GAIN SUMMER SCHOOL

PROCESS-BASED GROWTH MODELS

Development of models for environmental sustainability

Joao G. Ferreira
Chief Scientific Officer, Longline Environment Ltd.

This project receives funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 773330 (GAIN)

Process-Based Growth Models

Learning outcomes from this lecture

1. Understand the principles and applications of ecological models
2. Review the objectives and requirements of individual growth models
3. Exemplify the development of simple dynamic models and the data needs for calibration and verification
4. Demonstrate how these models can be leveraged to deal with populations, farms, and ecosystems
5. Provide management-level awareness of how ecological modelling supports aquaculture eco-intensification

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

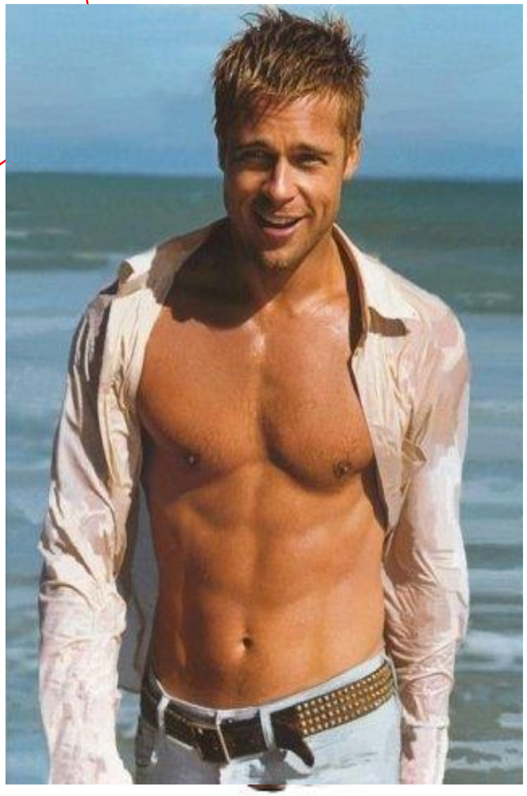
- Marine spatial planning, chlorophyll spatial distribution

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)

Why do we use models?

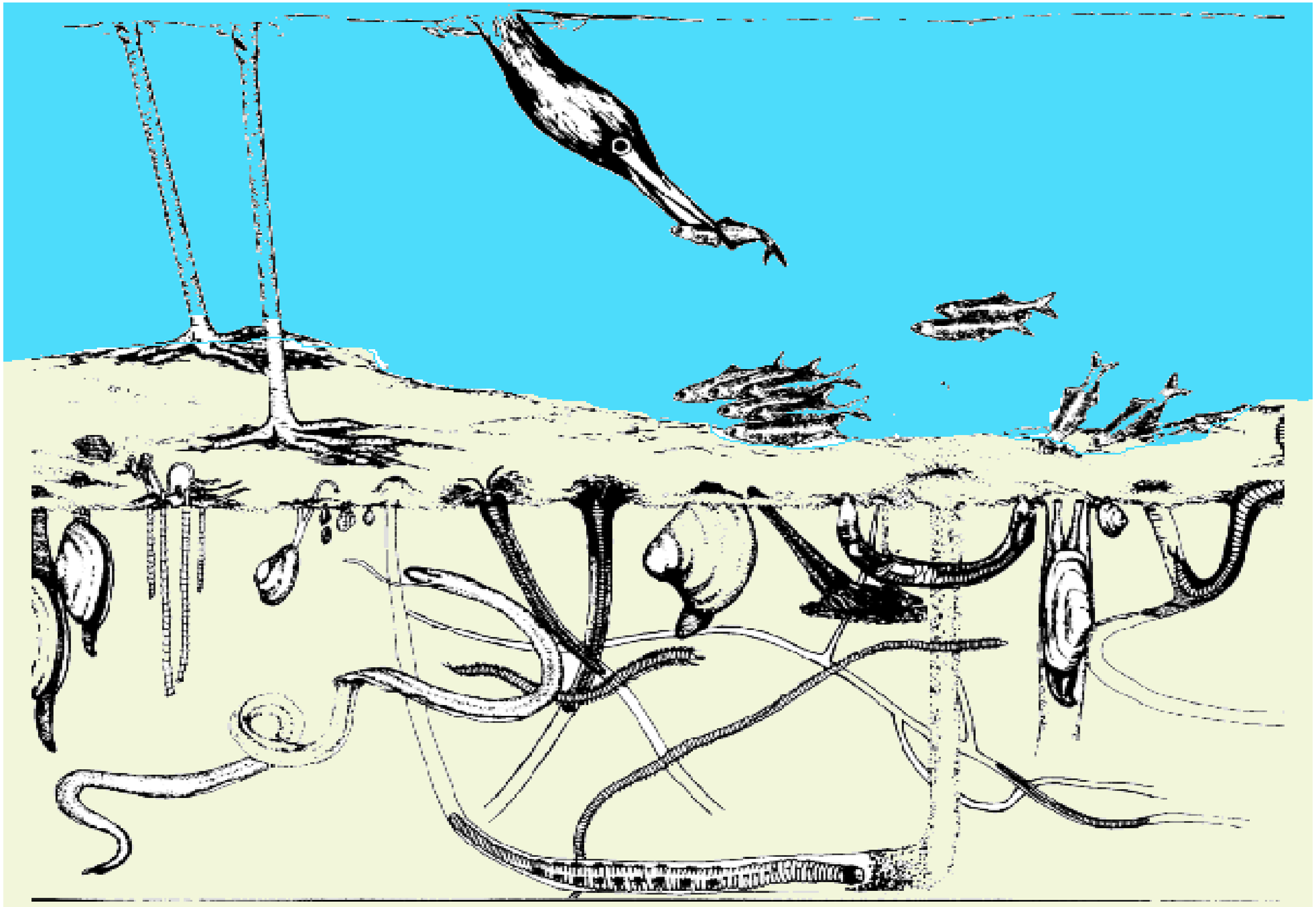
Measure state, perform experiments, simulate, simplify...

- 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. photosynthesis-irrandiance 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 models are complex

even for simple systems...



How many state variables would you use in this system?

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 models

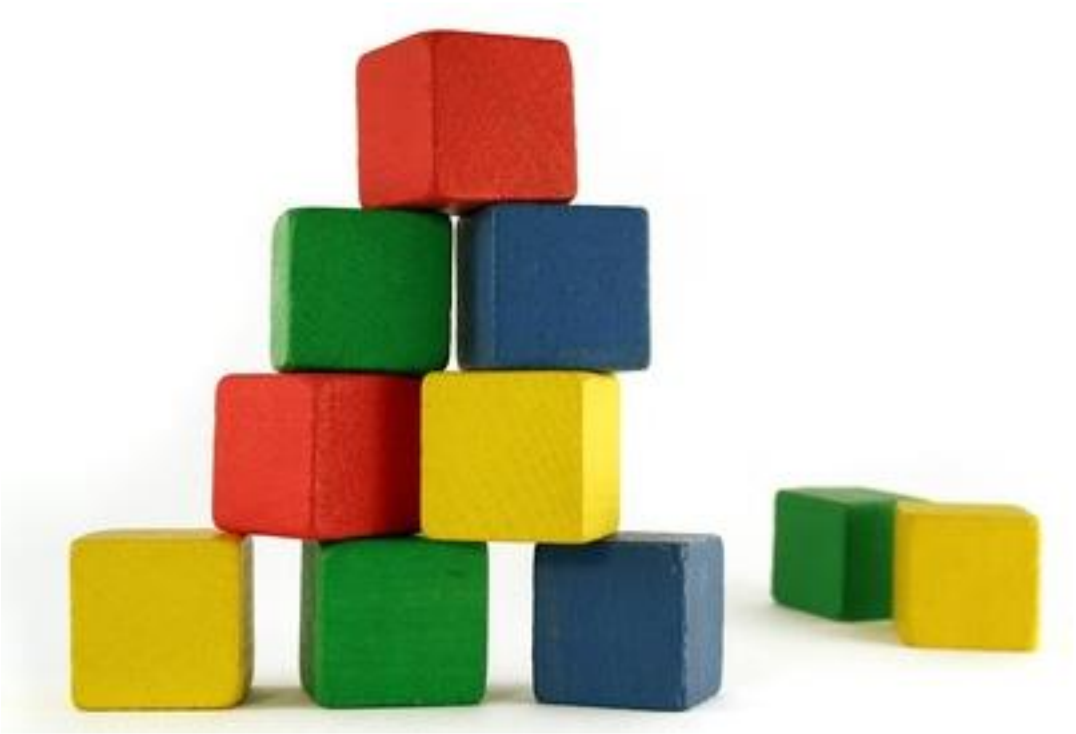
Research models and screening models

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 aquaculture management

Individual models

The building blocks for simulating growth



Reproduce individual growth based on physiology, account for environmental externalities. Adapt to respond to climate change drivers.

Types of cultivated organisms

Widely varying diets and potential trophic interactions

Type	Food source	Examples
Inorganic extractor	Dissolved nutrients	Kelp, Nori
Organic extractor	Particulate organic matter - phytoplankton and detritus	Mussels, oysters
Organic extractor	Particulate organic matter - Benthic detritus	Sea cucumber, sea urchin
Fed aquaculture	Pelleted feed, 'trash' fish	Gilthead bream
Mixed sources (often depends on whether culture is intensive or extensive)	Pelleted feed, organic waste (chicken manure etc), benthic macrofauna, phytoplankton	Shrimp (e.g. white shrimp Penaeus vannamei), tilapia (e.g. Oreochromis nilocticus)

The combination of different types is an optimization approach called Integrated Multi-Trophic Aquaculture (IMTA).

Why individual models are important

Production – what does growth depend on?

- Food supply, origin depends on type of organism
- Environmental conditions for optimal use of food (growth) shellfish food depletion, finfish current speed examples

Environmental effects – consequences of activity

- Dissolved materials from metabolism
- Particulate matter from food waste (both in feeding and ingestion)

Setup for a bivalve model in AquaShell

WinShell (WinShell setup_Eastern oyster_Mayhew grounds_NOAA_2019.2020)

Culture practice

Model specs

Start day for growth: 110 — Runtime (days): 1095

Number of animals: 1 — Box volume (m3): 1

Shellfish species: AquaShell Eastern oyster

Seed size — TFW (g): 1.55; Length (cm): -

Harvest size — Live weight (g): 116.05; Length (cm): 10.60

Drivers

Load model | Save model

	A	B	C	D	E	F
1	Julian day	Temperature	Salinity	Chlorophyll a	POM	TPM
2		(oC)	(-)	(ug L-1)	(mg L-1)	(mg L-1)
3	9	4.40	24.00	1.82	1.17	3.16
4	38	3.90	24.00	6.70	1.56	3.25
5	65	4.50	23.70		2.22	4.08
6	71	5.00	24.20	*4.15*		
7	127	12.50	23.60	9.15	1.40	3.24
8	150	15.00	24.10	14.68	2.13	6.36
9	178	16.40	19.00	11.27	1.98	4.65

Driver data

Results

Save results

	A	B	C	D	E	F	G	H	
1	Julian Day	Live weight	Length	Dry meat	Wet meat	Wet shell weight	Growth	Clearance rate	Spaw
2		(g TFW)	(cm)	(g DW)	(g)	(g WW)	(gDW ind-1 d-1)	(m3 d-1)	(g D\
856	963	111.0057733	10.35735361	3.075136762	27.95578875	83.04998451	0.014193728	0.105106265	
857	964	111.3459738	10.36626866	3.089145944	28.08314495	83.26282888	0.014009182	0.10509973	
858	965	111.6816941	10.37505148	3.102970631	28.20882392	83.47287017	0.013824687	0.105090459	
859	966	112.0129357	10.38370277	3.116610891	28.33282628	83.68010942	0.01364026	0.10507849	
860	967	112.3397007	10.39222322	3.130066808	28.4551528	83.88454792	0.013455917	0.105063859	
861	968	112.6619916	10.40061351	3.143338484	28.5758044	84.08618721	0.013271676	0.1050466	
862	969	112.9798112	10.40887433	3.156426037	28.69478216	84.28502908	0.013087553	0.105026749	
863	970	113.2931628	10.41700636	3.1693296	28.81208727	84.48107554	0.012903563	0.105004339	
864	971	113.60205	10.42501027	3.182049321	28.9277211	84.67432887	0.012719721	0.104979404	

Drivers - interpolated data | AquaShell Eastern oyster

Two main types of approach – Approach I

Generic growth models

- Uses growth equations such as Michaelis-Menten, or a growth constant
- Environmental effects are calculated indirectly (e.g. nitrogen removed as a proportion of shellfish biomass

Very simple oyster growth model

http://insightmaker.com/insight/7053

Two main types of approach – Approach II

Detailed process models

- Use equations that represent physiological processes
- Environmental effects are calculated as the outcome of those equations
- Such models deal with mass expressed in different units (phytoplankton chlorophyll, POM dry weight, tissue wet weight) by using an energy-based approach
- The two most common approaches use net energy balance (NEB) and dynamic energy budget (DEB)

More complex carp growth model

http://insightmaker.com/insight/6799

Further reading: Yang Yi, 1998. Aquacultural Engineering 18, 157-173

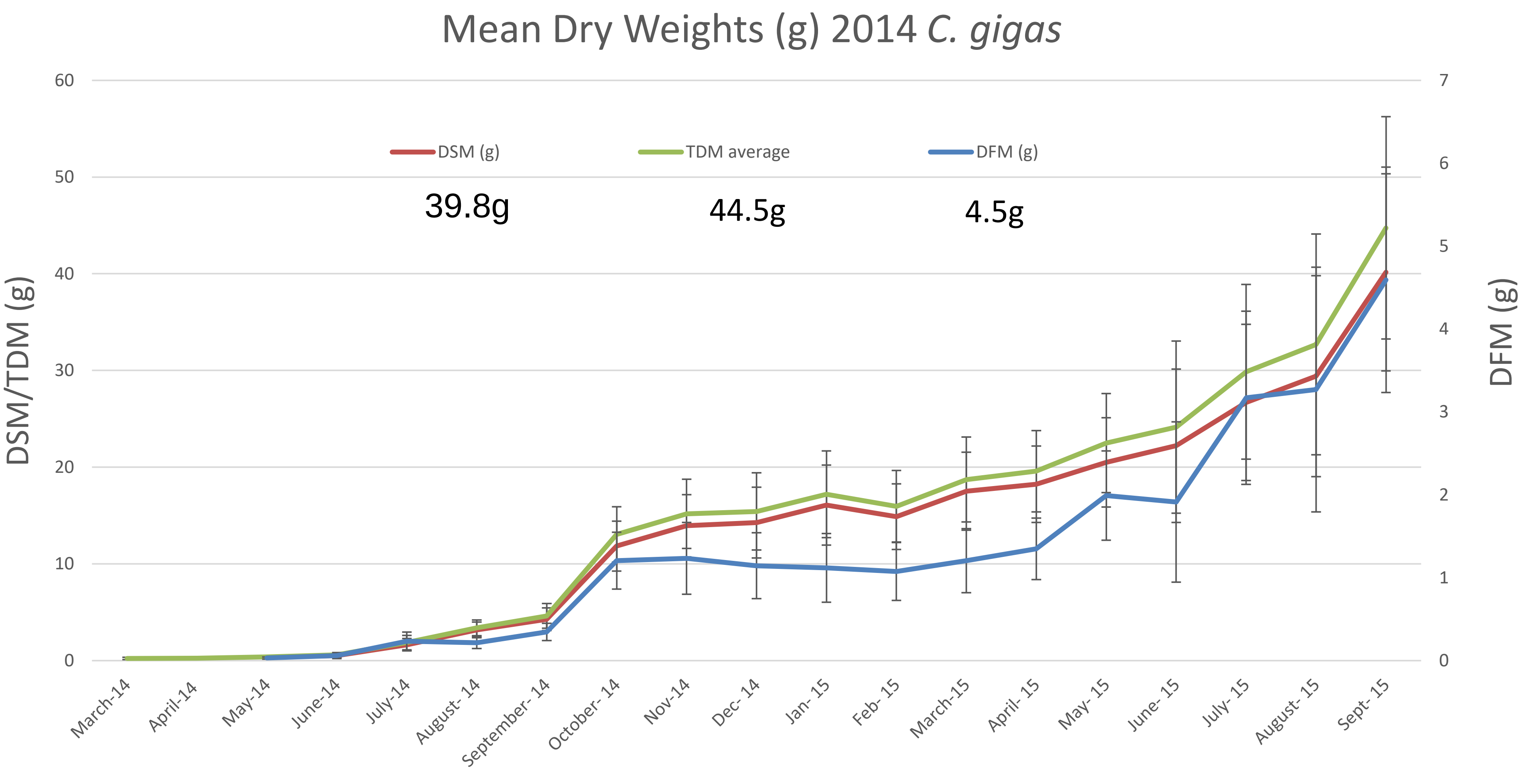
Typical functions in a NEB model

Application to filter-feeding shellfish such as oysters

Process	Description	Dependencies
Clearance	Intake and outflow of water	TPM, allometry, T, S
Filtration	Intake of organic matter	Clearance, particle concentration
Pre-ingestive selection	Release of uningested matter as pseudofaeces	Particle composition and concentration
Assimilation	Assimilation of digested matter	Food composition, food mass
Elimination	Release of undigested matter	As above
Excretion	Waste products of metabolism	Allometry, T, S
Growth	Partition of growth into somatic tissue, gonad, and shell	Mass balance resulting from the proportion of energy for each component

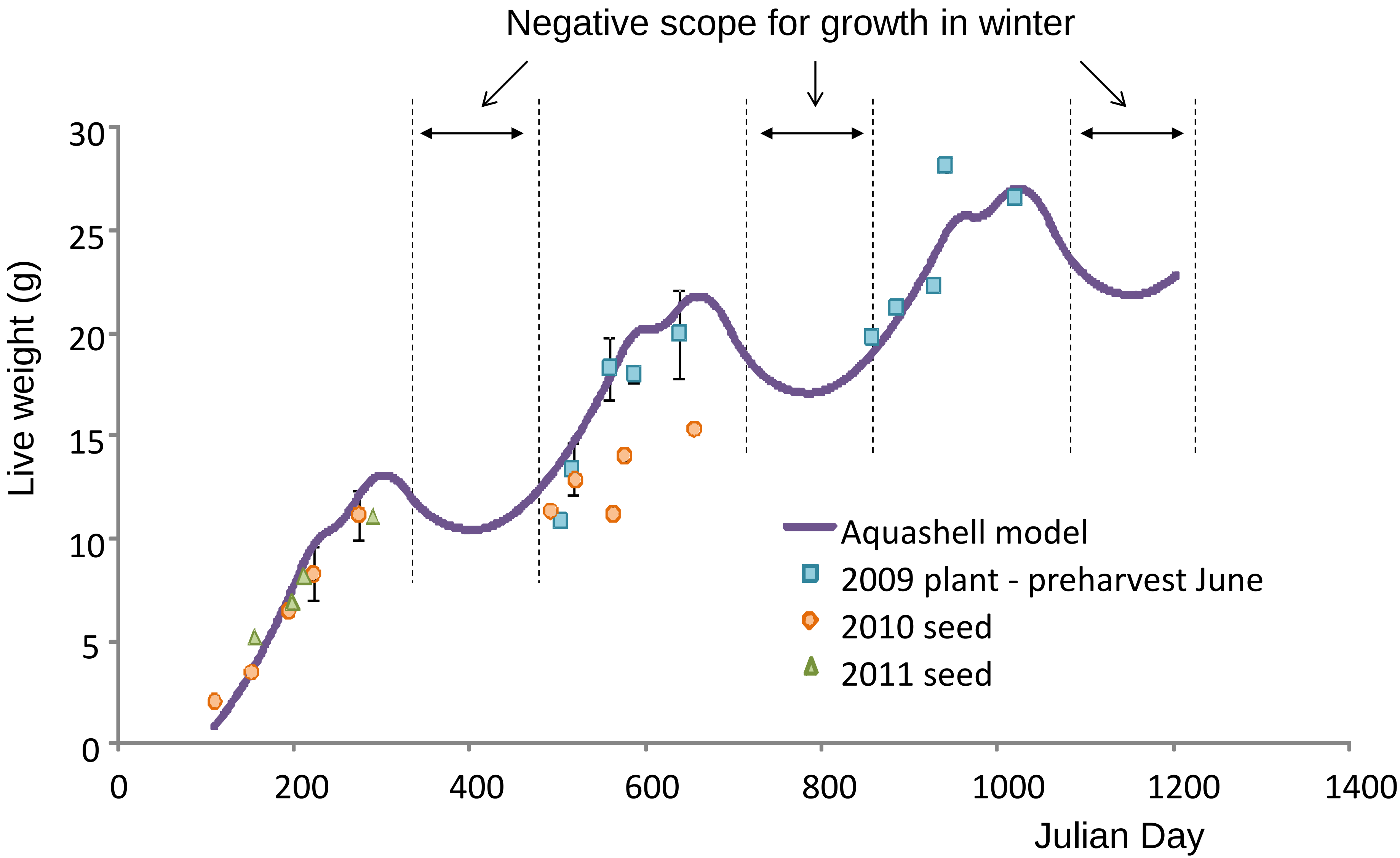
Net energy balance models can provide an appropriate description of growth, food removal, and environmental components.

Growth trials in Lough Foyle, Northern Ireland *Crassostrea gigas* seed



Experiments performed by AFBI (GAIN partner) and the Loughs Agency.

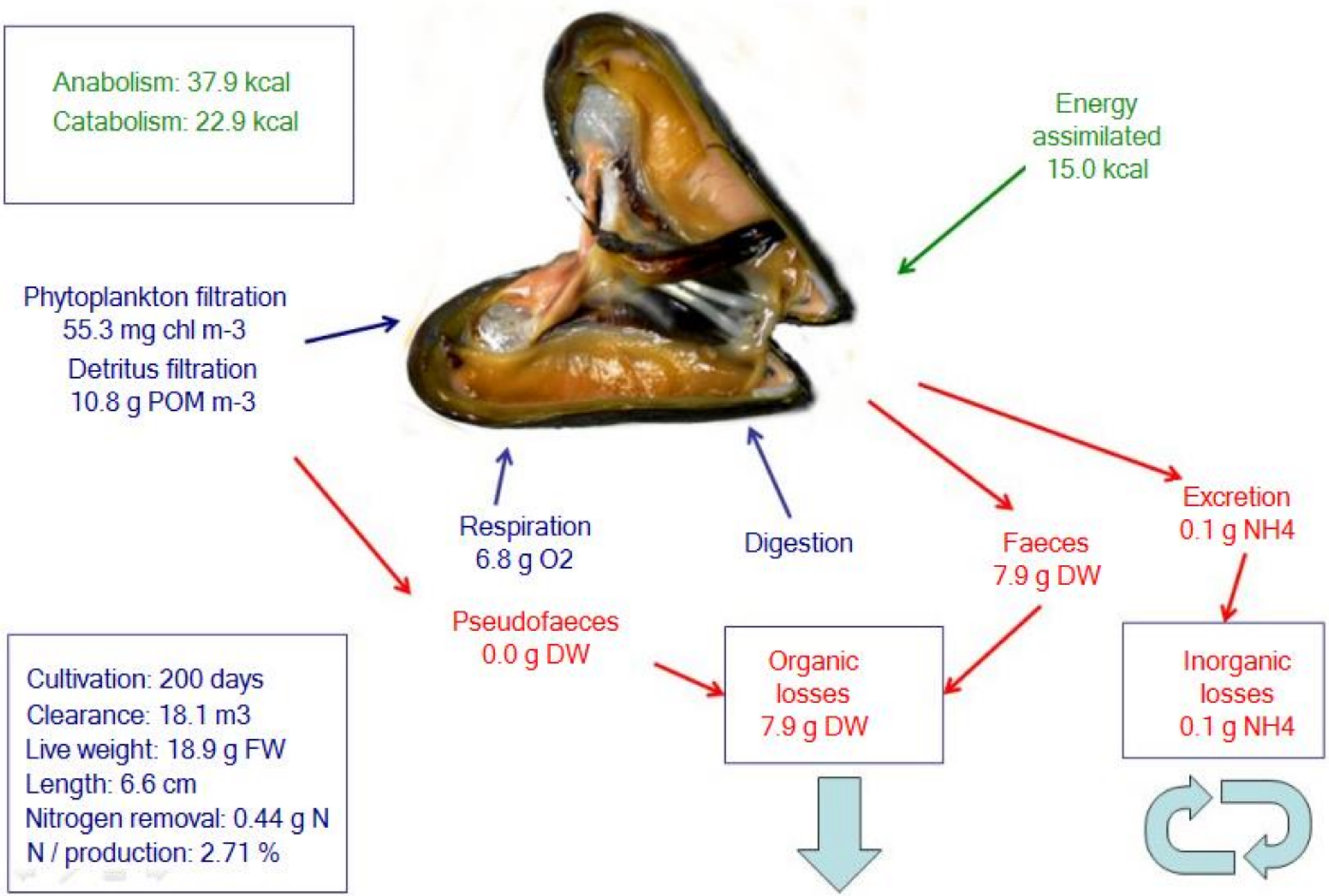
Simulation of clam live weight in Samish Island, USA, environmental drivers



The AquaShell model shows a good fit to measured data for live weight.

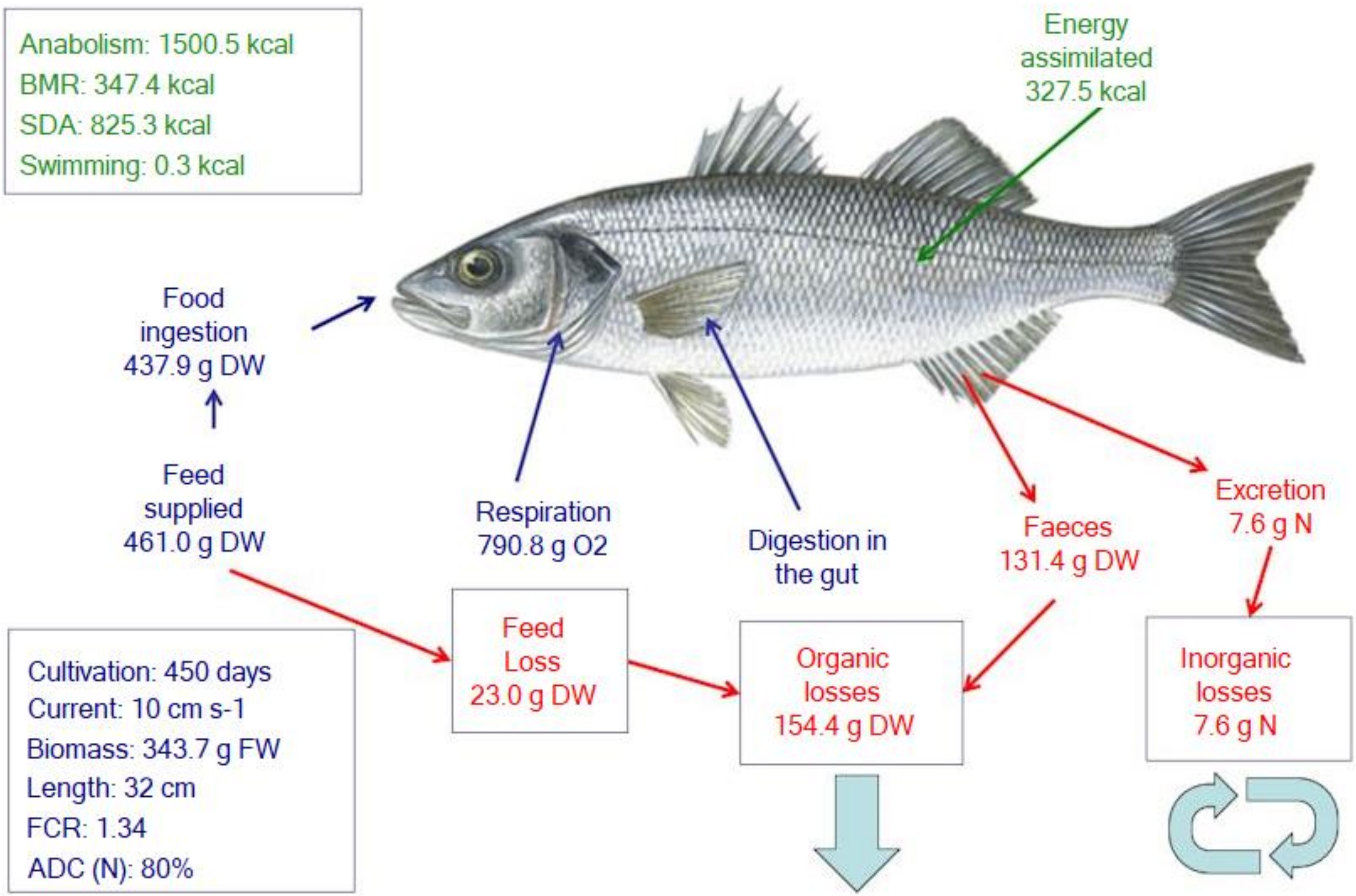
Mediterranean mussel growth model (AquaShell)

Mass balance



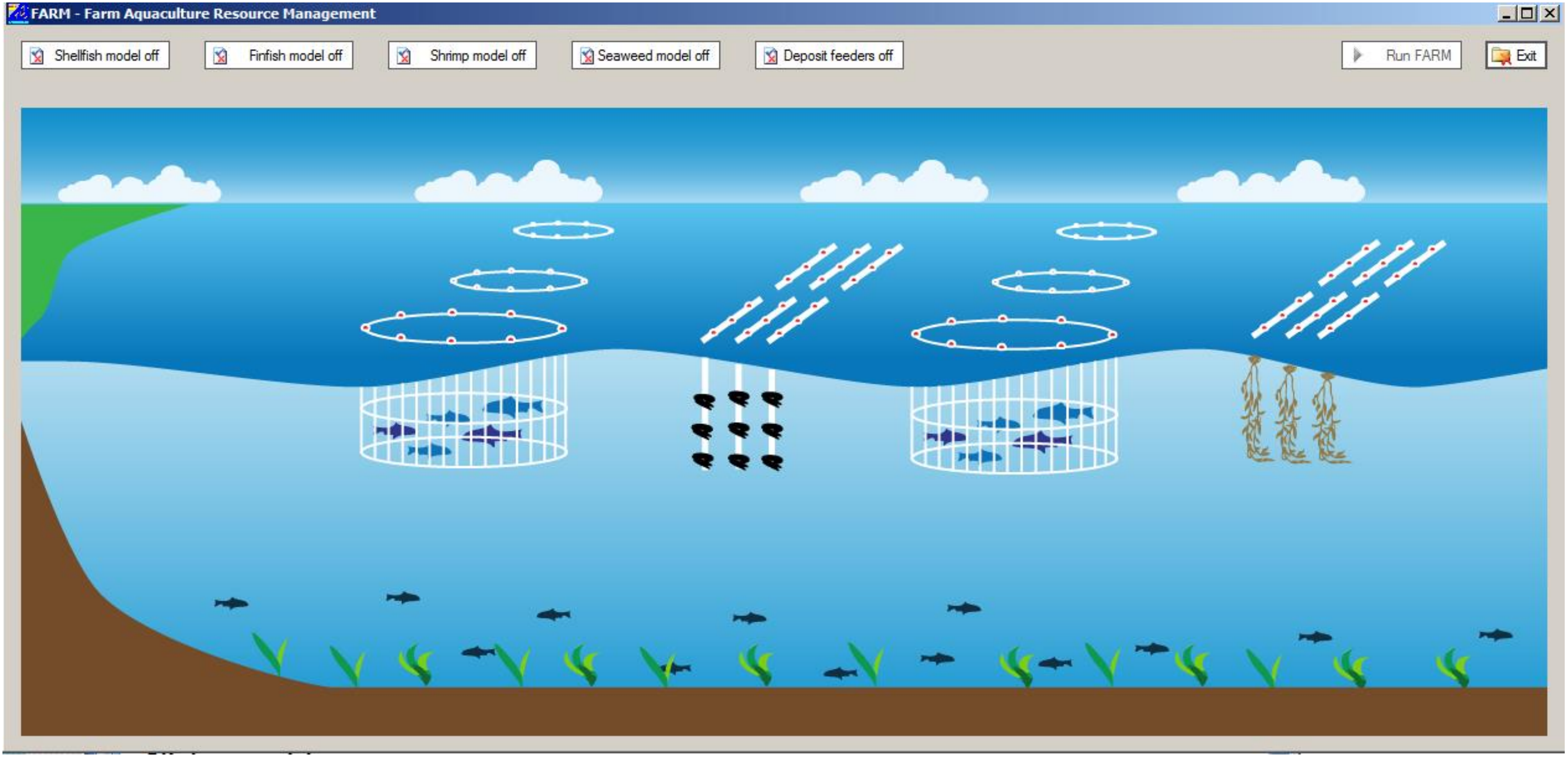
Simulation of Mediterranean mussel growth using environmental drivers provides outputs on production and environmental effects.

AquaFish individual growth model
Mass balance for European seabass



Model developed using feed tables courtesy of Culmarex. Growth is similar to the seabream model.

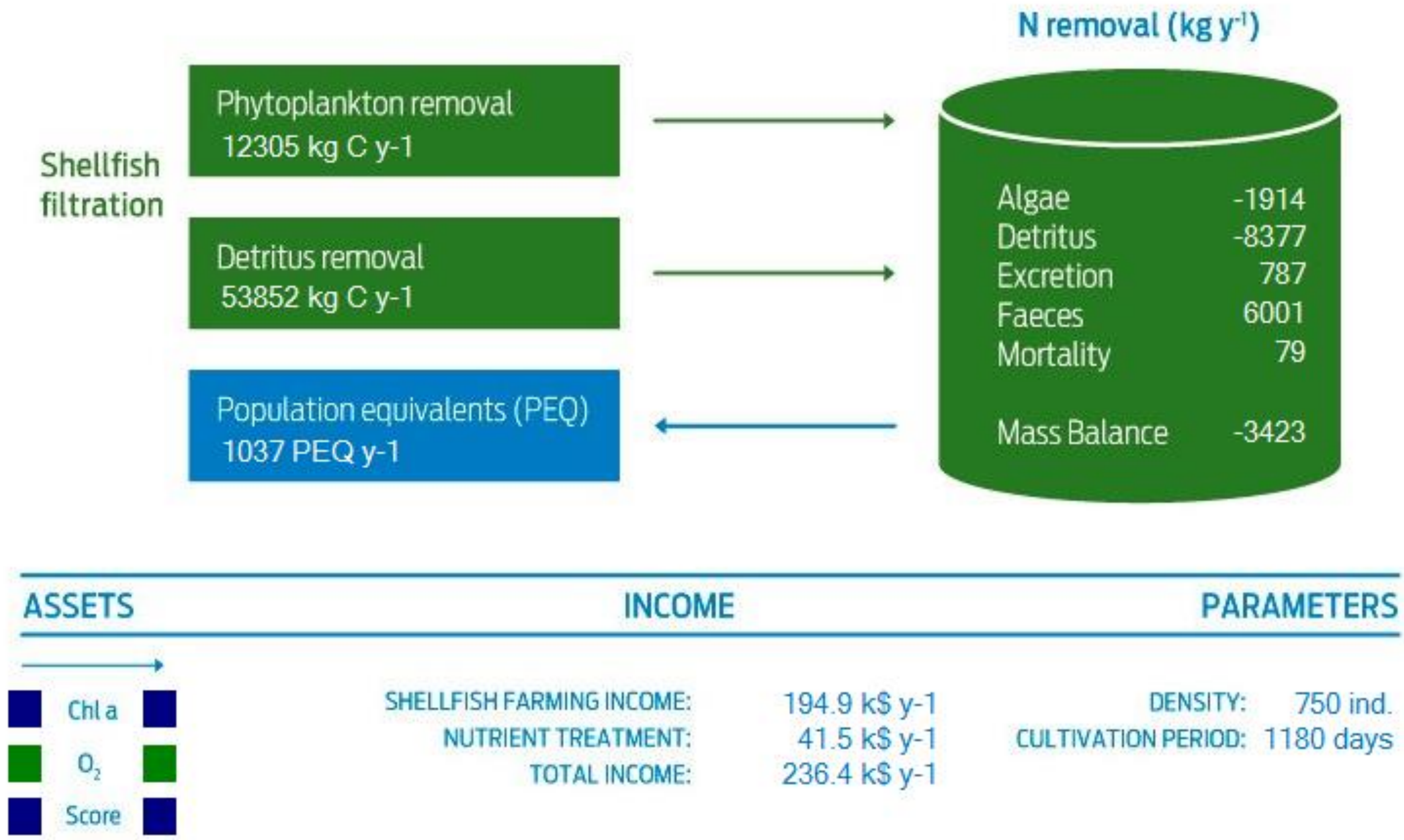
FARM model



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.

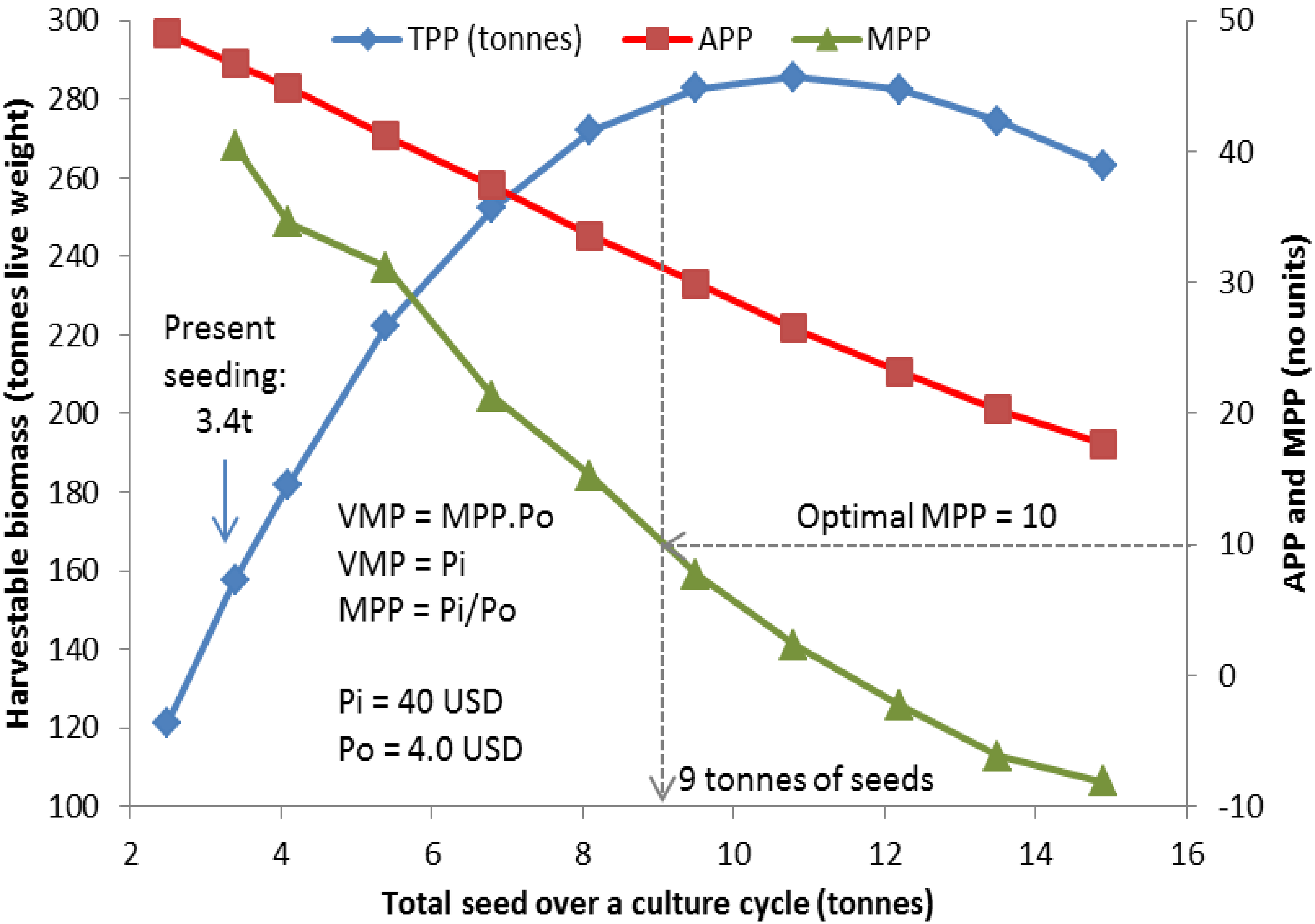
Samish Island Manila clam farm
FARM model simulation for nutrient trading



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

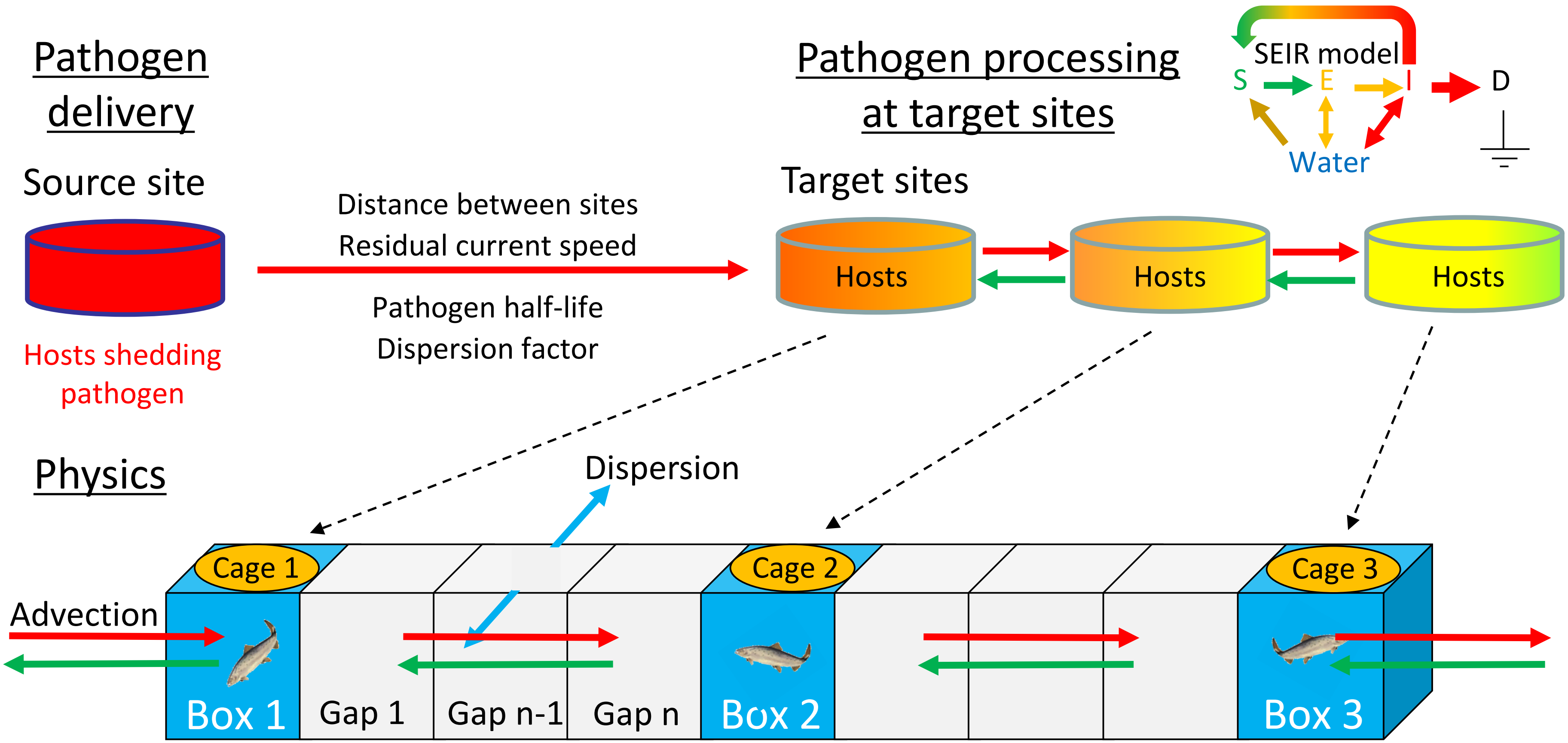
Marginal analysis

FARM model – application to Samish Island Manila clam farm



The 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.

ABC – General Approach



Husbandry

- IBM approach
- Feeding, growth
- Environment on aquaculture
- Precision harvest
- Size-dependent mortality

Environment

- Aquaculture on environment
- Key factors: dissolved oxygen, dissolved nutrients, organic waste, phytoplankton depletion

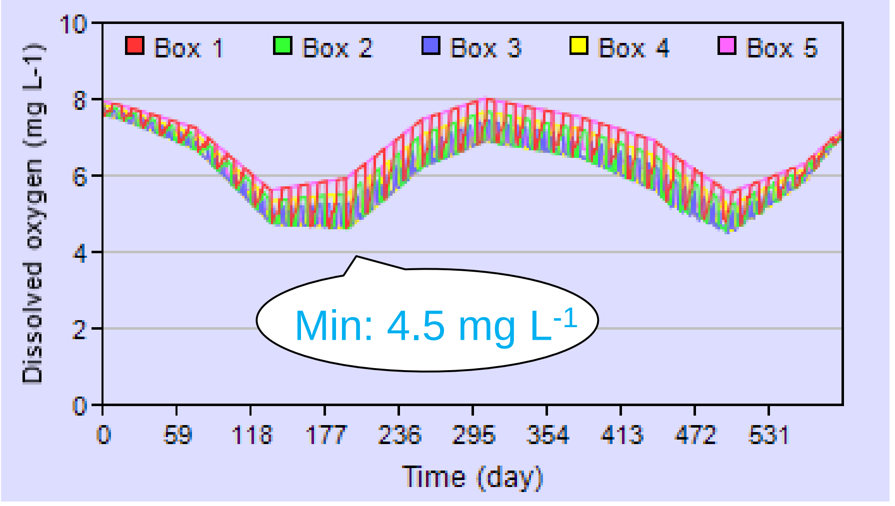
Pathogens

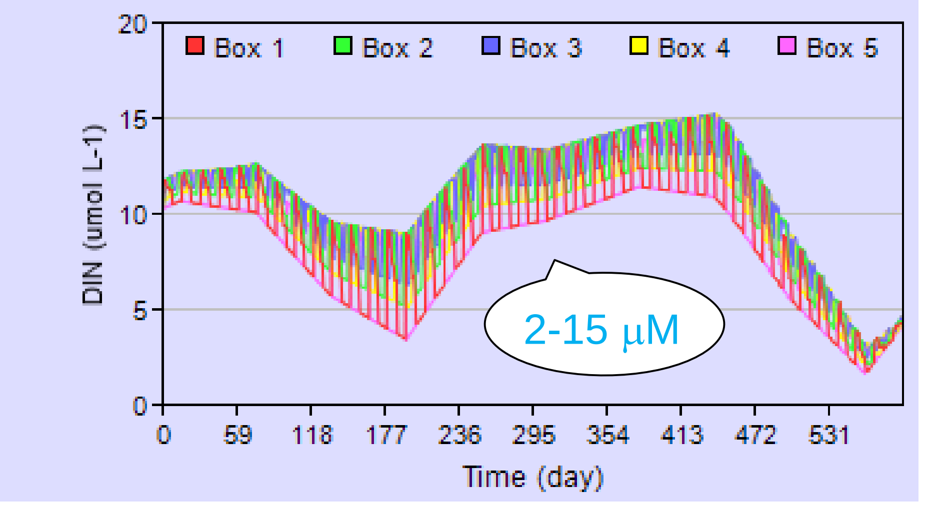
- Infection parameters
- Hill function for IHNv, OsHv, Vibrio
- Physical and biological decay
- Response to climate change
- Waterborne or relay

Environment – Dissolved oxygen and DIN for finfish

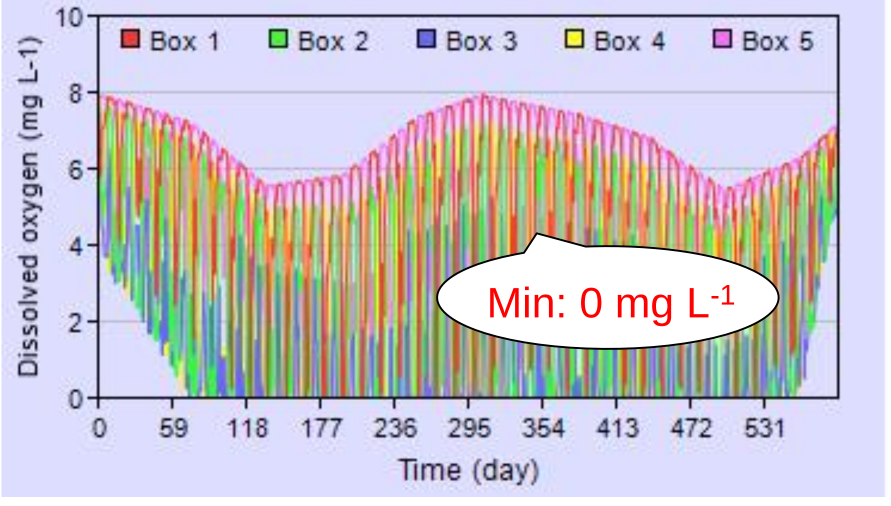
5 culture areas,100 m separation, one million gilthead per area

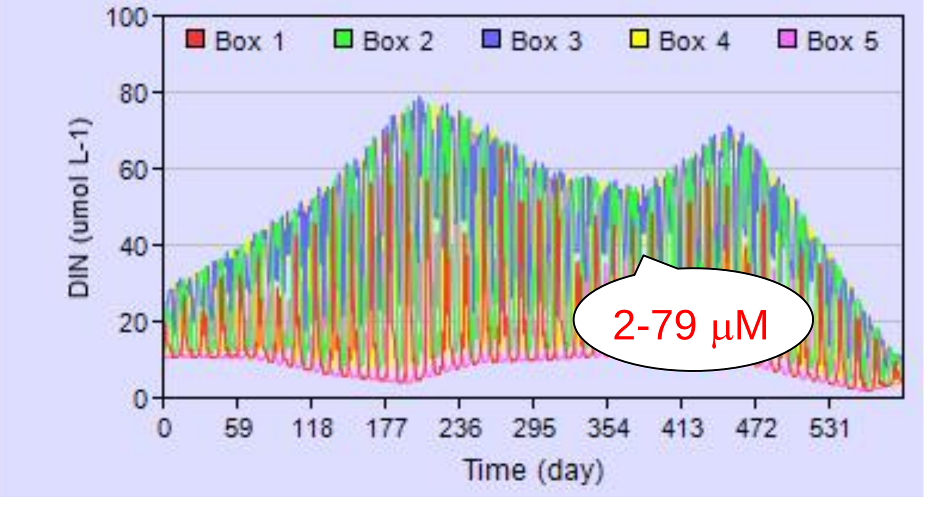
Farm simulated with lateral exchange of water properties (high dispersion)





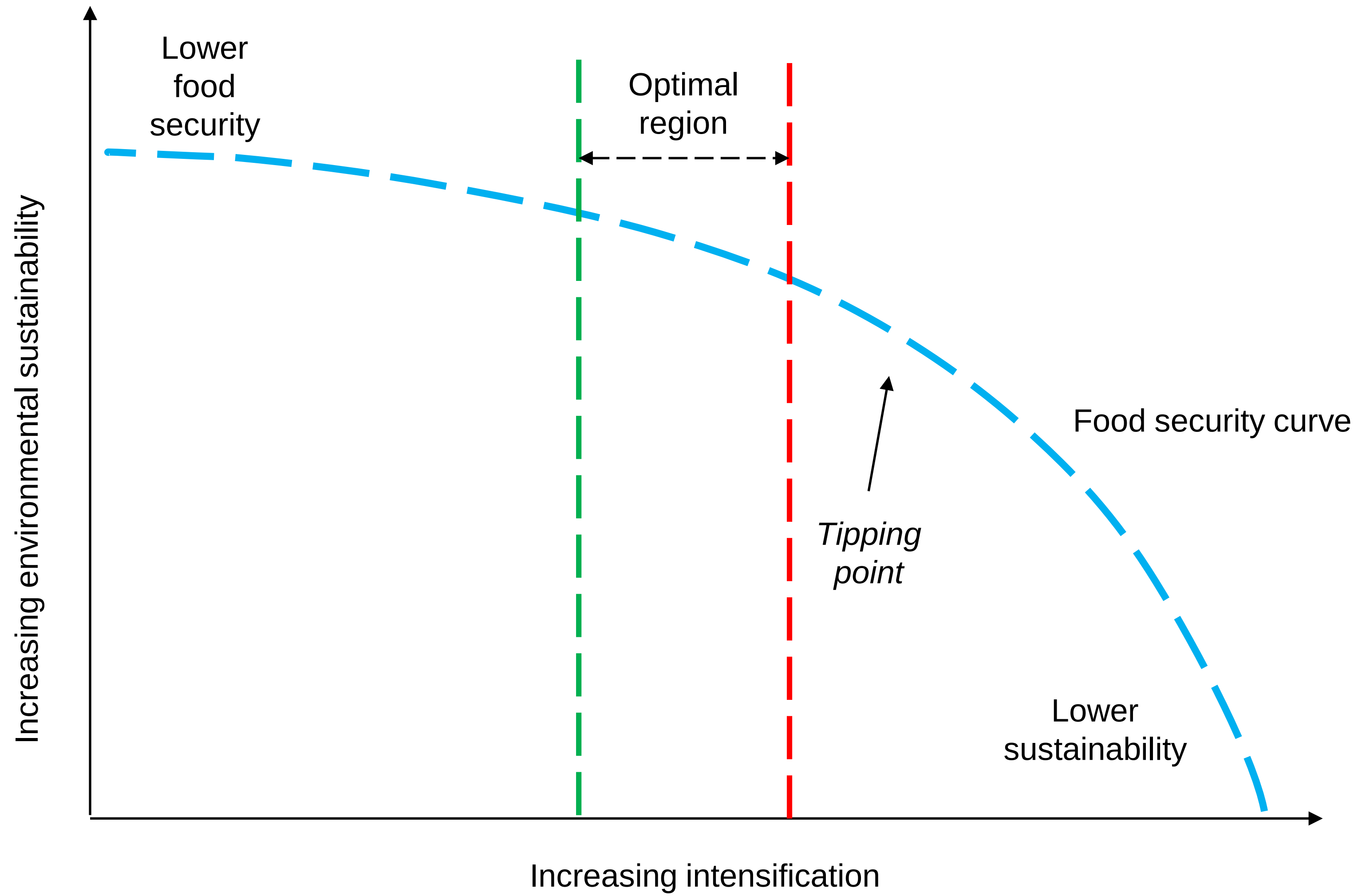
Farm simulated with no lateral exchange of water properties (low dispersion)





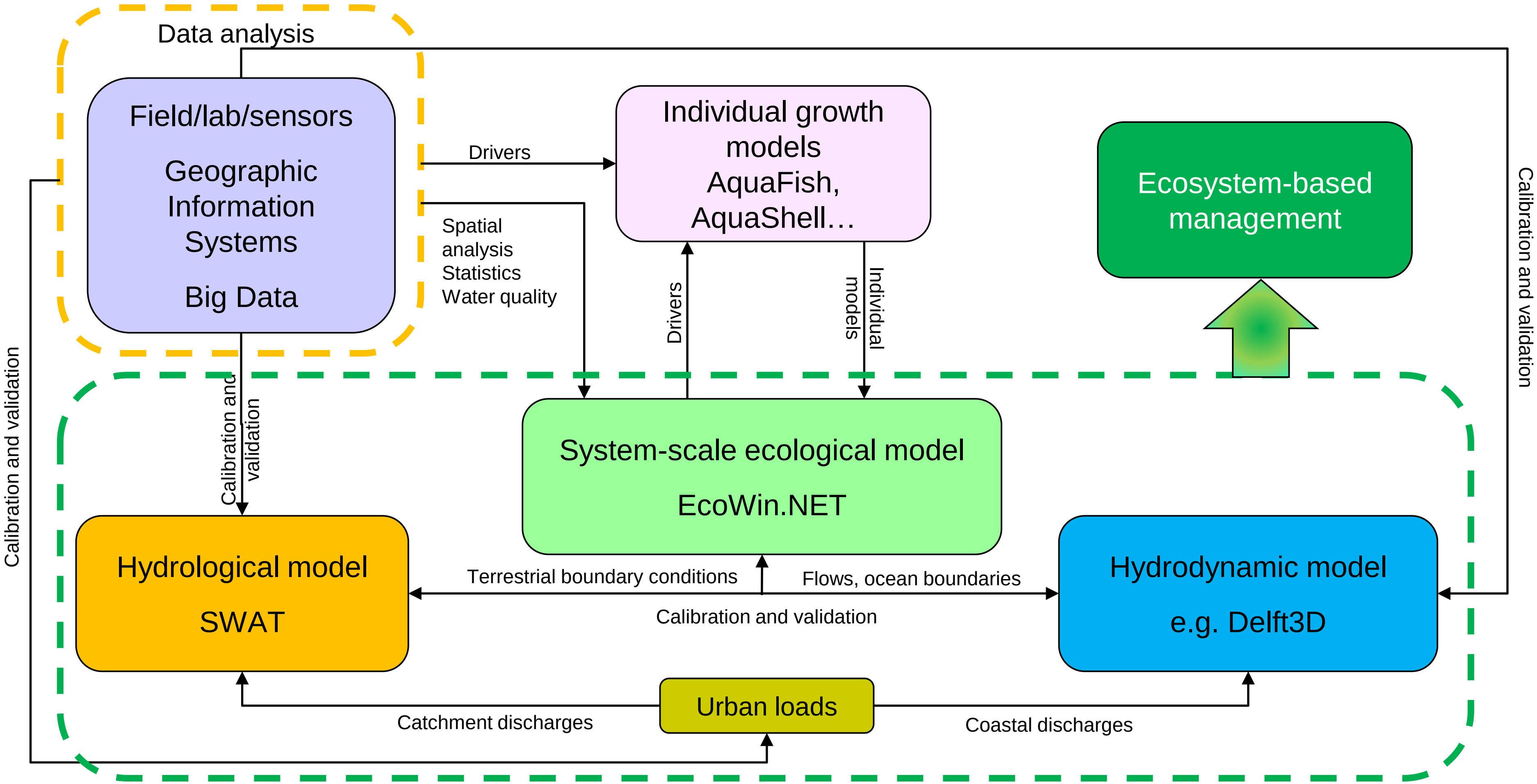
Two-way flow. Fish culture depletes oxygen and increases DIN within the farm area. Turbulence, stronger currents, and wider gaps help offset impact.

Aquaculture intensification and environmental sustainability



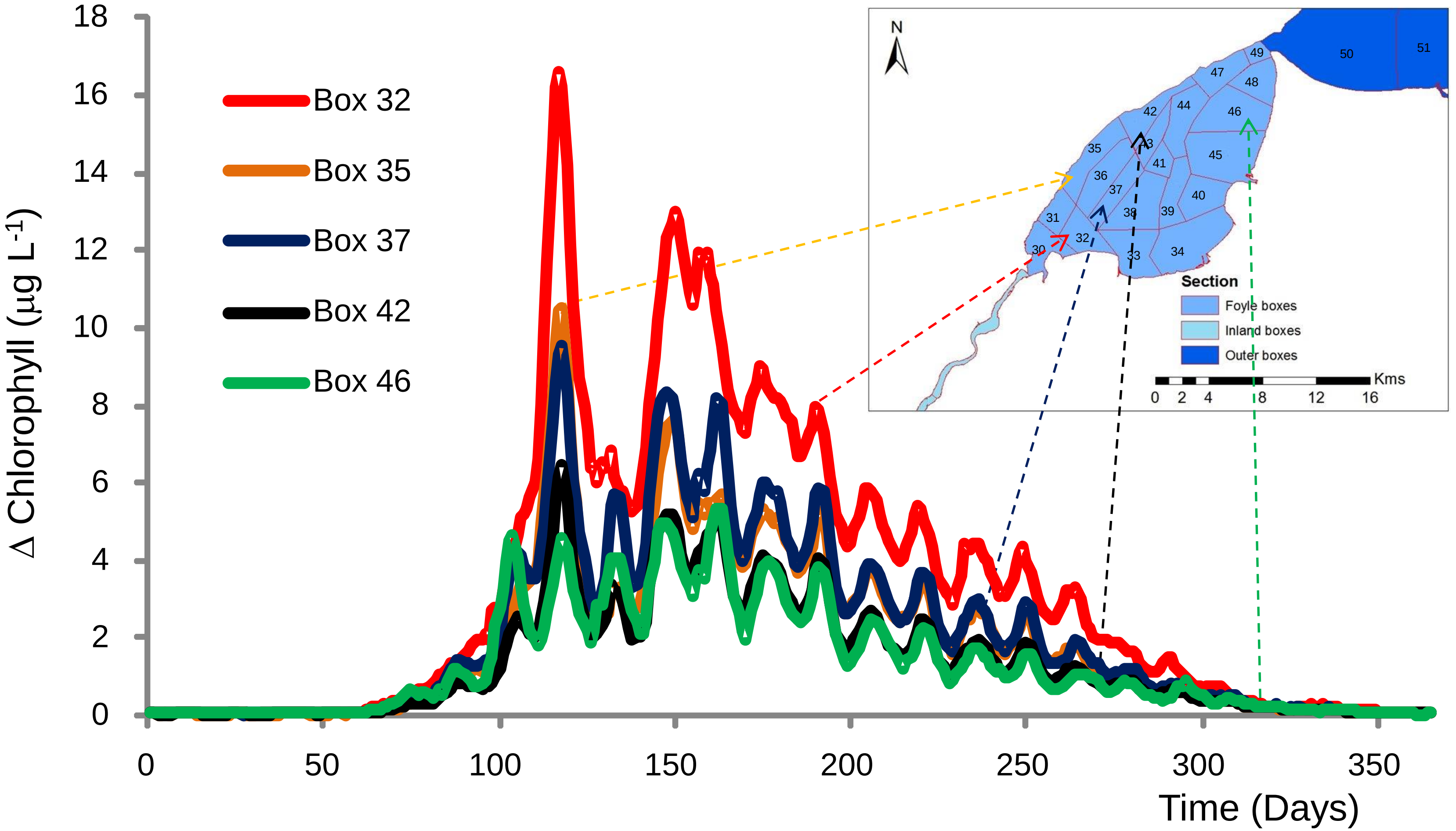
The challenge of eco-intensification: increase, but also do more with what you already have.

SUCCESS framework – models for integrated management



Individual models help to drive complex simulation frameworks.

EcoWin.NET Lough Foyle Standard Model Phytoplankton drawdown by shellfish, Year 9



The strongest drawdown is in the central and upper parts of the lough, where both native oyster (*O. edulis*) and blue mussel (*M. edulis*) are grown.

Synthesis

- Cultivated species have widely differing feeding habits
- Individual growth models help identify what variables need to measured in the environment
- More detailed models of growth provide a better representation of environmental effects
- Individual models are the building blocks for population modelling
- Population models provide farm- and ecosystem-scale information that can be used to assess carrying capacity
- In combination with other models, individual models allow the scaling of growth and environmental effects and help quantify the potential for eco-intensification of aquaculture

https://www.gain2020.com/summerschool

OUR CONTACTS

info@epcsrl.eu
joao@longline.co.uk39 0444 169000

EUROPEAN PROJECT CONSULTING

OUR LOCATION

Via Prati, 11 Dueville (Vi)

INFO@EPCSRL.EU

This project receives funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 773330 (GAIN)