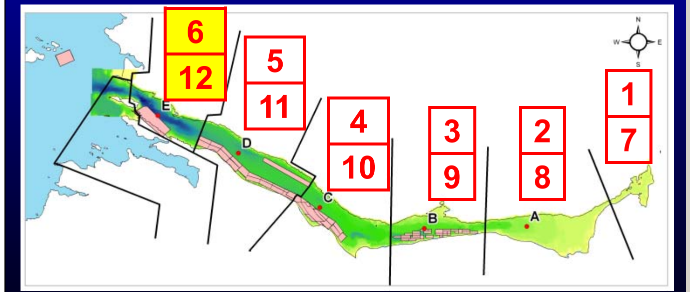
Phytoplankton concentration (outer Harbour)

Correlation – surface:

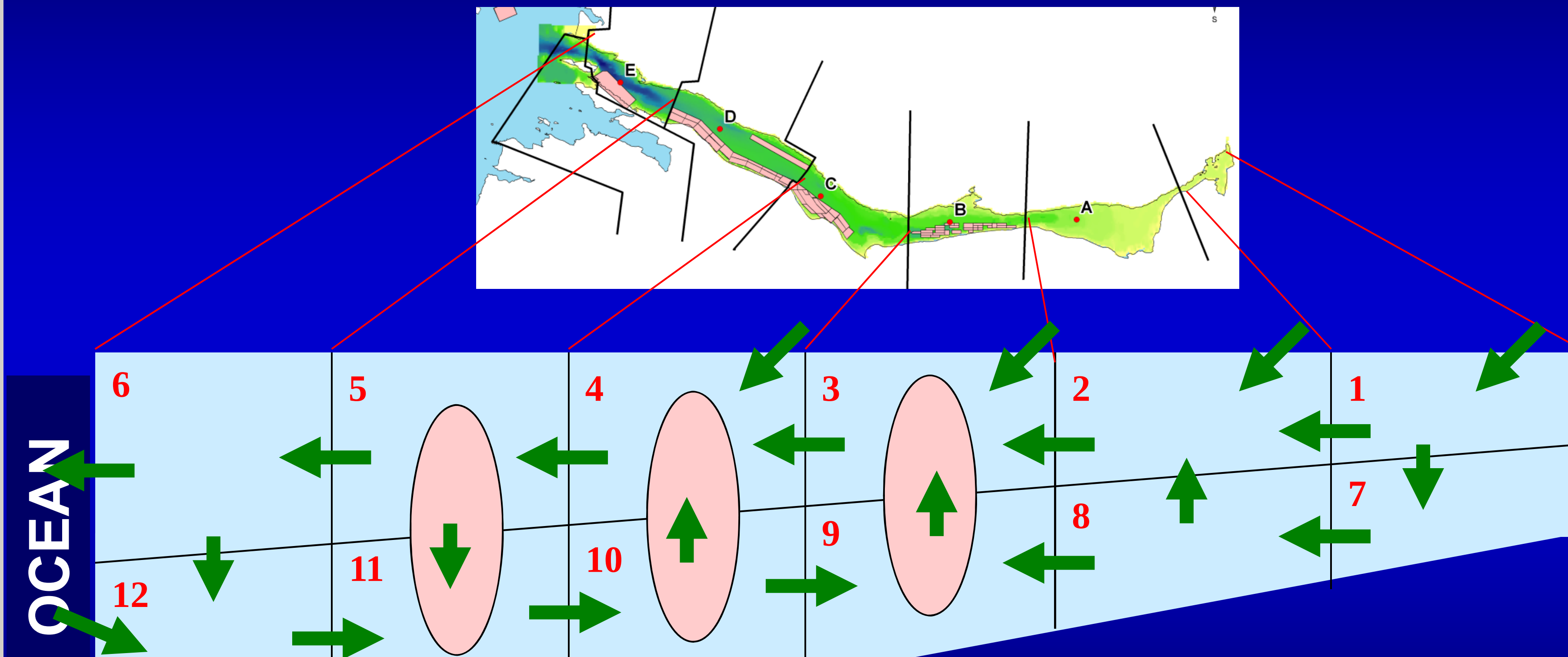
Control: 0.94 ($p<0.05$)
Inner: 0.89 ($p<0.05$)

Correlation – bottom:

Control: 0.72 ($p<0.10$)
Inner: 0.77 ($p<0.05$)



EcoWin2000 3-D model: phytoplankton circulation



Inputs ≈ Outputs (c. 320 tonC.y^{-1})

NPP = 49% of ocean exchange

Shellfish uptake = 44% of ocean exchange

System is a small net exporter

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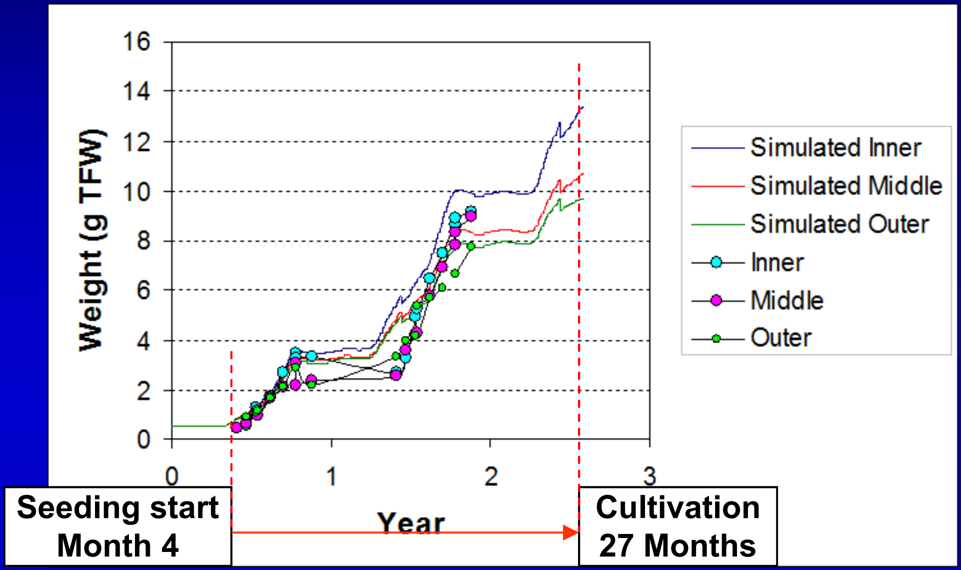
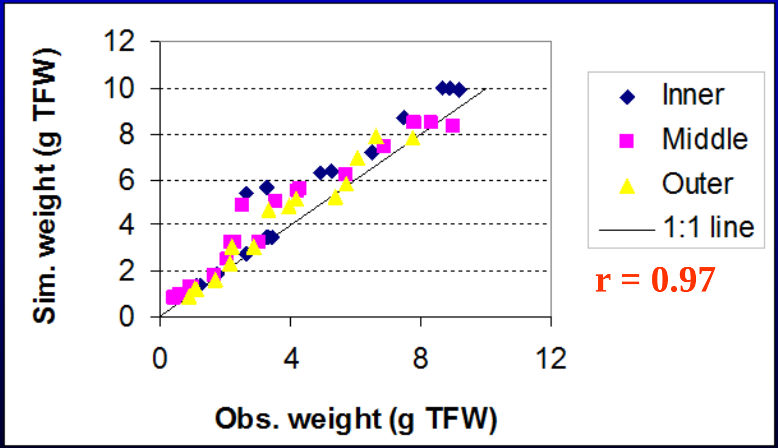
EcoWin2000: shellfish cultivation and harvest

- **Summary**:
  - Seeding density: **400** ind.m^{-2}
  - Seed application: **2** ton.ha^{-1}
  - Harvest: **35** ton.ha^{-1}.y^{-1} (**12** ton.ha^{-1}.y^{-1} total area)
  - Average Physical Product: **17**
- Simulated vs. Observed annual harvest:
  - **1820** vs. **1630** ton.y^{-1}
  - Total mussel biomass: **3925** vs. **3230** ton.y^{-1}
- Better growth in the inner harbour, with significant differences in final mussel weight.
  - Inner: **41** ton.ha^{-1}.y^{-1}, APP **21**
  - Middle: **35** ton.ha^{-1}.y^{-1}, APP **18**
  - Outer: **32** ton.ha^{-1}.y^{-1}, APP **16**



Mussel individual weight



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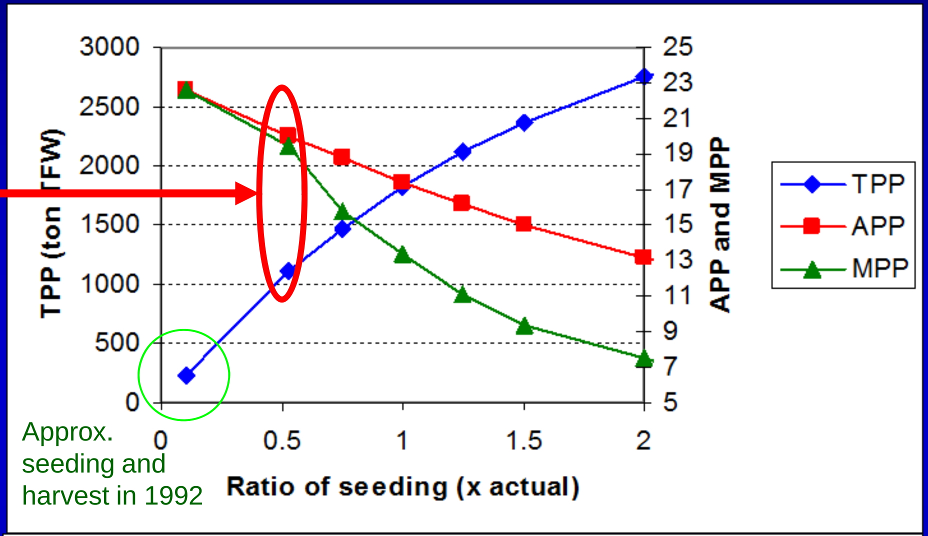
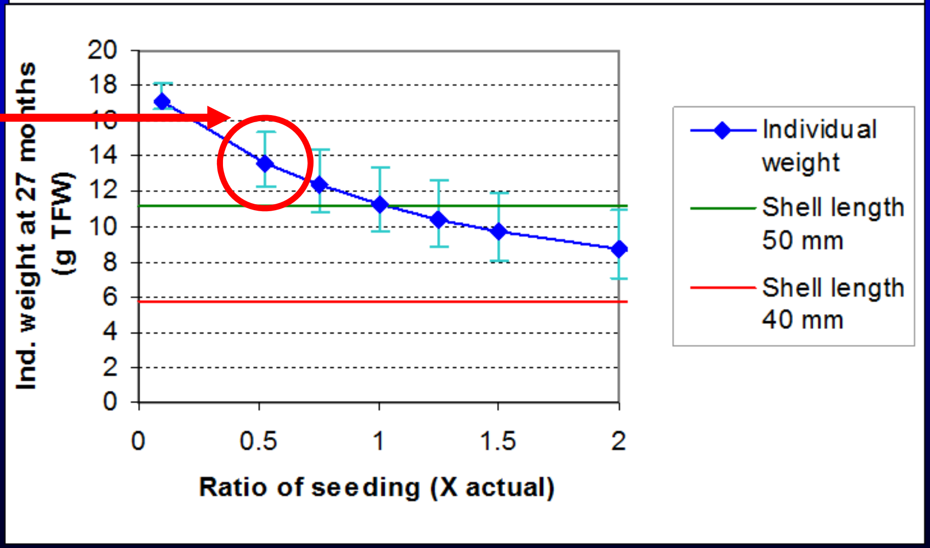
Changes to mussel cultivation density

- Scenario: change seeding density from **10%** to **200%**

- <u>**Summary:**</u>
  - Mussel harvest increases with seeding density, but...
  - APP declines
  - Single individual weight declines; at 2x density, no culture site can produce mussels with 50 mm in 27 months

- Decrease in density by **47%**
  - Mussel annual harvest drops by **39%**, but...
  - APP increases by **15%**
  - Mussel weight at 27 months increases by **20%**
  - On all sites, mussel shell length reaches 50 mm in 27 months

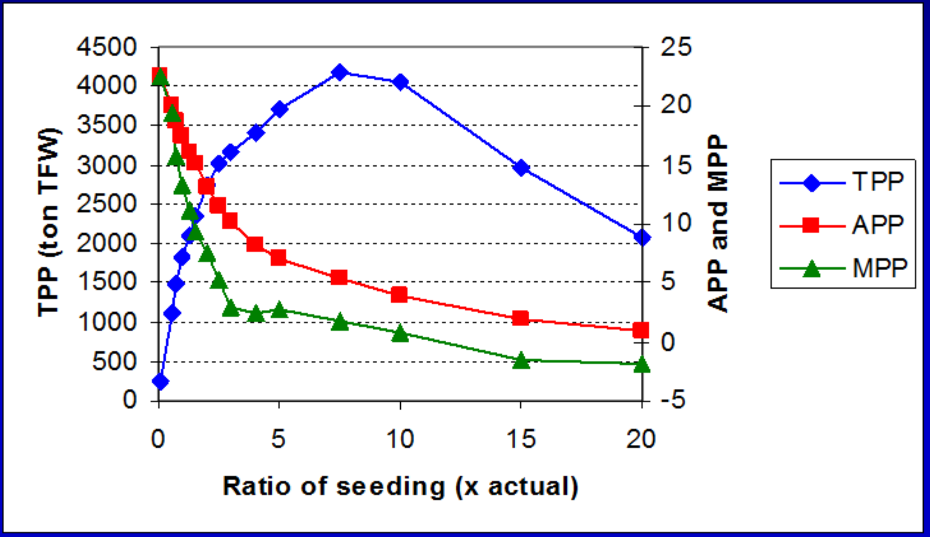


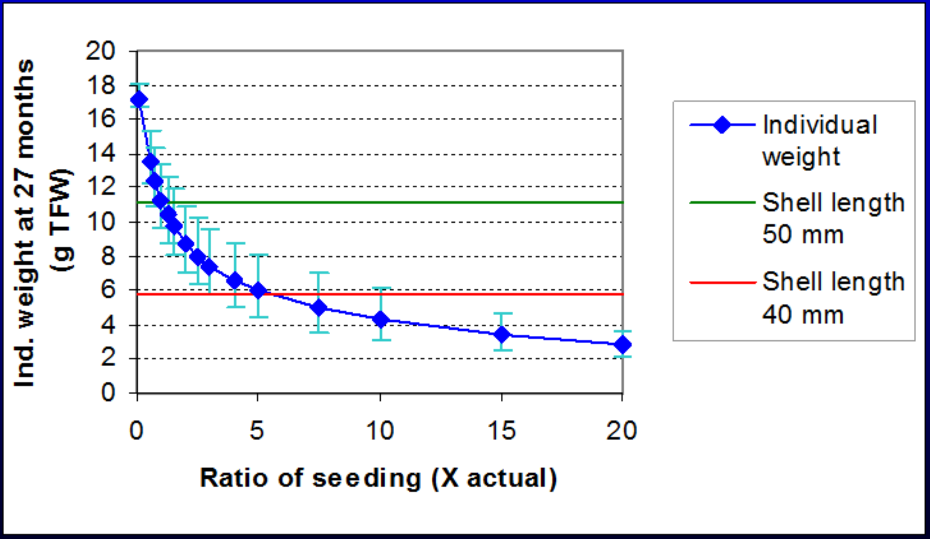


Killary shellfish carrying capacity

- Scenario: increase seeding density to **20X** present values

- **Summary:**
  - Maximum mussel harvest: ~**4000** ton TFW.y^{-1}
  - Max. Harvest estimated by Rodhouse and Roden (1987): ~**3000** ton TFW.y^{-1}
  - Seeding density for maximum harvest: **7.5x** present
  - Individual weight drops with increased seeding density
  - With seeding density over **3x**, sites stop producing mussels over 40 mm in 27 months





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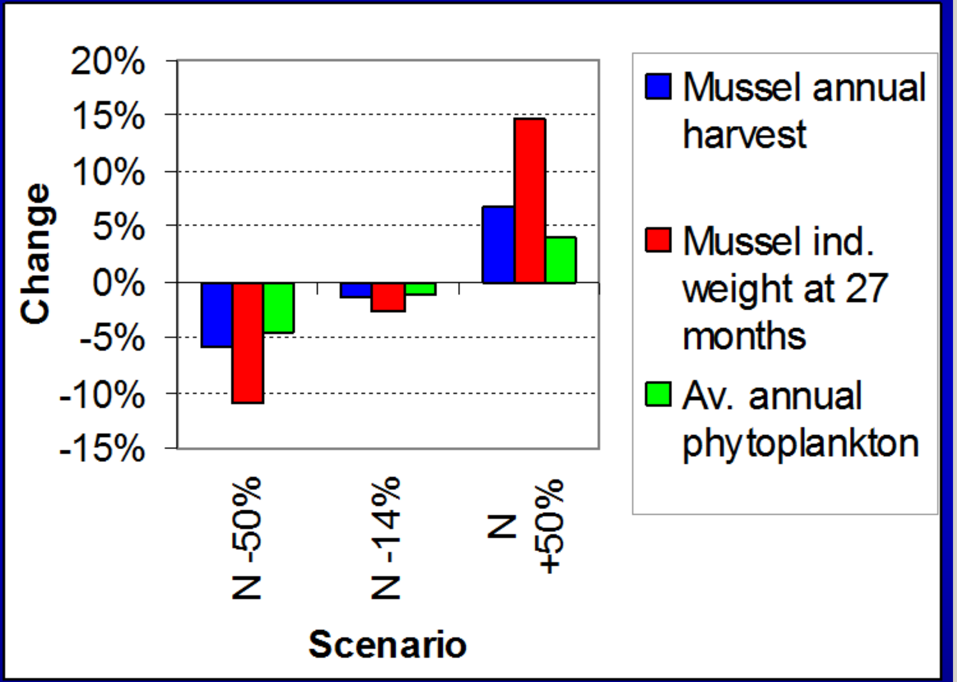
Killary nutrient change scenarios

- Scenario:
  - a) decrease land N inputs by **50%**
  - b) decrease agricultural N inputs by 50%: c. **14%** decrease in total land N inputs
  - c) increase land N inputs by **50%**: equivalent to new 5500 inhabitants in the catchment

- **Summary:**
  - A 50% N decrease can noticeably impact mussel production, but...
  - the impacts of a 14% decrease are relatively small
  - An increase in N inputs could have a positive impact on mussel growth



Scenario results – summary

What are ecosystem models useful for?

Great expectations (Frederick E. Smith, 1969)

Ecosystems are at least as complex as the systems in economics... Present technology permits models so complete that their performance in the computer simulates precisely the economic systems.

Forty years on: let's stay in touch with reality...

- We are no nearer a paradigm in ecology to allow us to simulate ecosystems accurately. We also can't predict the weather;
- We can simulate production and environmental effects reasonably well;
- The solutions to these issues depend in good part (>50%?) on economic and social components. We can't simulate those at all well;
- Better use of real-time monitoring and simple digital tools (e.g. smart phones) will help us understand the social component better. Will we be able to simulate behaviour patterns?
- Virtual technology tools need to be more production- and management-oriented, and adapt to local realities and conditions.