Sistemas de Informação e Modelação em Ambiente

http://ecowin.org/sima

Basic principles of ecological modelling

J. Gomes Ferreira

http://ecowin.org/

Universidade Nova de Lisboa

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SIMA - Ecological Modelling
Learning by doing

Learning outcomes

1. Understand the principles and applications of ecosystem modelling

2. Develop simple dynamic models and assess data needs for calibration and verification

3. Use various types of ecological models to address real world problems, with a focus on the marine environment

4. Provide management-level awareness of how ecological modelling supports environmental decision-making

Assessment (groups of 3)

Develop a primary production model with phytoplankton as a state variable, forced by light and nutrients, running for a yearly period (50%)

Extend and adapt the model developed to include bivalves (oysters, mussels or clams, different groups can choose different animals) (50%)

SIMA - Ecological Modelling Course Plan

Session	Date	Topic
1	2019.04.26	Module outline - structure, contents, assessment Basic principles of ecological modelling
2	2019.04.26	Review of simulation software Getting our hands dirty: Light attenuation, Nutrient limitation, PI curve Phytoplankton biomass - the first state variable
3	2019.05.03	Primary production in the sea, and how to model it Vernal blooming of phytoplankton (Sverdrup) Phytoplankton blooms in estuaries (Ketchum)
4	2019.05.03	Getting our hands dirty: Vollenweider and Dillon-Rigler models for phosphorus control of eutrophication Model for water balance in a lake, Addition of nutrients to the model
5	2019.05.10	Assessment 1 (30% based on presentation and InsightMaker model)
6	2019.05.10	Circulation and hydrodynamics - simple lake and estuary models Lake 1-D model for water temperature (very simplified) Model for water column stability - Richardson Number Estuarine 1-D model for salinity
7	2019.05.17	Models for aquaculture production and environmental effects Getting our hands dirty: Grow your own oyster, How big can an oyster grow? Adding realism to the model,
8	2019.05.17	Getting our hands dirty (continued) Population model for oyster aquaculture in Long Island Sound
9	2019.05.24	Case studies
10	2019.05.24	Project development and brainstorming
11	2019.05.31	Project development and brainstorming
12	2019.06.07	Assessment 2a (presentation 30%)
13	2019.06.14	Assessment 2b (report 40%)

Basic principles of ecological modelling

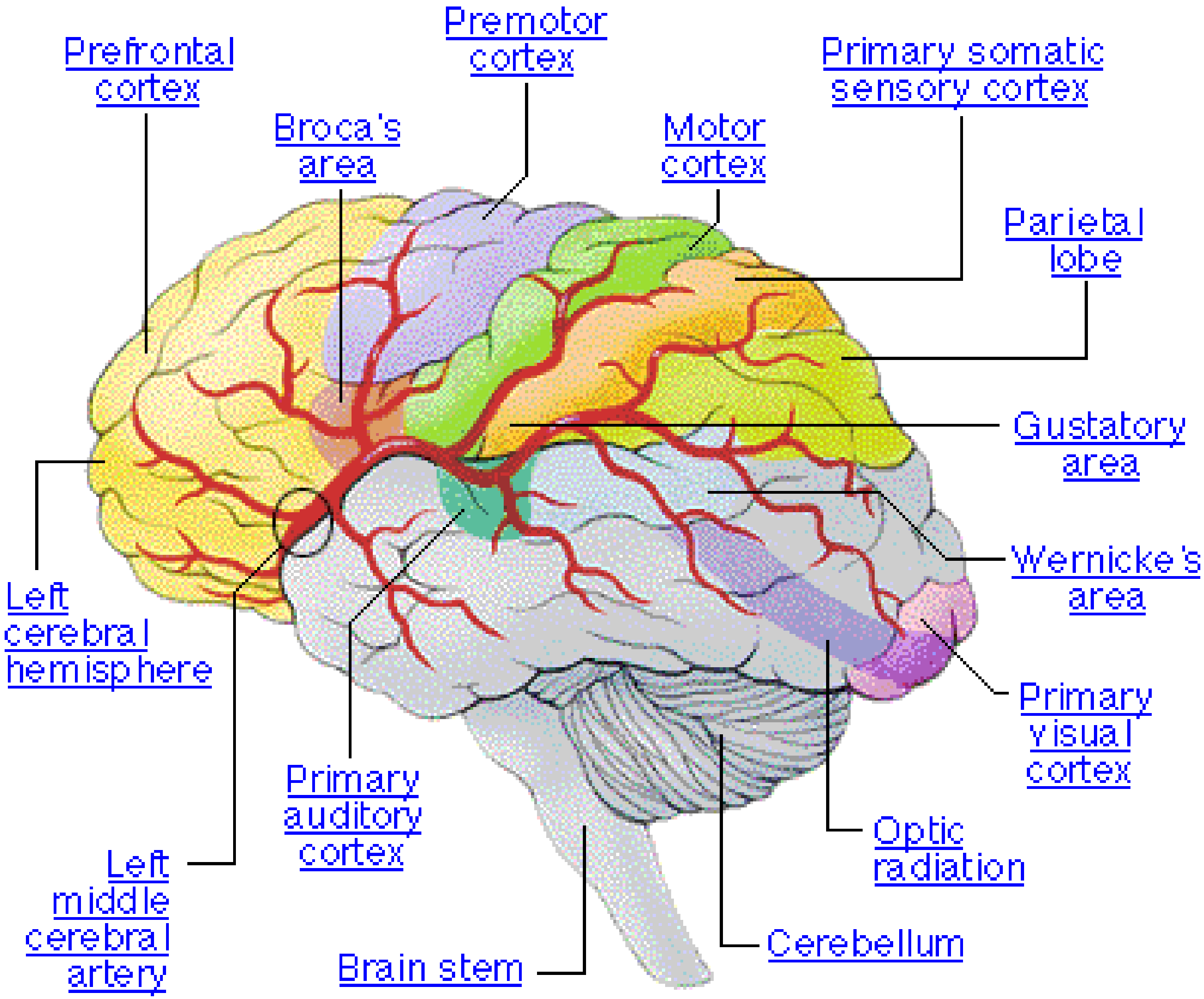
Concepts, examples, and applications

Topic

- General principles of ecological modelling
- Complex models (research models)
- Screening models (management models)
- Simulation platforms
- Synthesis

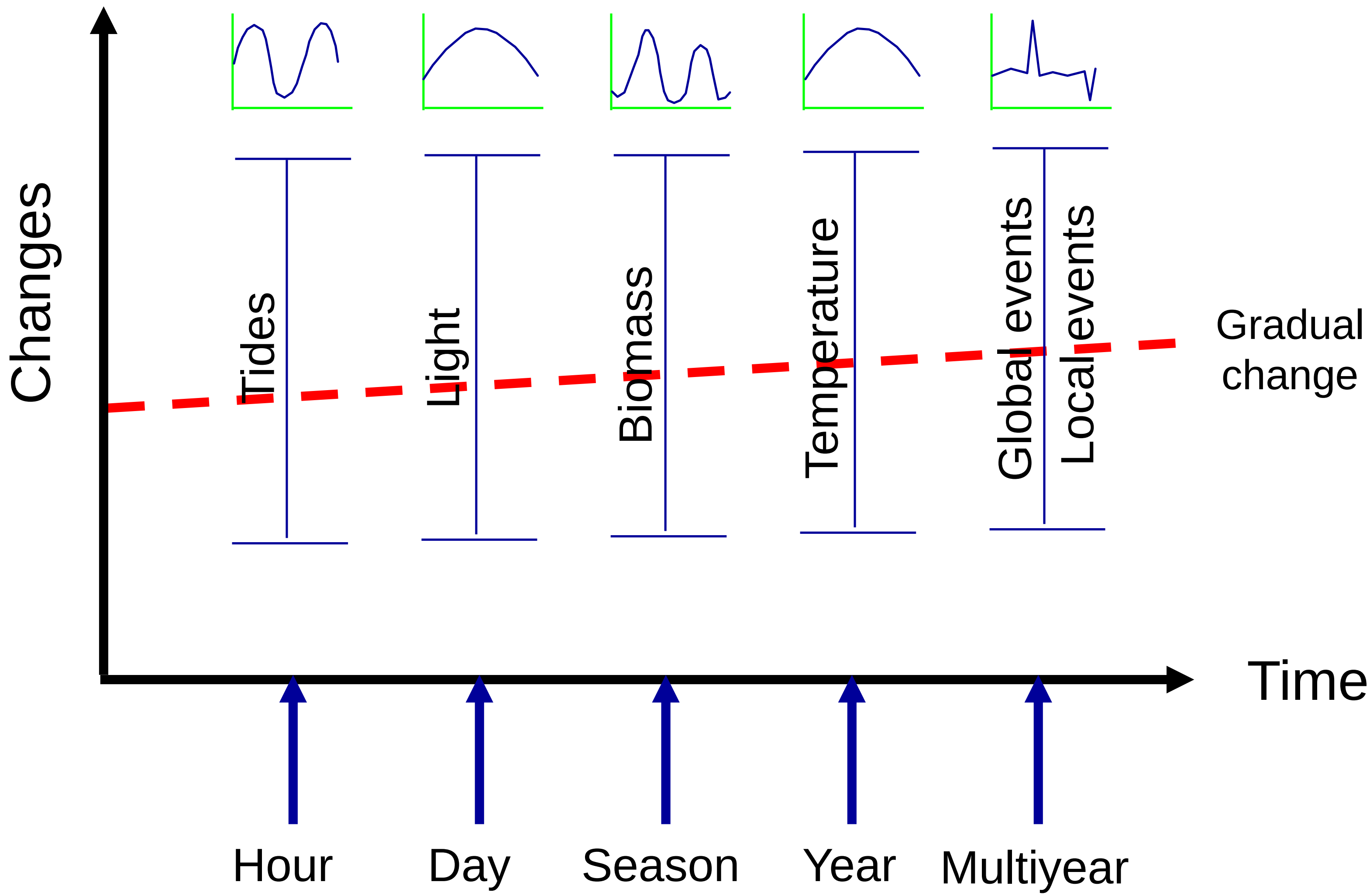
Different questions, different models. There is no silver bullet.

Here is the best model…



Turn your brain on. Turn your computer off.

Changes in coastal systems



The noise in the distributions masks the signal of change

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

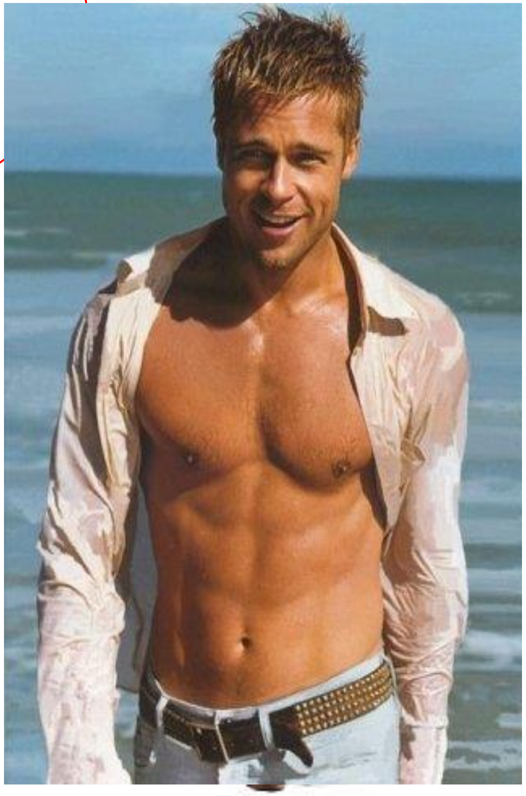
- Marine spatial planning, chlorophyll spatial distribution

Mathematical models

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

Physical models

- Harbour scale models, toys

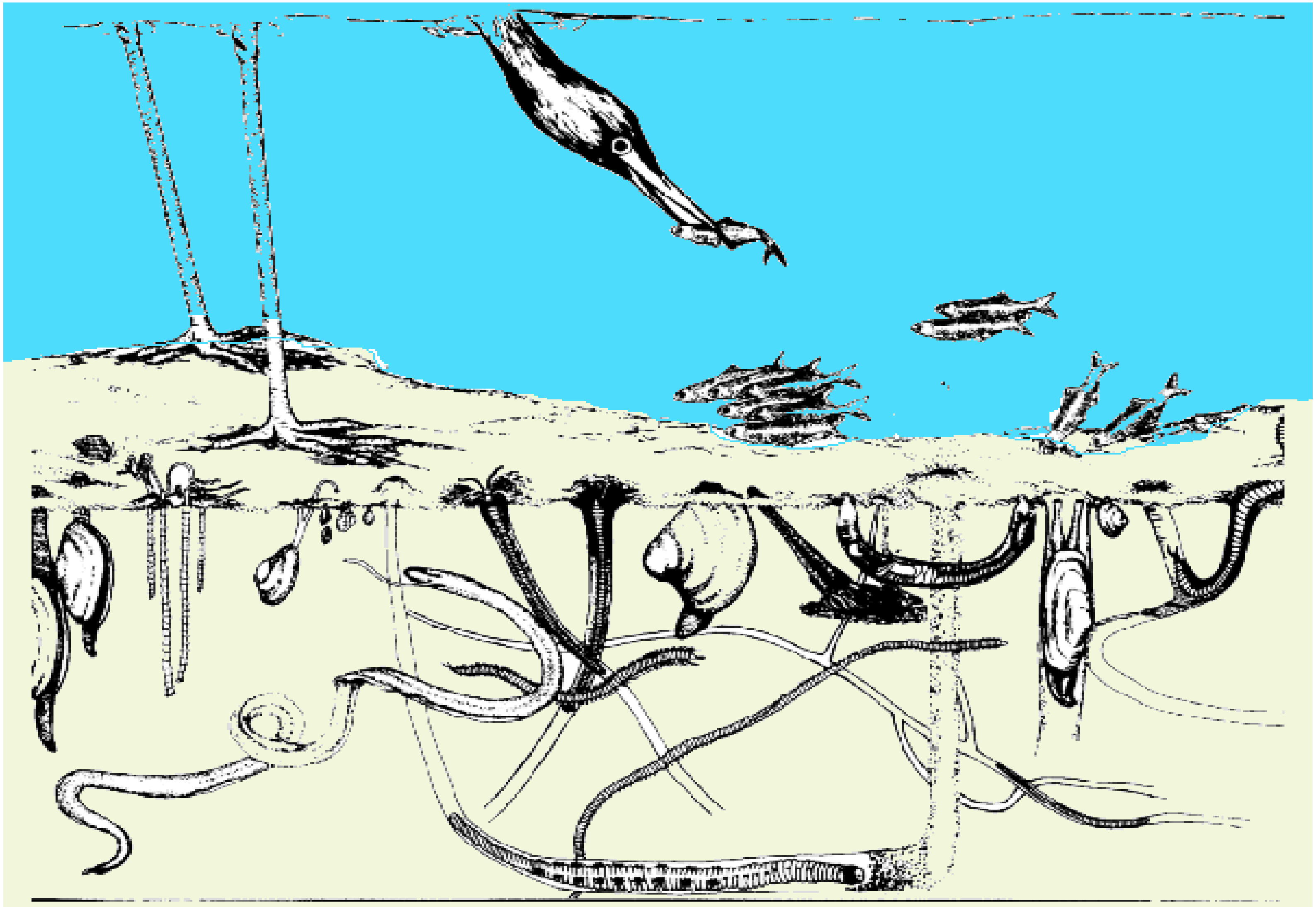


Other models

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 <u>links</u> 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
- Realism
- Accuracy
- Simplicity

Models should be portable

Loss of realism is expected

Loss of accuracy due to smoothing, difficulty in accommodating stochastic events, etc

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

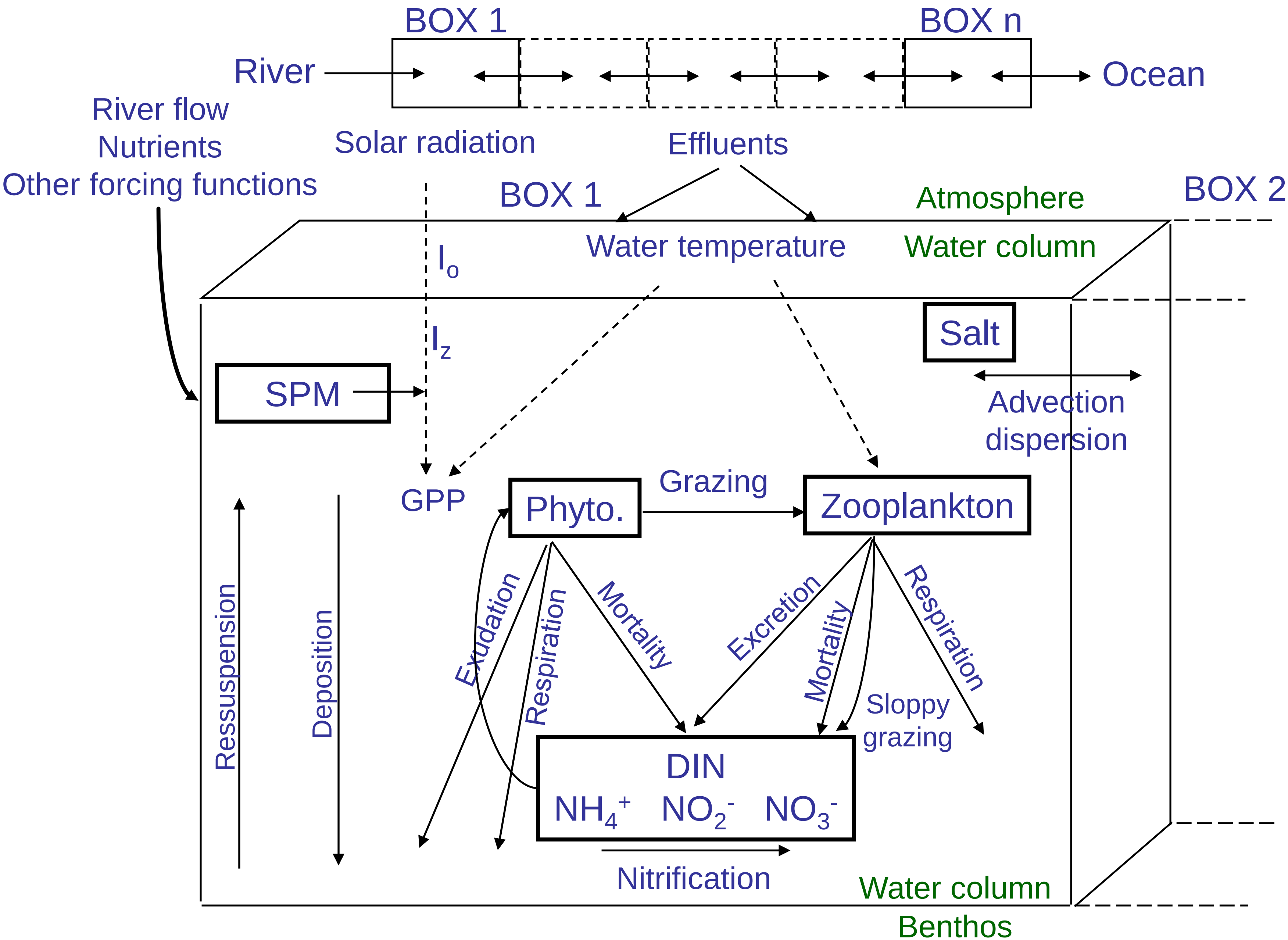
- Statistical
- Zero-dimensional (time only)
- One-D (rivers, narrow estuaries)
- Two-D (non-stratified estuaries, coastal areas)
- Three-D (systems with pronounced horizontal and vertical gradients)

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.

General scheme of a simple ecological model



Even simple ecosystems are complex to 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

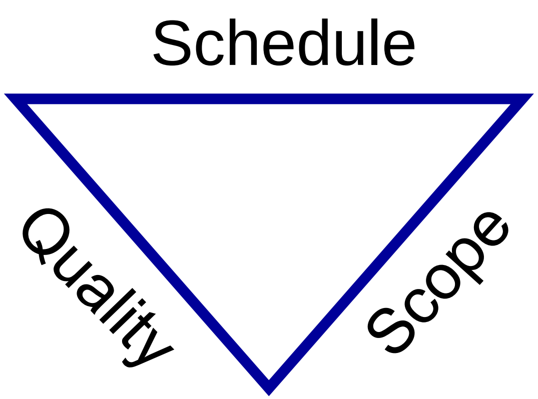
Re-use if possible, develop if necessary

Ecological Models

Technical aspects

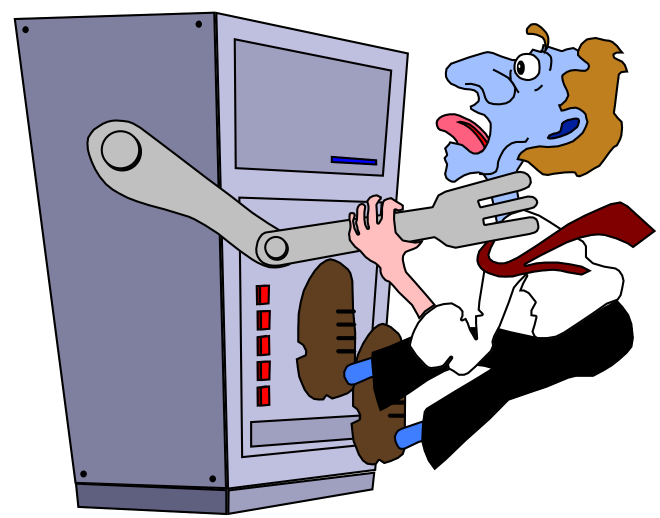
- <u>Development</u>
  Visual (e.g. PowerSim)
  "Hard-coded?"
  Hybrids (e.g. Matlab-based, EcoWin2000)

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



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

- Protocol coupling



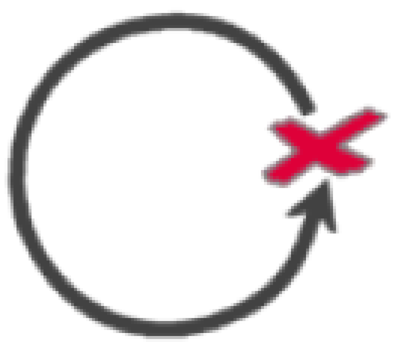
Há muitas maneiras de fazer bacalhau

Ecological Models

Spreadsheets and visual models

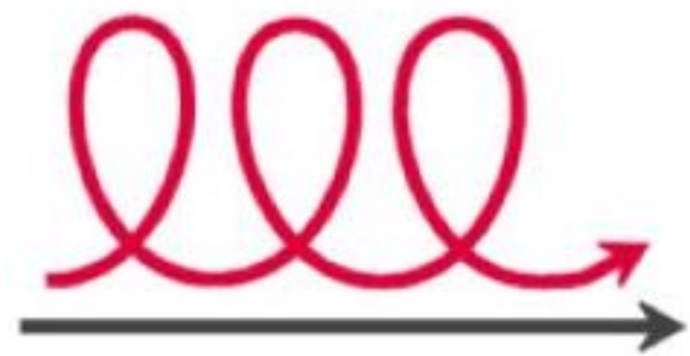
Spreadsheets

- 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

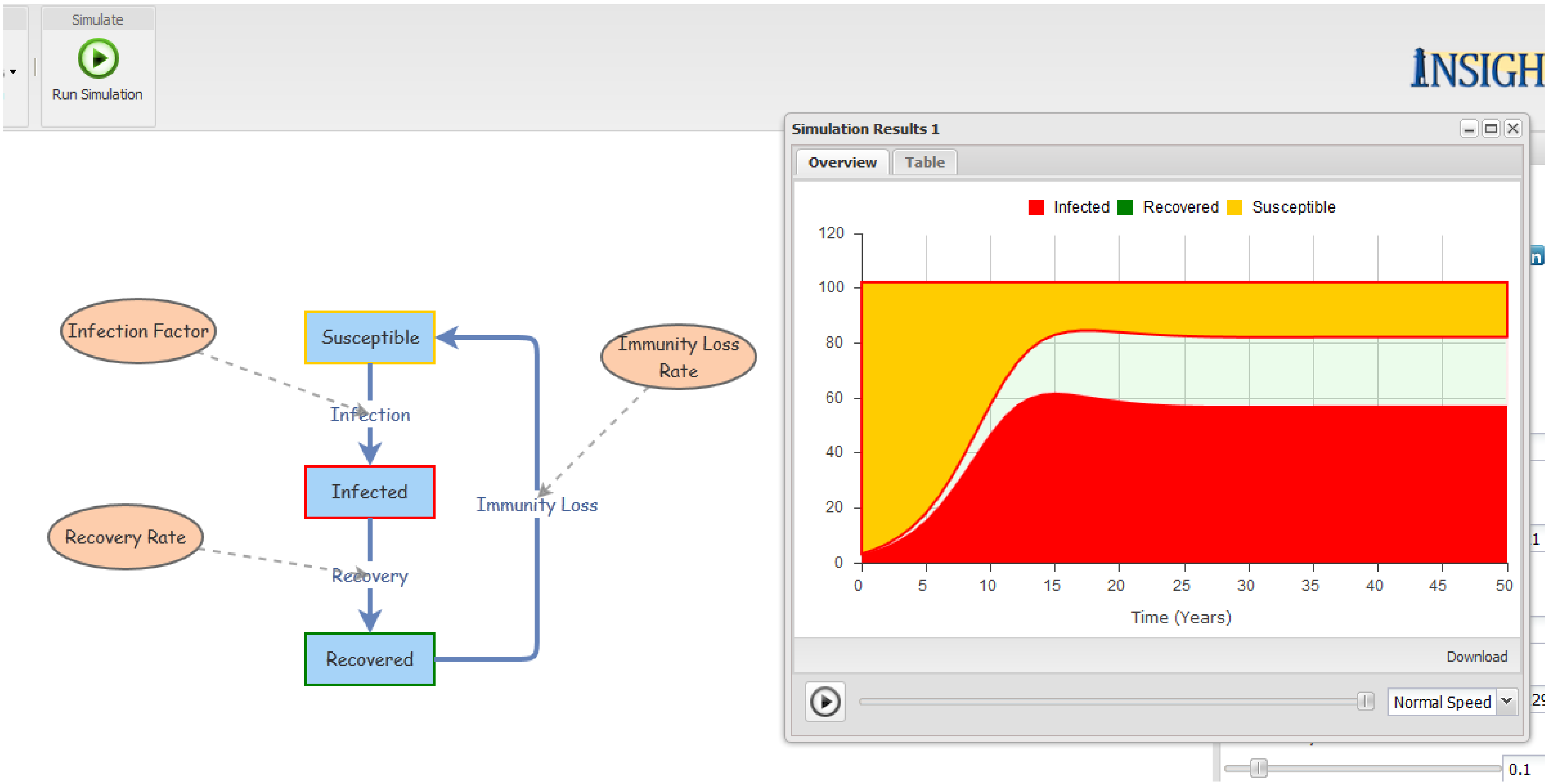
Ecological modelling

Hands on – learning by doing

Visual modelling tools are the best way to acquire basic modelling skills.

Ecological modelling

Community modelling platform



The SIR model, by (Sir) Robert May and Roy Anderson: a classic disease model

Ecological models

Research models and screening models

Characteristics	Research models	Screening models
Resolution	High spatial and temporal resolution	Low resolution, or integrated in space and/or time
Complexity	Several-many state variables	Focus on a few diagnostic features
Difficulty of use	Substantial, usually have a “champion” group/groups	Minimal, require few parameters
Cost	High due to typical data requirements and complexity	Low cost
Application	Detailed management support, usually supplied as a service	Broad compliance analysis, scoping work, more a product than a service
Target audience	Academics, consultancy	Managers, public
Integrity	Hard to verify, hard to modify	Easy to do both, more prone to misuse

Both types of models play important roles in water quality management

Screening models

Distilling information

- Used for broad comparison and assessment
- Relate pressure, state and response
- May be ecosystem scale or other scales, e.g. regional, fish farm
- Are highly aggregated and easy to apply
- Can be data-driven or use inputs from more complex models
- Are easily understood and interpreted by managers

Screening models synthesise information, and are quick and easy to apply

Screening models

Examples

Model name	Objective	Usage
OSPAR-COMPP	Eutrophication assessment	EU, mainly NE Atlantic
ASSETS	Eutrophication assessment	US, Worldwide, EU
HEAT	Eutrophication assessment	EU mainly Baltic
DEPOMOD	Local effects of finfish aquaculture	Scotland, elsewhere
MOM	Local effects of salmon aquaculture	Norway, elsewhere
FARM	Open water shellfish culture, IMTA	EU, US, China
FARM	Pond-scale culture	EU, Asia
FISHNETS	Diseases in aquaculture	EU

Useful for diagnosis, scoping, and comparisons

Case study - Open water shellfish farming

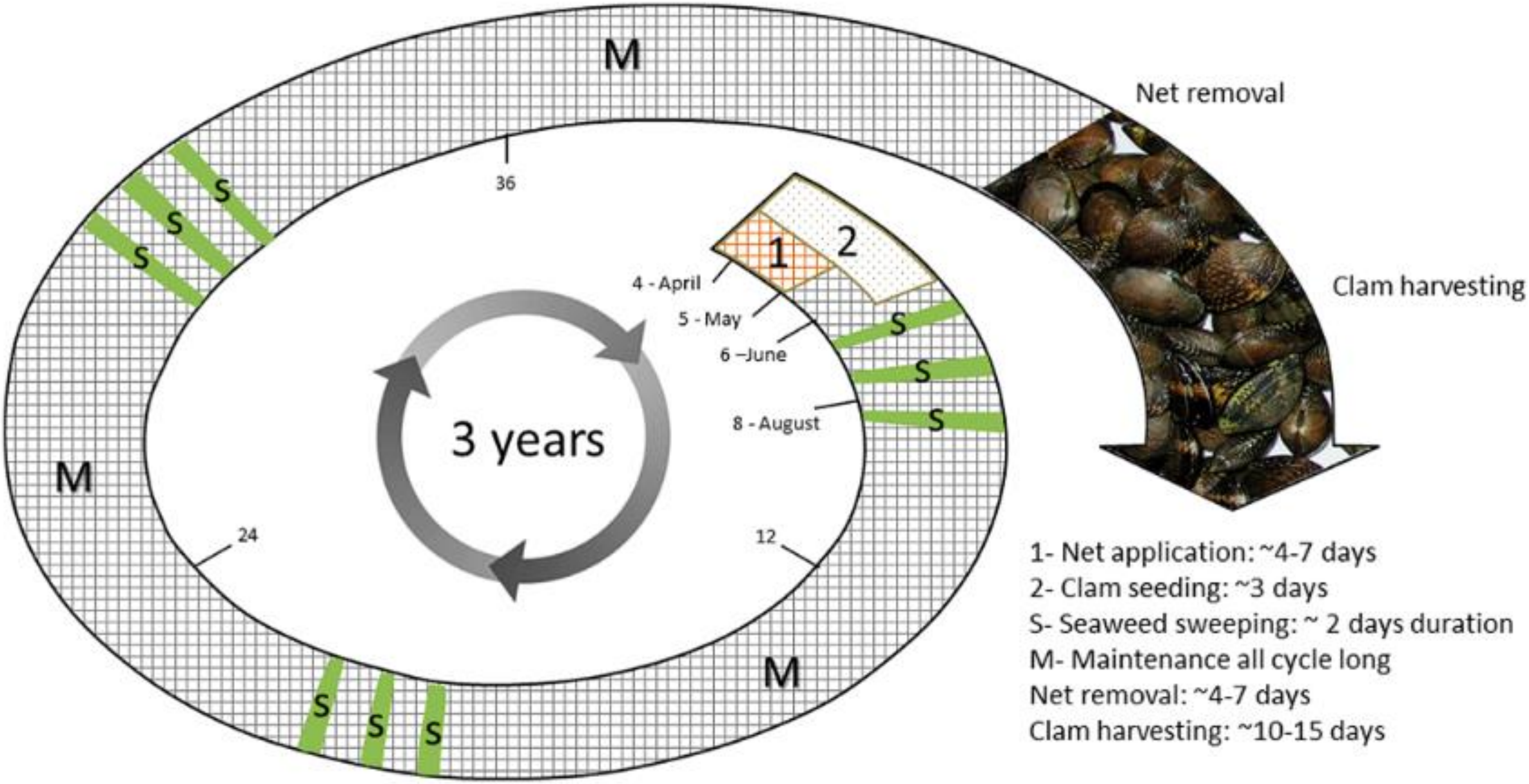
- Manila clam in a commercial farm in North Puget Sound, USA;
- Fieldwork (data acquisition for water quality, clam growth measurements, etc);
- Development, calibration, and validation of an individual growth model for Manila clam (*Tapes philippinarum*);
- Integration into the FARM (Farm Aquaculture Resource Management) model, calibration and validation of the population model;
- Seaweed fouling was incorporated in FARM, to simulate potential effects on yield;
- Standard model to simulate cultivation cycle, profit and loss, and environmental effects.

Down on the farm

Growing Manila clams in North Puget Sound

Culture practice in Puget Sound

Manila clams in bottom culture



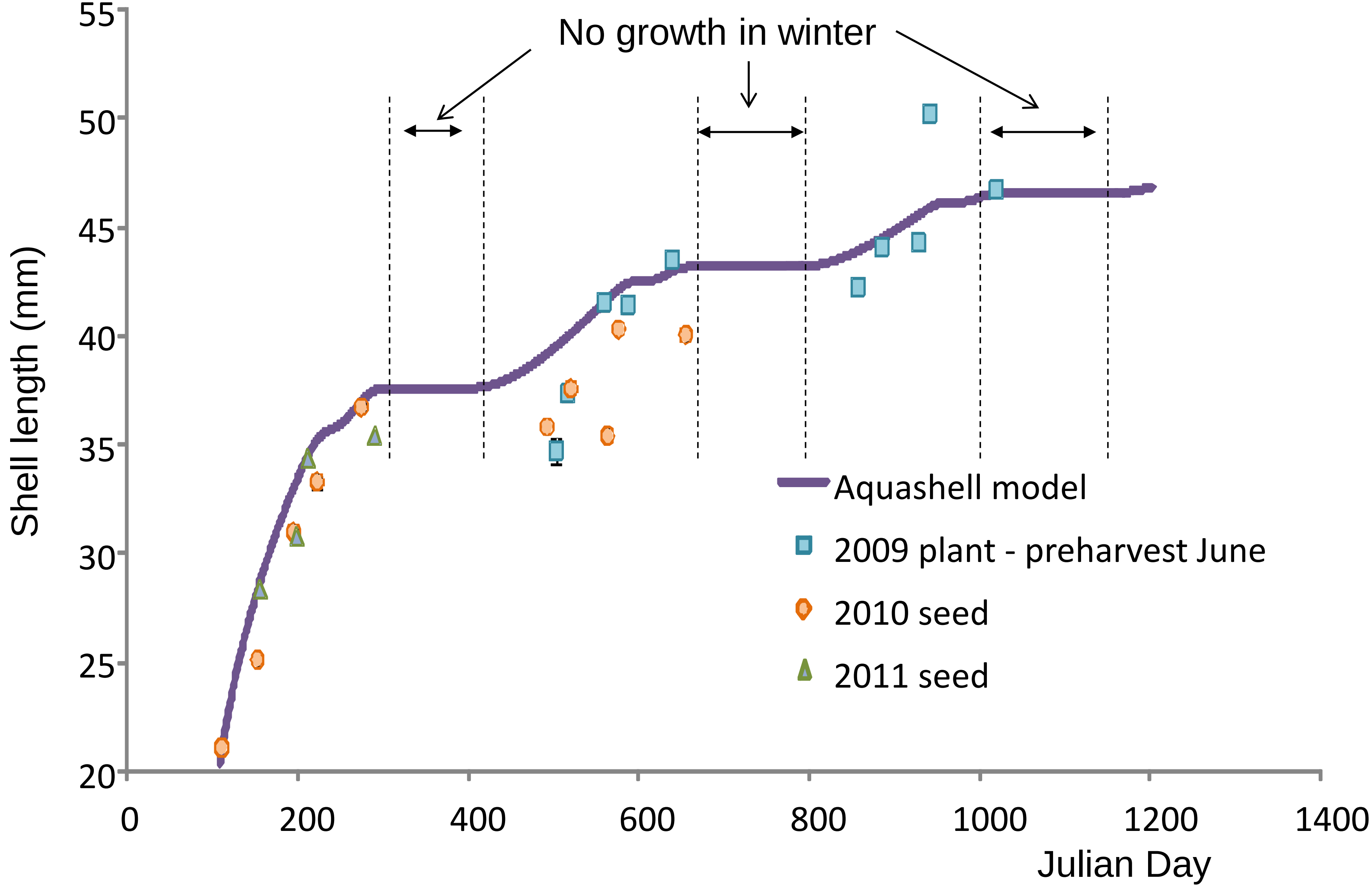
Cultivation in three cohorts for annual harvest.

Individual Growth Model for Manila clam AquaShell

Developed to:

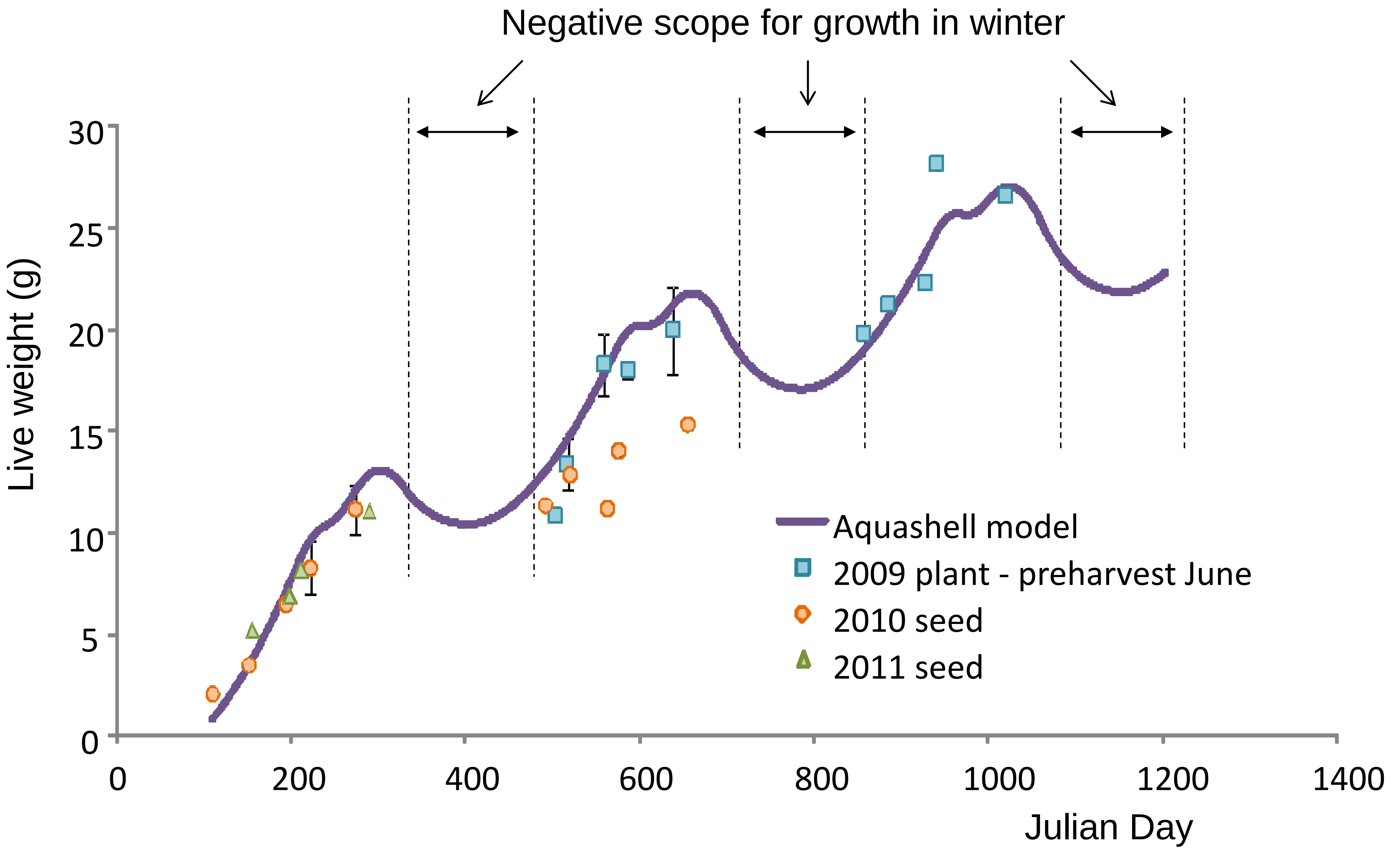
a) simulate change in individual weight, expressed as tissue dry weight, scaled to total fresh weight and shell length;
b) integrate relevant physical and biogeochemical components, such as chlorophyll, temperature and salinity, and partition phytoplankton and detrital food resources;
c) provide environmental feedbacks for production of particulate organic waste (faeces and pseudofaeces), excretion of dissolved nitrogen, and consumption of DO;
d) scale to both ecosystem and local (farm) models for full analysis of production and environmental effects.

Simulation of clam shell length with Samish Island environmental drivers



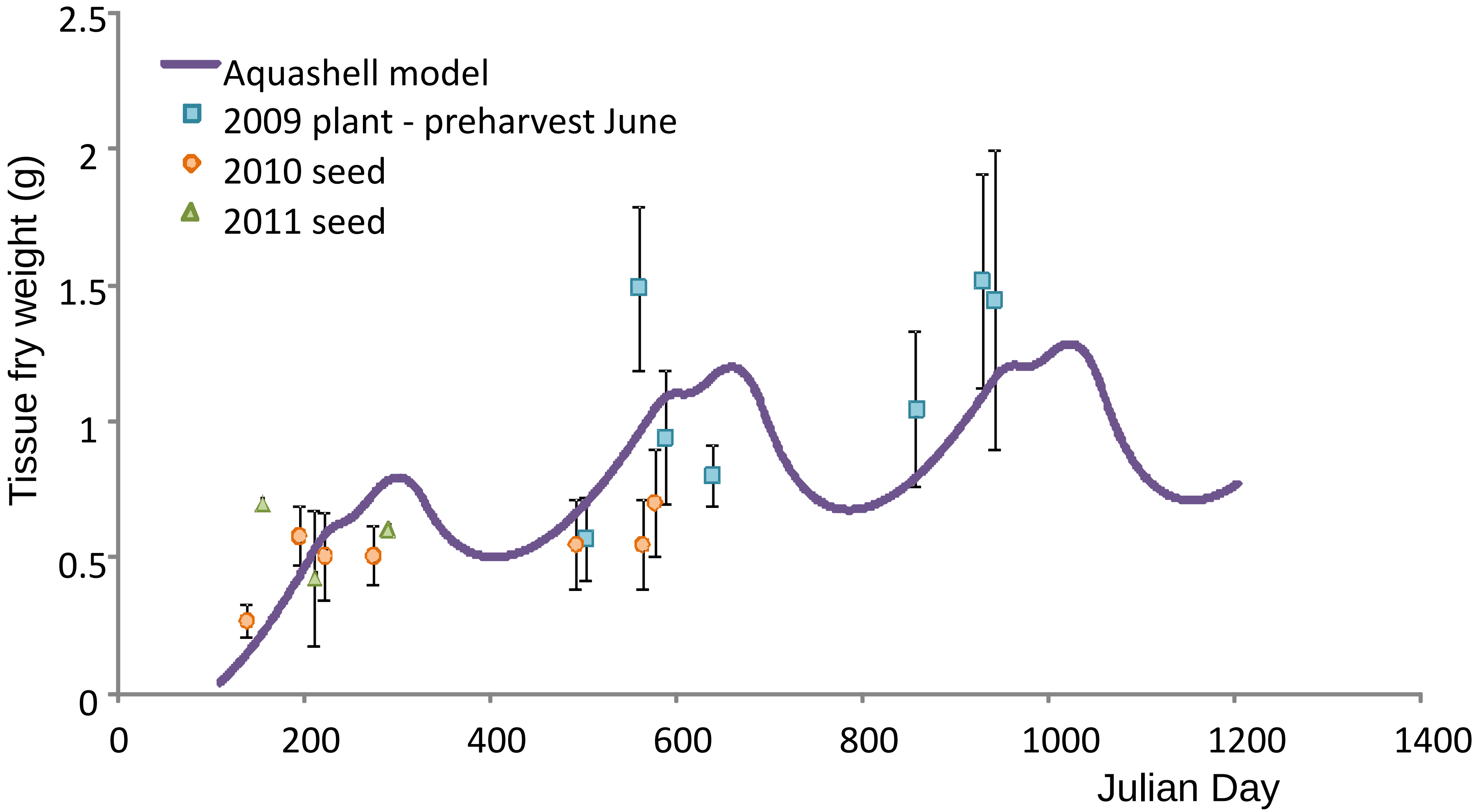
The individual model provides a good fit to project data for shell length.

Simulation of clam live weight with Samish Island environmental drivers



The AquaShell model also shows a good fit to project data for live weight…

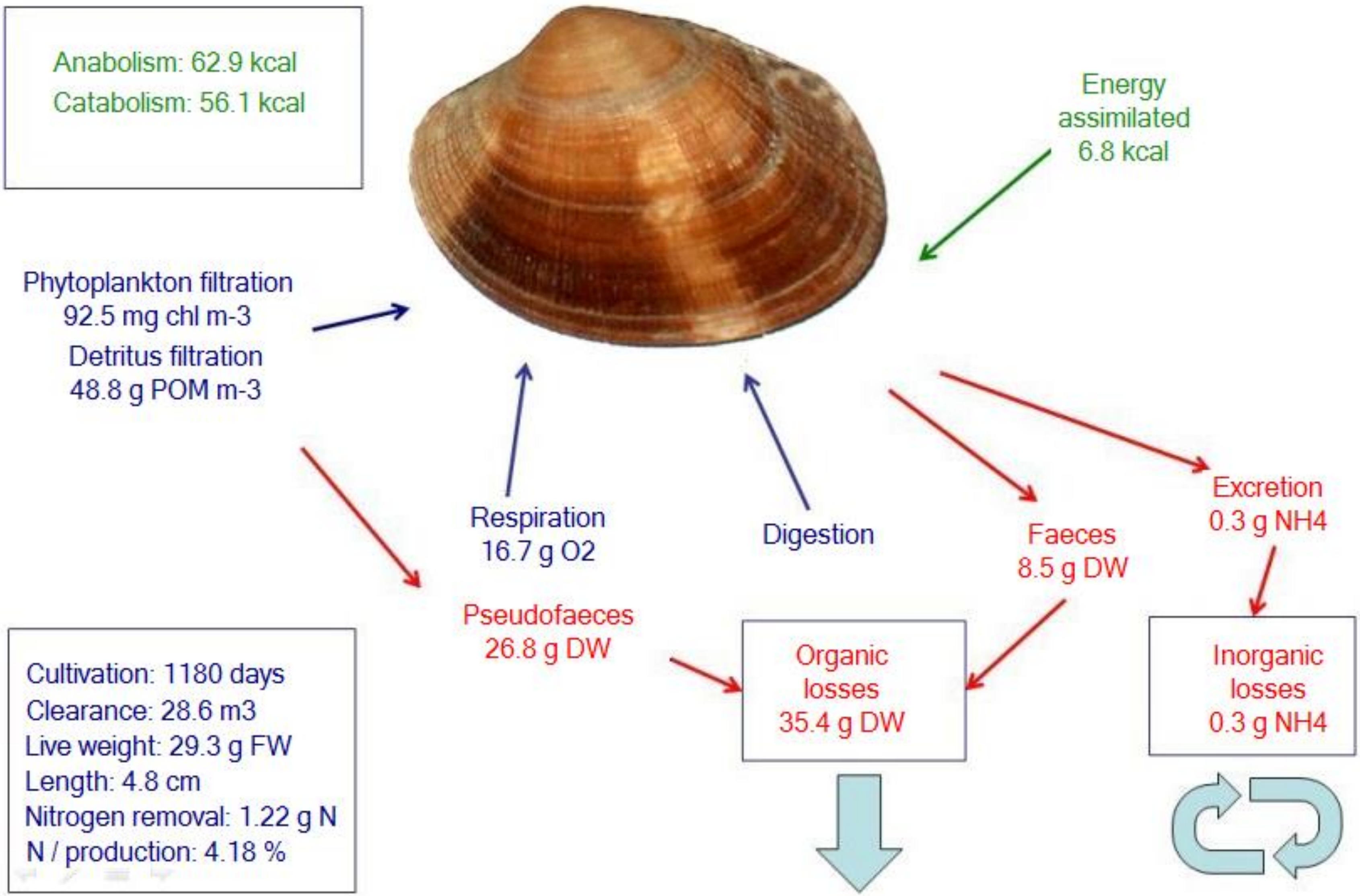
Simulation of tissue dry weight with Samish Island environmental drivers



And for tissue dry weight. So we're okay to move to the farm scale. But first…

Manila clam growth model (AquaShell)

Mass balance



Simulation of Manila clam growth using Samish Island drivers provides outputs on production and environmental effects. These are then scaled to the culture area.

Setup for the FARM model in Samish Island

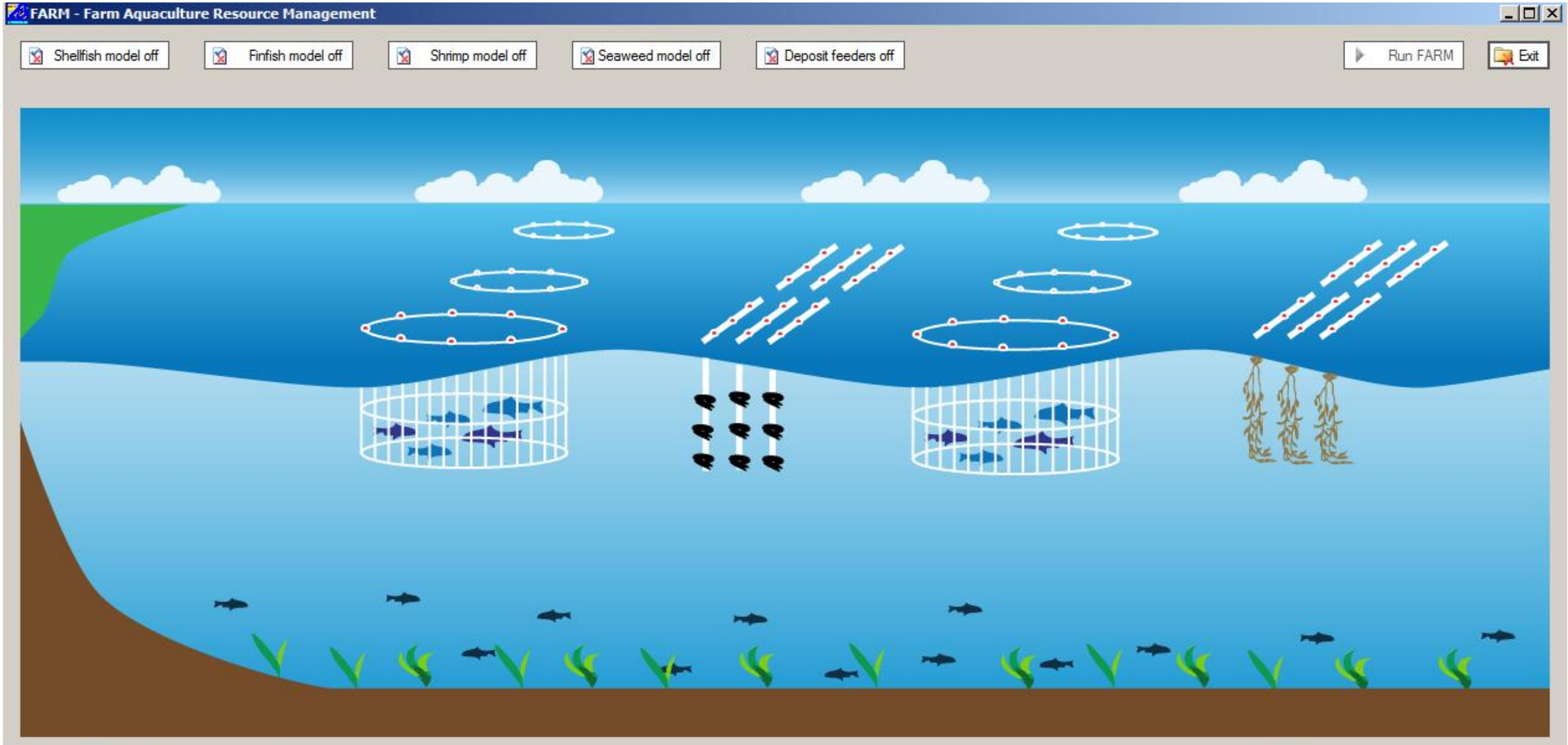
FARM Aquaculture Resource Management

Type	Descriptors	Notes
Farm location data	Latitude: 48.5ºN Length: 300 m; Width: 75 m; bottom culture under nets, intertidal	Latitude used for seaweed fouling model (light climate); 6 farmed acres
Culture practice	Seeding day 200; cycle: 1180 days; Mortality: 50%; seed weight: 0.1 g; Minimum harvest weight: 17 g TFW	Animals grown in 3 separate year class strips. FARM simulates the whole system
Environment	Semi-diurnal tidal cycle, current speeds generated by peak spring and peak neap speeds	Can be improved by simulating the tidal harmonics
	Salinity, temperature, chlorophyll, detritus, total particulate matter	Project data, Puget Sound database from WA Dept. Ecology, U.S. Navy
Seaweed fouling	Seaweed biomass starts at 5 g DW m^{-2}, sweeping assumed to take place mid-year every year	Model growth, light and nutrient dependency for opportunistic seaweeds such as *Ulva*, as well as respiration, exudation, and mortality
Economics	Seed cost: $4 per 1,000; Farmgate value at harvest: $2.33 per lb	Seed from BC commercial suppliers, sale price: British Columbia govt.

Although FARM was designed to be as simple as possible, i.e. as a screening model for farmers, it can be used for detailed simulations. http://farmscale.org/

FARM model

Application to Integrated Multi-Trophic Aquaculture (IMTA)



FARM model for finfish, shellfish, seaweed, and deposit feeders.

Ferreira et al., 2012. Cultivation of gilthead bream in monoculture and integrated multi-trophic aquaculture. Analysis of production and environmental effects by means of the FARM model. Aquaculture 358-359, p. 23-34.

Production and environmental effects of Manila clam farming in North Puget Sound (per 1180 day cycle)

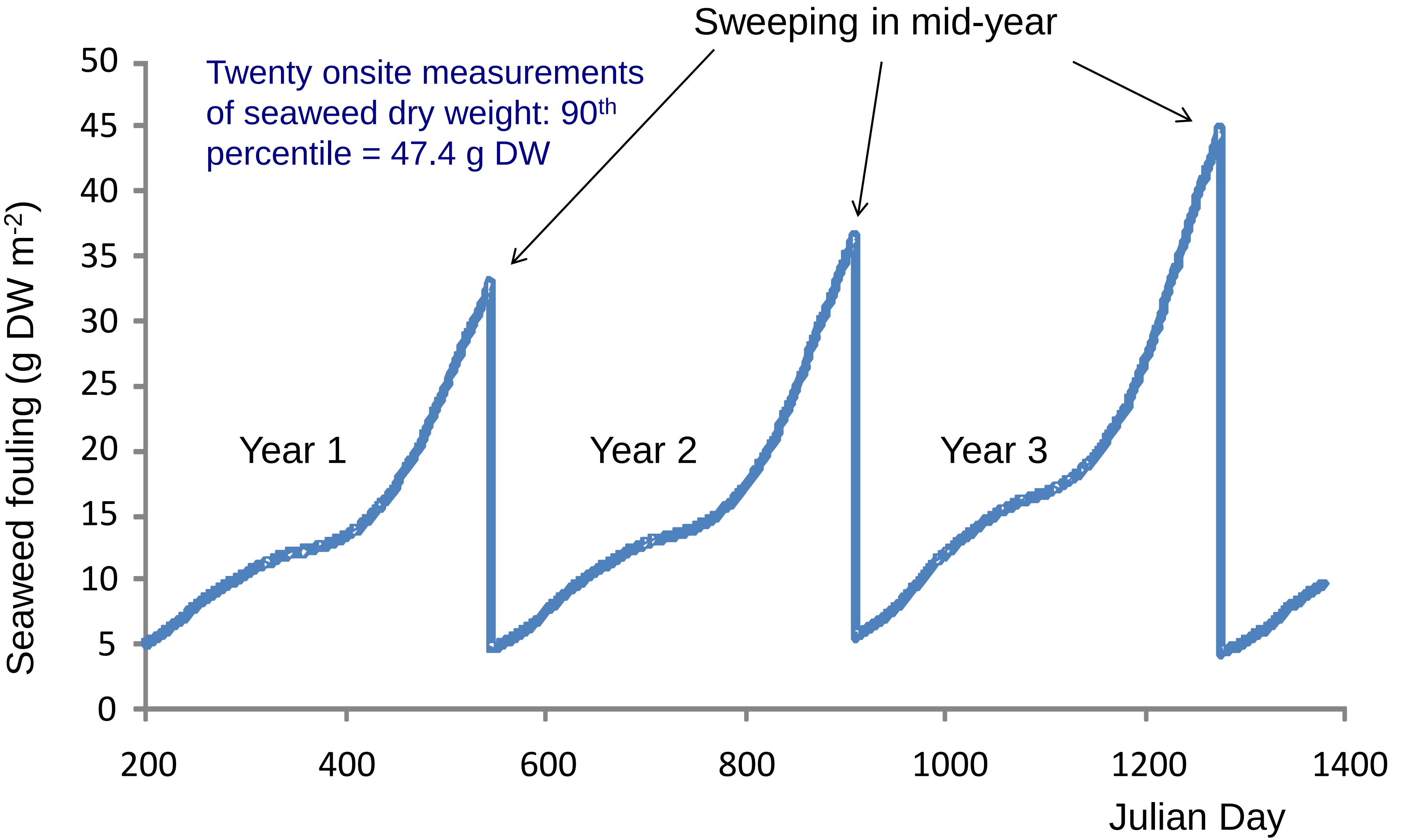
Variable	Model results
Model inputs	
Seeding (kg TFW) per production cycle	3,400
Model outputs	
Production	
Total (TPP) (kg TFW) per production cycle	157,600
Average Physical Product (APP, Output/Input)	47
Environmental externalities	
Change in percentile 90 NH_4^+ concentration (μmol L-1)	8.92 (in) – 9.04 (out)
Change in percentile 90 chlorophyll (mg chl m^{-3})	4.49 (in) – 3.98 (out)
Change in percentile 10 O_2 concentration (mg L-1)	6.17 (in) – 6.10 (out)
ASSETS eutrophication model score	5 - No change (in to out)
Profit and loss	
Manila clam sales ($ per cycle)	630,000
Total income ($ per cycle)	**630,000**
Seed ($ per cycle)	135,000
Total marginal expenditure ($ per cycle)	**135,000**
Income-Expenditure ($ per cycle)	**495,000**
Farm profit ($ per cycle)	**495,000**

Reported annual harvest is 70,000 – 100,000 lb. Annualized output from FARM is 107,217 lb, considering 18 g live weight (TFW) as a minimum weight for harvest

Annualized gross profit determined with FARM is about 153,000 dollars.

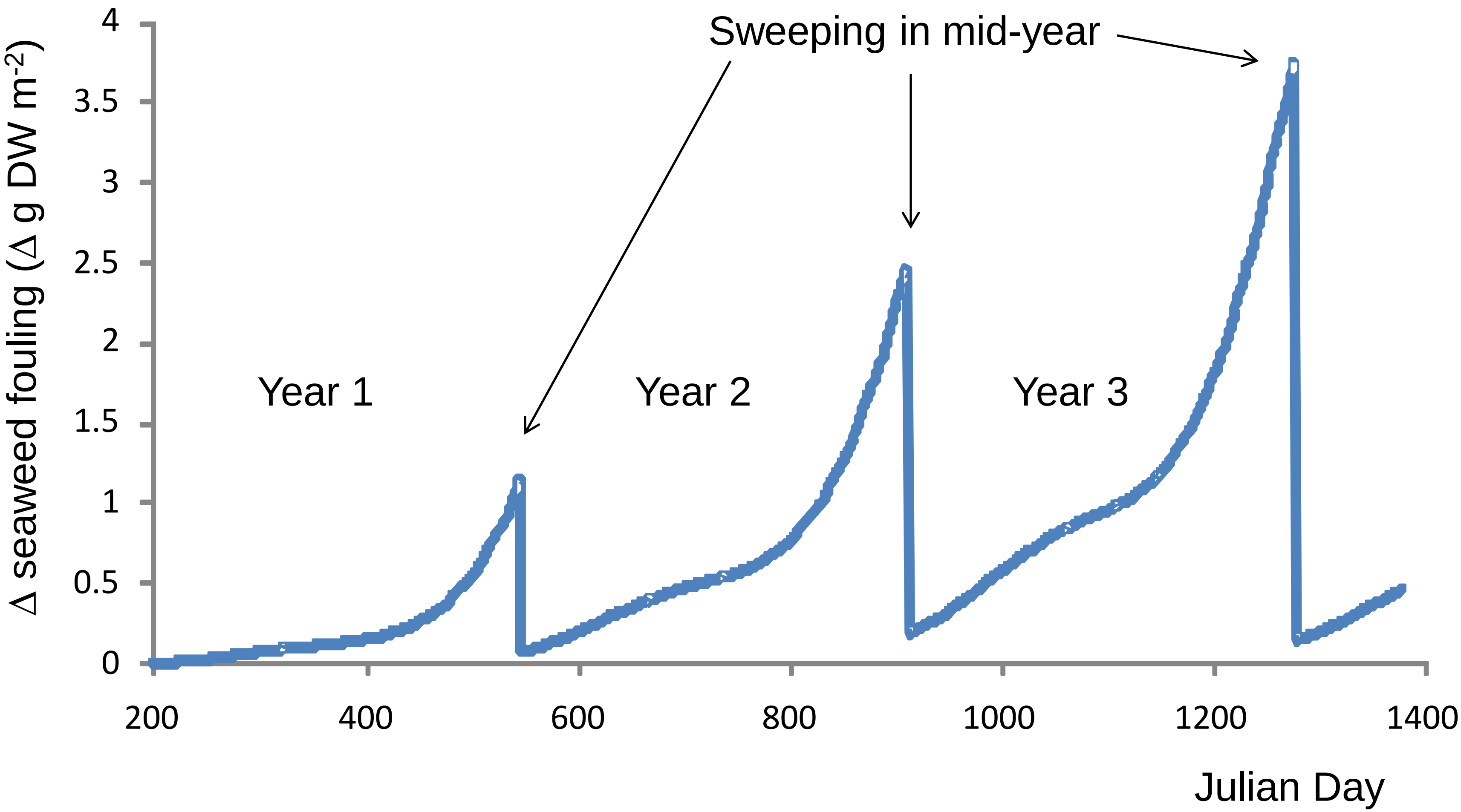
Seaweed fouling and sweeping simulation

FARM model – Samish Island Manila clam farm



As the Manila clams grow bigger, more NH_4^+ is excreted, stimulating seaweed fouling; this is why the biomass peaks increase from year to year.

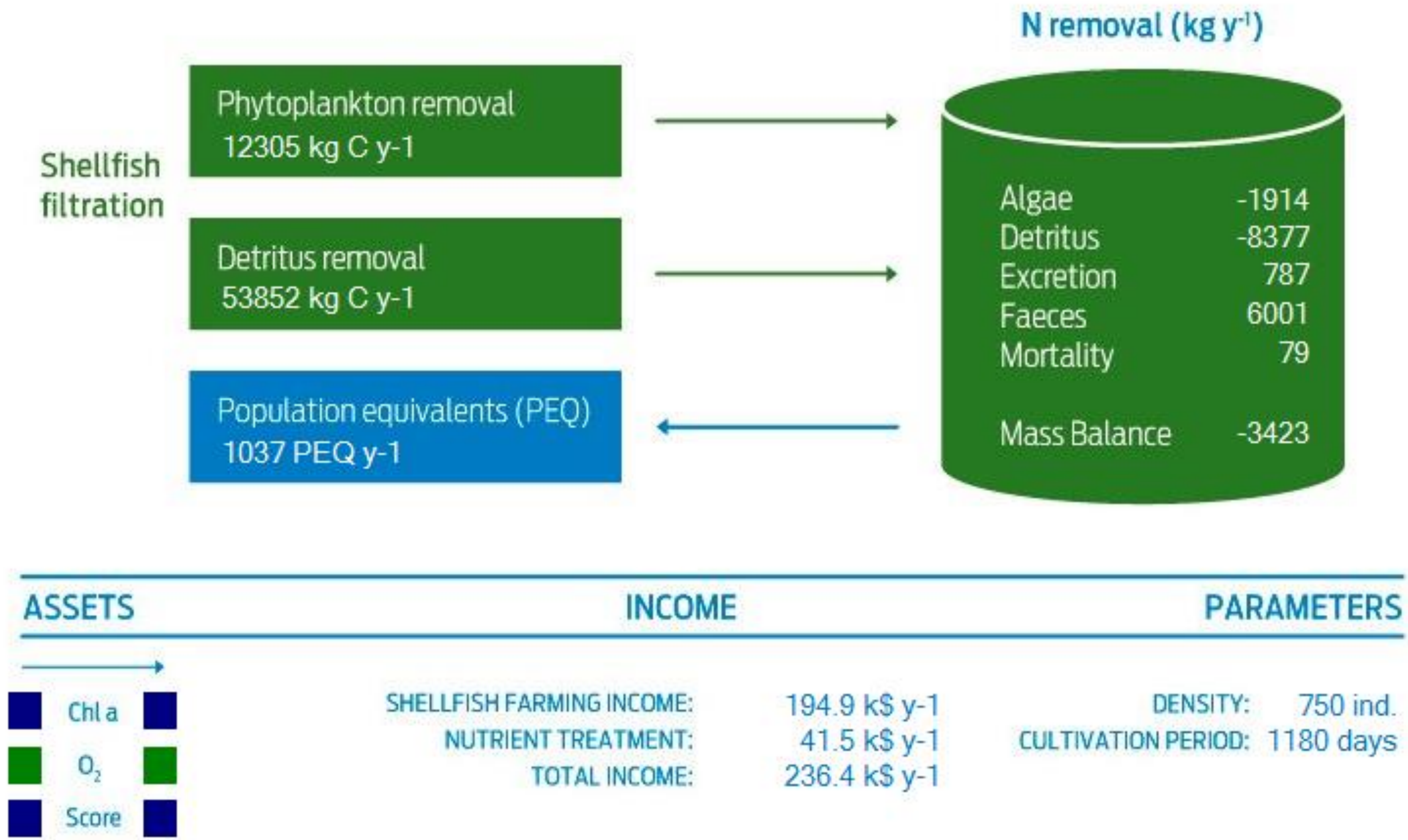
Change in seaweed fouling with and without clam excretion – FARM model results



The difference in seaweed fouling with and without clams increases from year to year. Of course without predator nets, most likely there wouldn't be any seaweeds.

Samish Island Manila clam farm

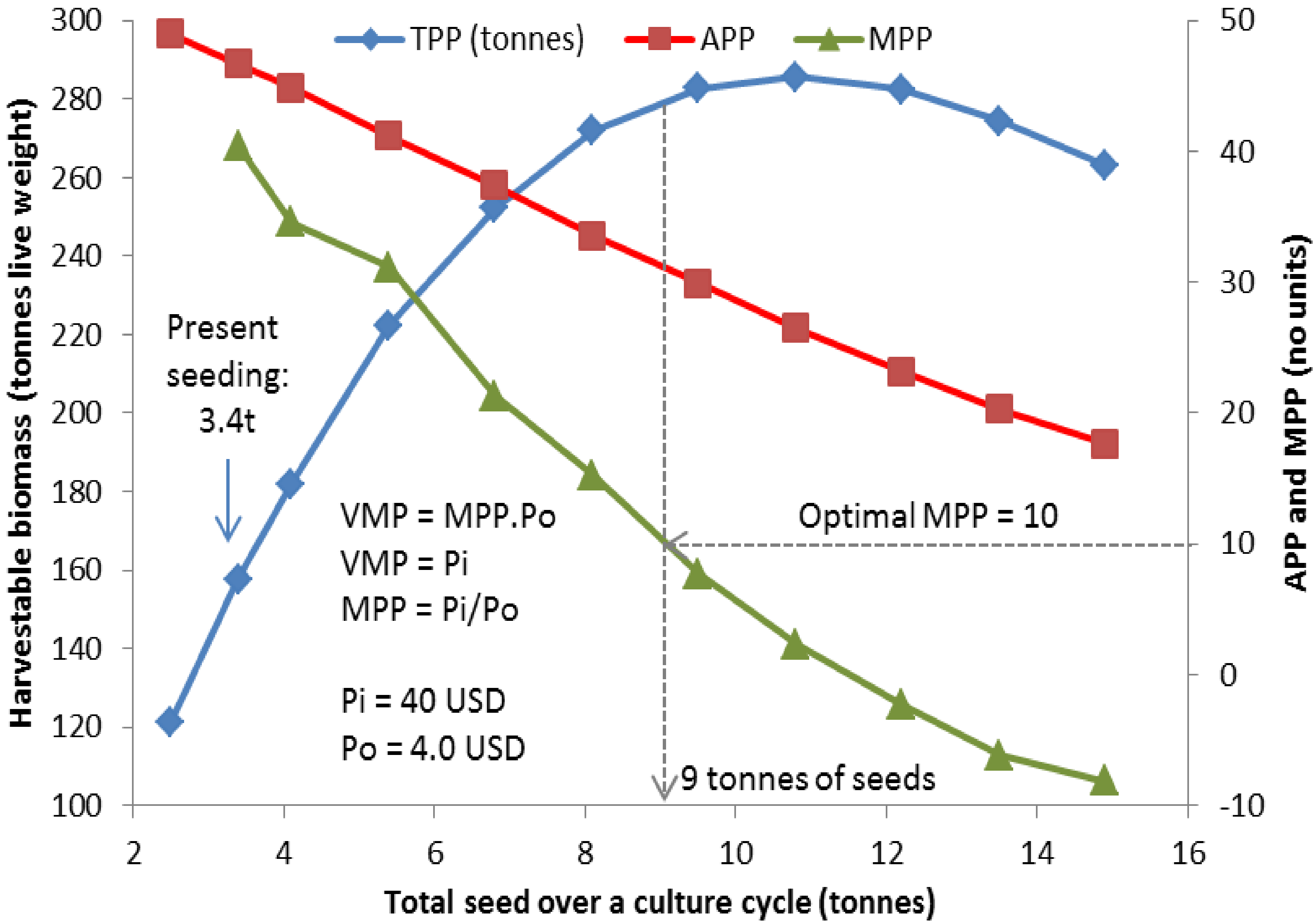
FARM model simulation for nutrient trading



At a cultivation density of 70 animals per sq ft. clams provide an annual ecosystem service equivalent to over 1000 people in reducing eutrophication.

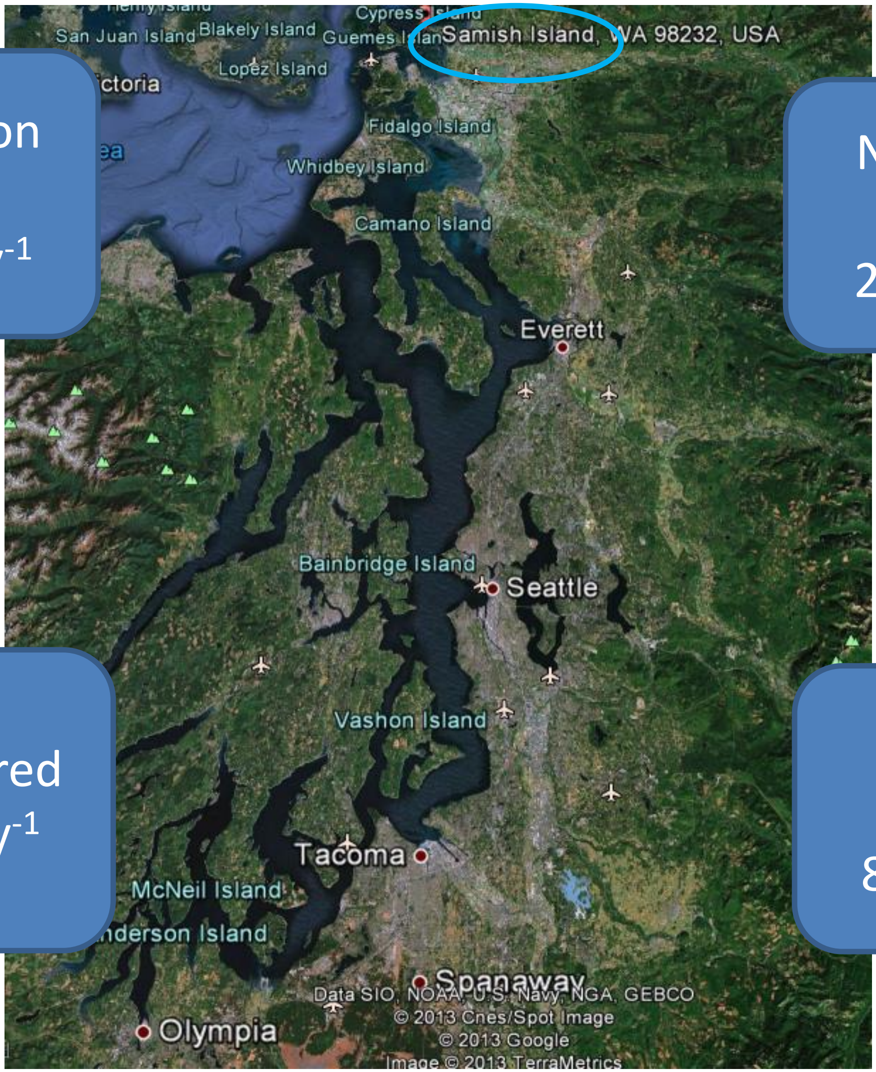
Marginal analysis

FARM model – application to Samish Island Manila clam farm



The Samish Island farm appears to be well below carrying capacity, with respect to food supply. However, at the current stocking density, high mortality is already a problem.

Scaling FARM results to Puget Sound Manila clam culture



Phytoplankton filtered
1007 ton C y^{-1}

Net nitrogen removal
280 ton N y^{-1}

Detritus filtered
4407 ton C y^{-1}

Population Equivalents
87818 people

Every year, clams provide Puget Sound with an ecosystem service equivalent to about 87,000 people, or 3.4 million dollars, in removing primary symptoms of eutrophication.

Post-harvest feeding frenzy

The attack of the killer fish (video runs at 10X normal speed).

Summary

- No question, no model. What is your question?
- No model can predict the weather. The weather affects circulation (wind, freshwater flow), salinity (rainfall), food (chlorophyll depends on e.g. clouds, temperature). Ecosystem models show general patterns;
- Many different models exist. Models are simplifications of reality, but can be very useful. No model does everything;
- Models can (and often should) be combined, which often adds huge value to the end product.

All slides
http://ecowin.org/sima/