GAIN Green Aquaculture Intensification SUMMER SCHOOL

LONGLINE ENVIRONMENT

GAIN SUMMER SCHOOL

LOW TROPHIC LEVEL AQUACULTURE ECOSYSTEM SERVICES

Application to integrated catchment management

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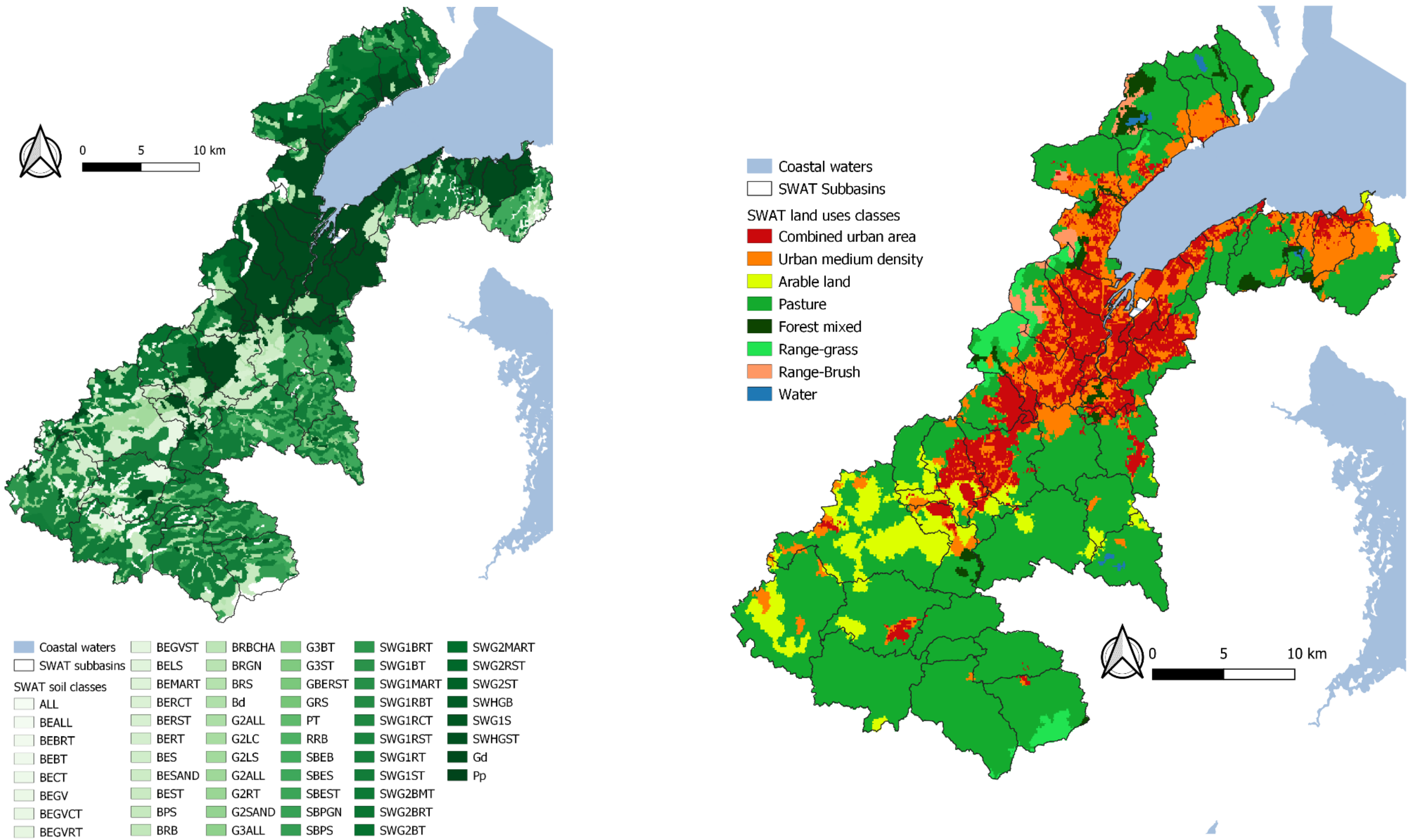
Low Trophic Level Aquaculture Ecosystem Services

Learning outcomes from this lecture

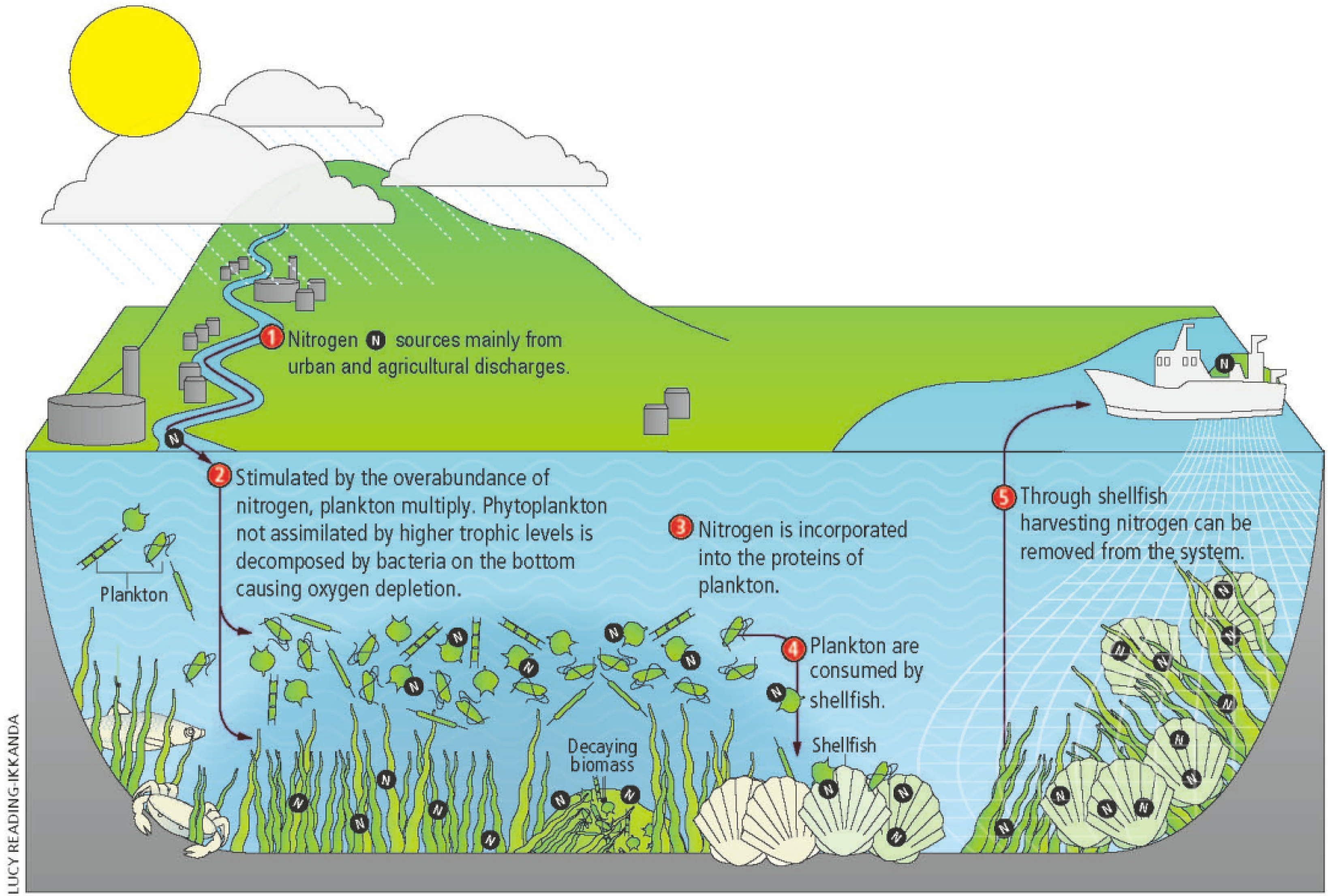
1. Understand options for nutrient management in coastal systems
2. Review assessment of nitrogen bioextraction within the GAIN project
3. Quantify loading of nitrogen to European coastal waters
4. Evaluate the potential role of bivalve shellfish in bioextraction
5. Increase awareness of how top-down control can play a part in integrated catchment management

Sources of nutrients to the coastal zone



Land use in Belfast Lough catchment, Northern Ireland. Different land uses have different unit nutrient loads, and the method and cost of emission control varies.

Conceptual model of eutrophication



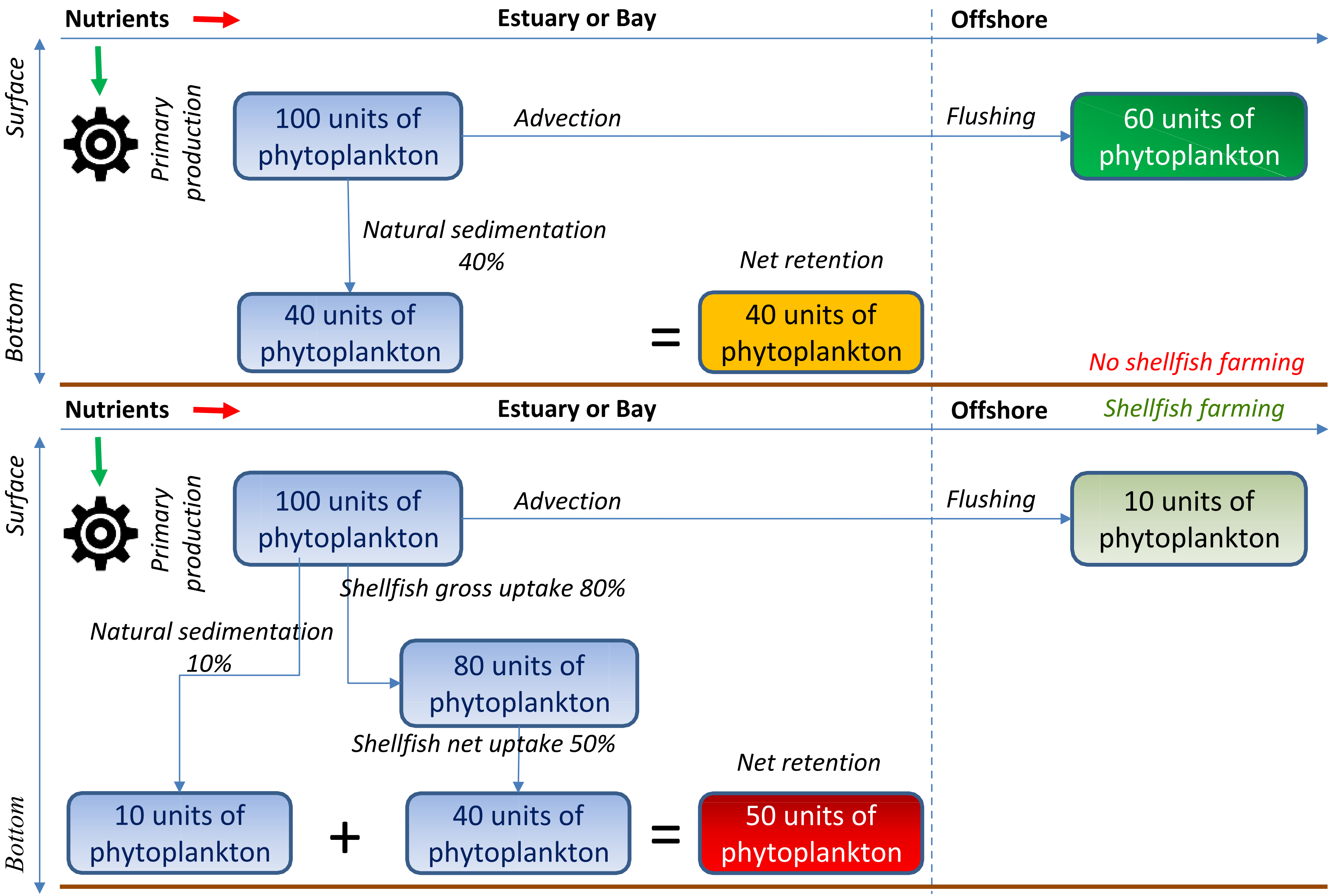
Long Island Sound Study. 2010. Bioextraction Fact Sheet.

Eutrophication and top-down control

EXTERNAL FORCING	PRIMARY SYMPTOMS	SECONDARY SYMPTOMS
Nitrogen and phosphorus	Decreased light availability Chlorophyll a Macroalgal growth	Loss of SAV SAV Spatial coverage SAV Coverage trends
	Increased organic decomposition Chlorophyll a Macroalgal growth	Low dissolved oxygen Dissolved oxygen
	Algal dominance changes Diatoms to flagellates Benthic to pelagic algae	Harmful algae Nuisance algal blooms Toxic algal blooms

Top-down control : the circuit-breaker between primary and secondary symptoms.

Particulate nitrogen trapping (self-study)



Shellfish take out more than they put back, but sometimes not locally.

Assessment of Bioextraction in GAIN

Eco-intensification by adding value to secondary products (including emissions)

1. Determine how much nitrogen (N) is removed from European waters through bioextraction by farmed shellfish;
2. Partition overall N removal to the national scale based on European bivalve production;
3. Assess the relevance of removal by farmed shellfish in terms of the total N loading to European seas;
4. Evaluate the potential role of European shellfish growers in watershed nutrient credit trading for eutrophication control.

Seaweeds are also a candidate for bioextraction, however GAIN didn't have a significant seaweed focus due to volume, market, and nature of extraction.

Valuation of bivalve regulatory services

Approach	Examples
Define suitable indicators	Nitrogen Phosphorus…
Select appropriate methods	Tissue content at harvest, net N removal…
Determine equivalency	Land-based treatment…
Determine value of services	PEQ cost for WWTP…

General approach is relatively simple to apply. Some obvious challenges are: accurate harvest data, variability in nutrient content, range of sources.

Top-down control of eutrophication by bivalves

Nutrient loading to European marine waters

EU shellfish production review

Review on proximate analysis of nutrients in shellfish

↓

Application of two separate approaches to assess potential top-down control by bivalves on coastal eutrophication

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Simulate shellfish nutrient removal and evaluate the potential of shellfish aquaculture to offset nutrient discharges to European Seas

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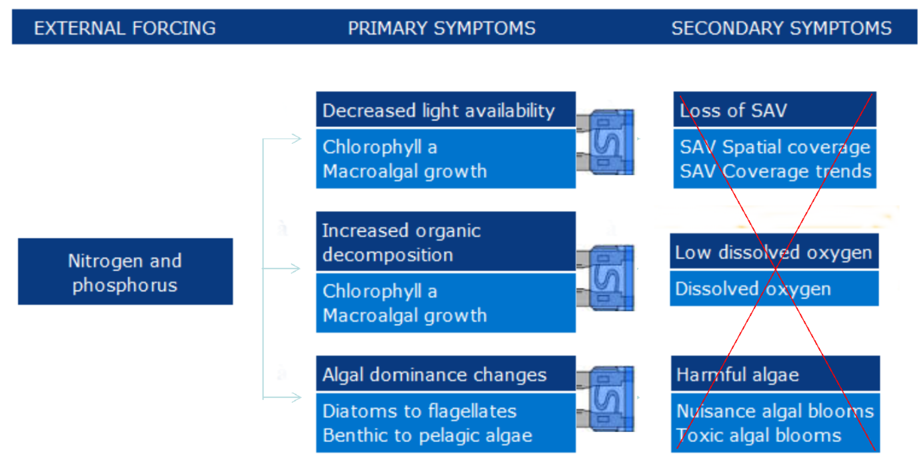
Framework proposal on a nutrient trading policy in Europe, using shellfish regulatory services for nutrient management.



Shellfish farming can be used to offset the consequences of nutrient loading, mainly in the context of rural elements, but beware of moral hazard.

Quantification of nutrient loading

Point sources

1. Direct measurement;
2. Coefficients related to e.g. production or raw materials;
3. Modelling.

Diffuse sources

1. 'Soft' models such as ECM (Export Coefficients Model);
2. Detailed models such as SWAT.

Just as with global satellite data, there are models such as HYPE that provide worldwide predictions for water and nutrient loading.

The trend is to use more complex models, although e.g. daily predictions are always stochastic since weather forecasting capacity is limited.

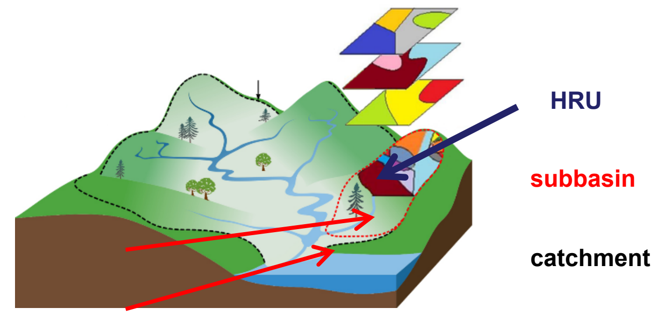
The SWAT modelling framework

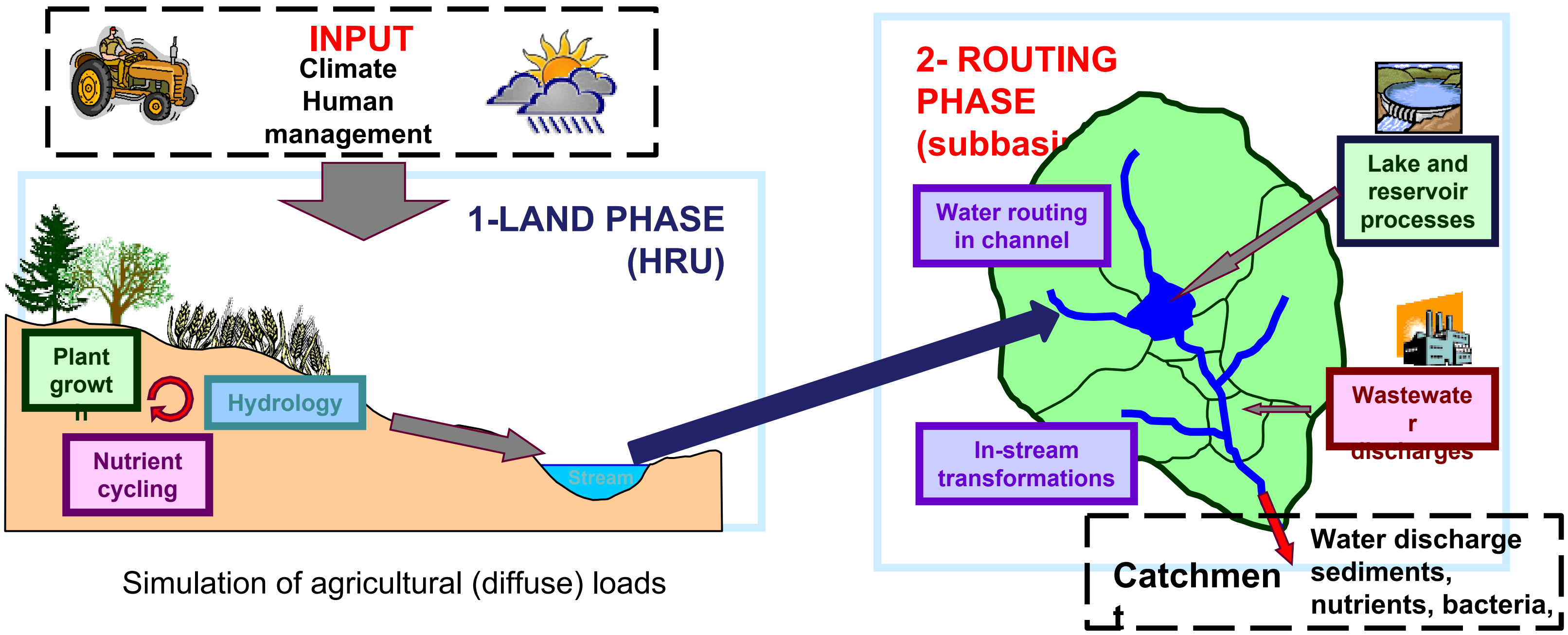
SWAT Soil & Water Assessment Tool

Eco-hydrological catchment model (USDA).

Simulate the quality and quantity of surface and groundwater.

Predict the environmental impact of land use, land management practices, and climate change at the catchment scale.

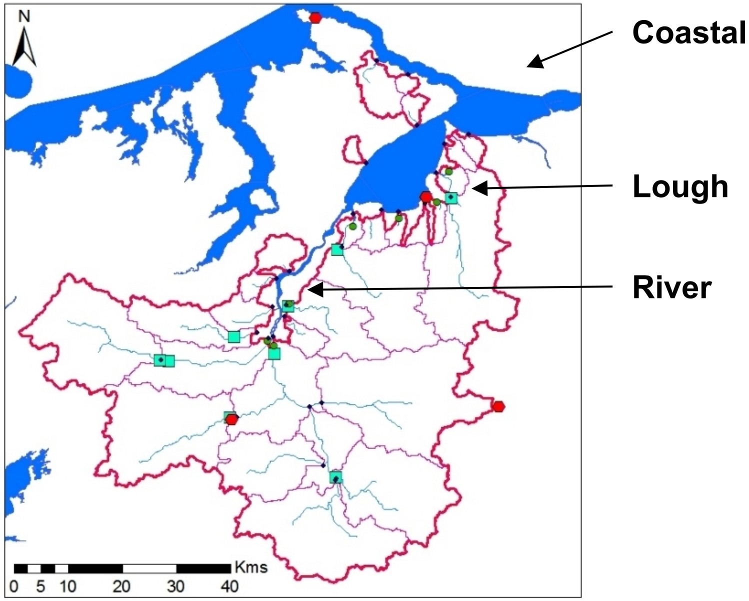


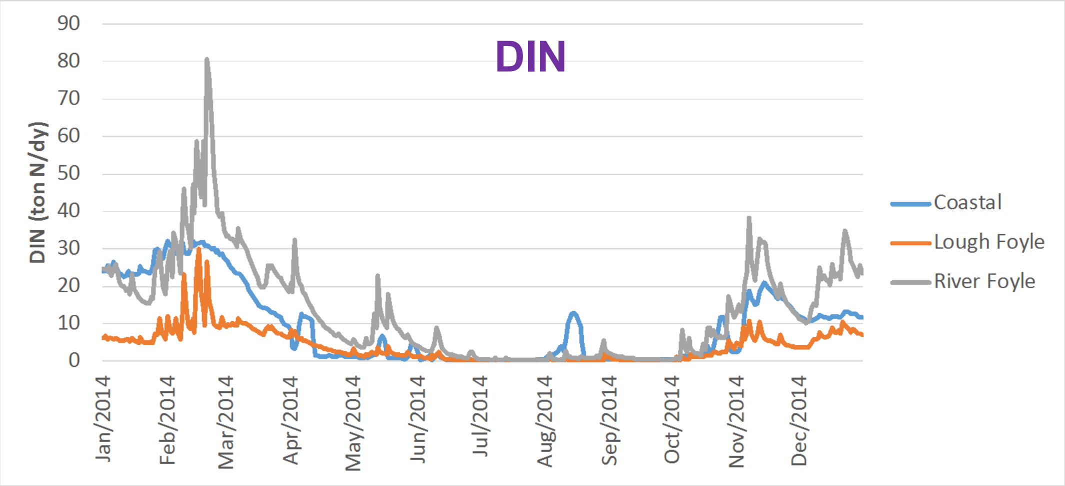


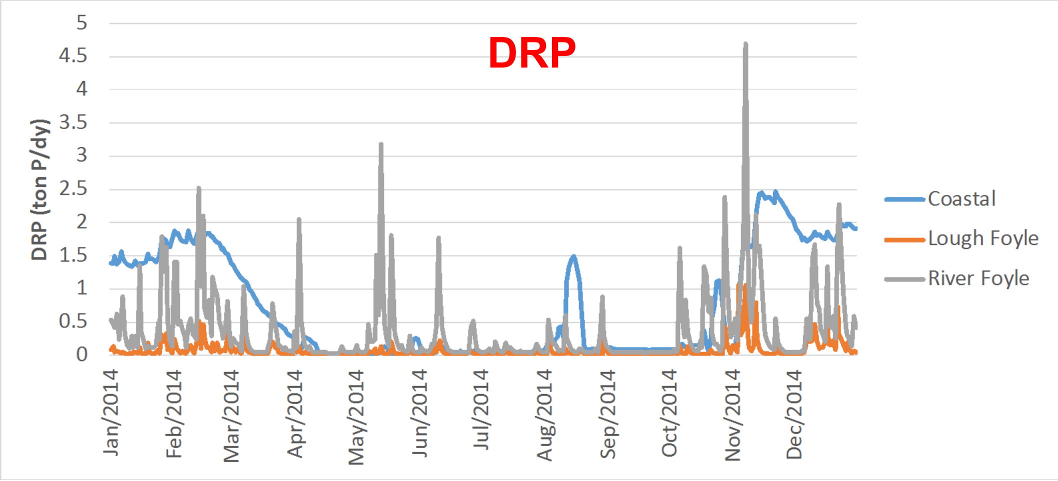
Simulation of agricultural (diffuse) loads

SWAT is probably the most used hydrological model in the world. Longline is now running it with an hourly timestep to simulate bacterial loading associated with flash floods—this is critical for the shellfish industry.

Nutrient loads in time: 2014 (self-study)



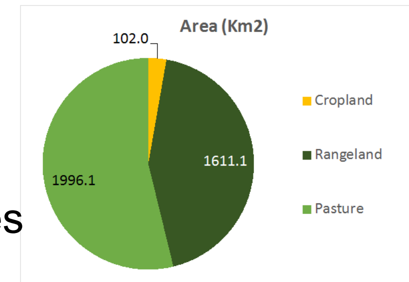


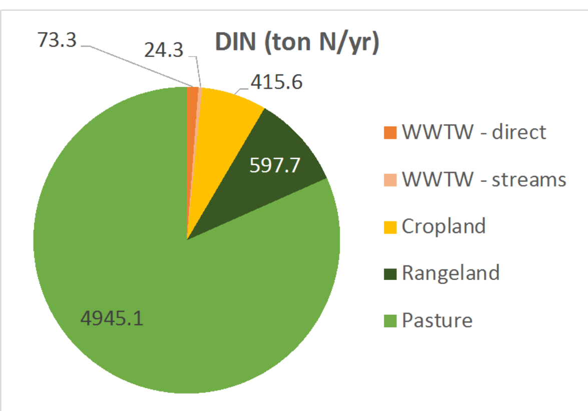


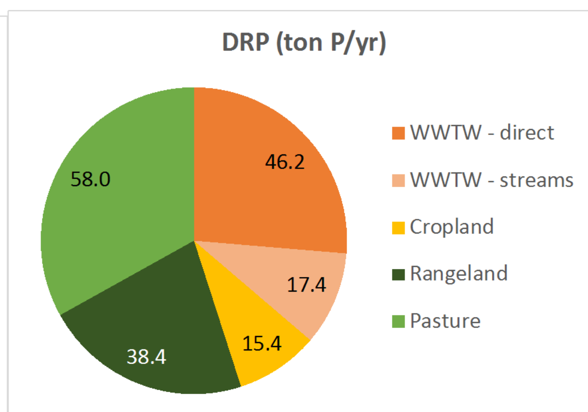
Source apportionment for Lough Foyle

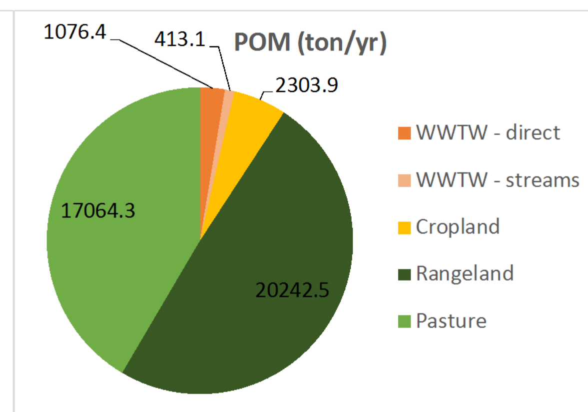
- Main DIN source: diffuse pasture – follows fertilizer application

- DRP sources: point-source & diffuse
  - Diffuse: low erosion rates leads to exports at “background” values
- DIN & DRP results broadly agree with Foy and Girvan, 2004
- POM sources: diffuse – follows landuse
  - Diffuse: low erosion rates leads to exports at “background” values
  - Point source: negligible exports due to WW treatment

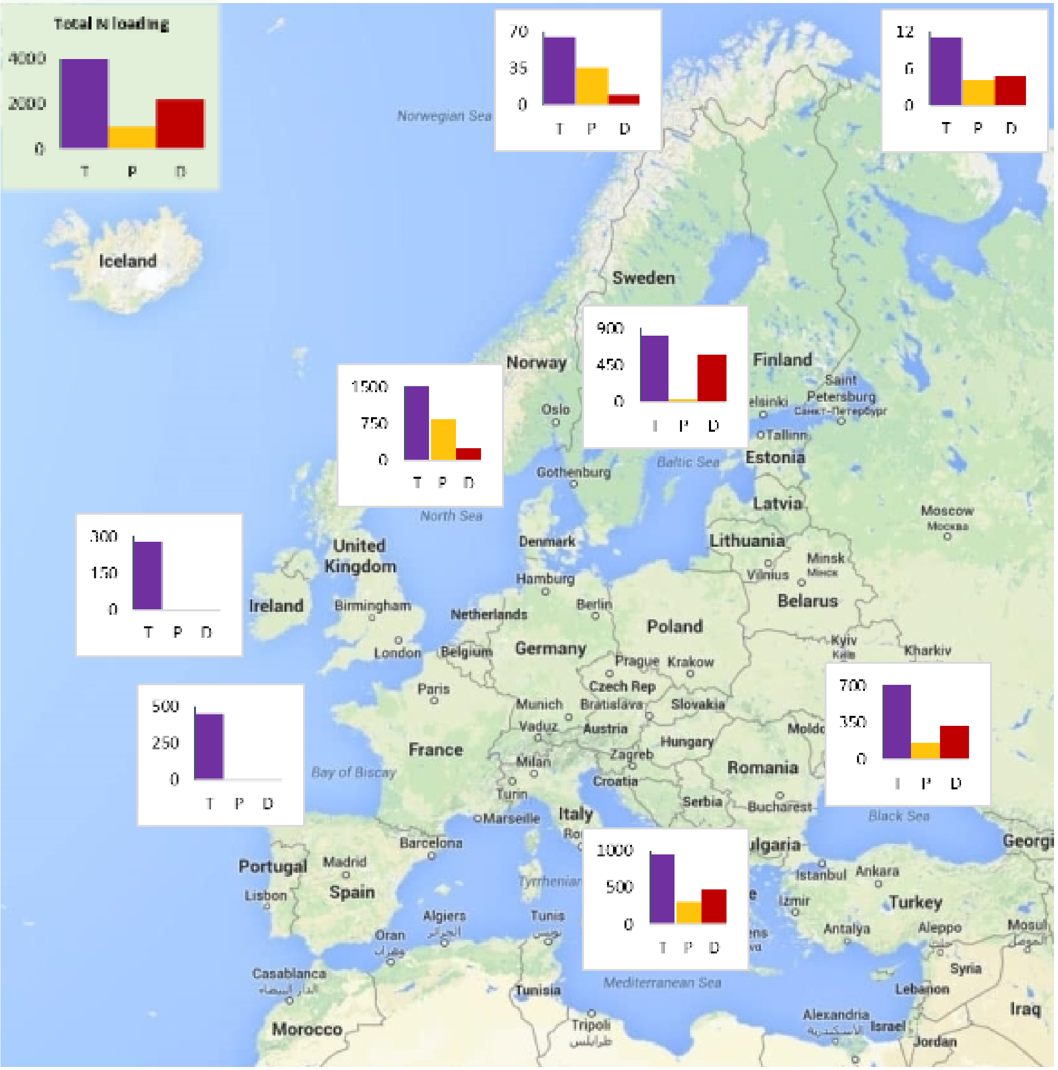








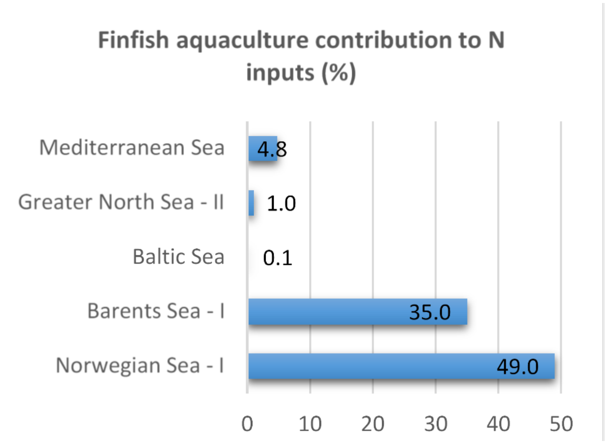
GAIN results - Nitrogen loading to European Seas (10^3 tonnes y^{-1})



Total N loading to European Seas is 5 672 kt y^{-1} (4 777 kt y^{-1} excluding North Africa)

Finfish aquaculture contribution to N loading varies between 49% (Norwegian Sea) and 1% (Greater North Sea)

Overall, the contribution of finfish aquaculture to the total N load to European coastal waters is 2%



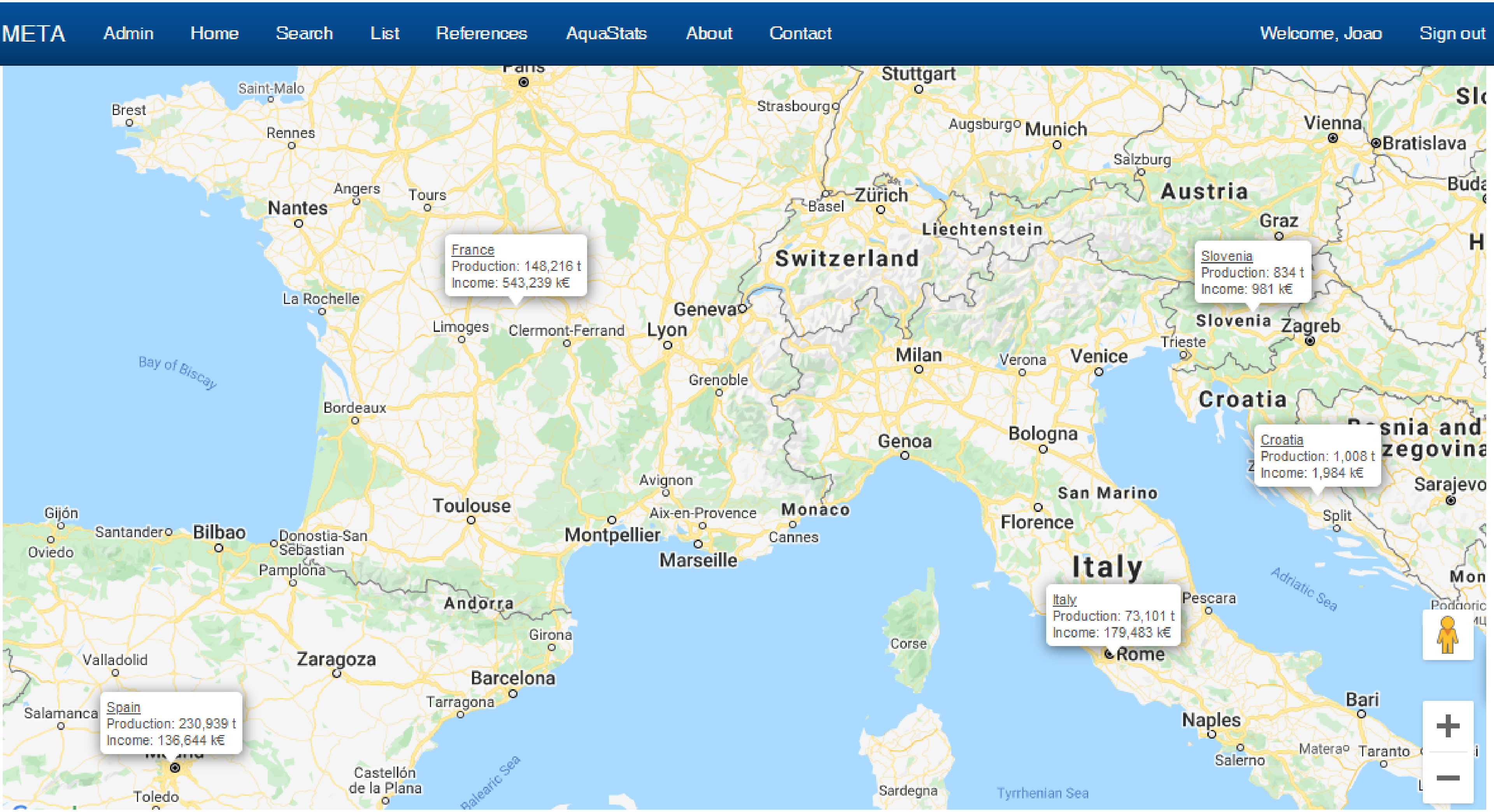
In almost all European waters, the diffuse nitrogen load is higher than point-source discharges.

Nutrient sources and coastal loading in the USA (self-study)

Region and source	Nitrogen 10^3 t y^{-1} (% total)	Phosphorus 10^3 t y^{-1}
NE coast		
Rivers and estuaries	270.0 (40.3)	17.6
Atmospheric	210.0 (31.3)	13.7
SE coast		
Rivers and estuaries	130.0 (19.4)	8.5
Atmospheric	60.0 (9.0)	3.9
Sub-total US east coast	670.0	43.6
Gulf of Mexico		
Rivers and estuaries	2100.0 (88.2)	136.8
Atmospheric	280.0 (11.8)	18.2
Sub-total US Gulf of Mexico	2380.0	155.0
Pacific Northwest		
Point sources	100.9 (21.8)	6.6
Diffuse sources	362.2 (78.2)	23.6
Sub-total US Pacific NW	463.2	30.2
Marine finfish aquaculture	0.9	0.2
Total United States	**3514**	**222.9**

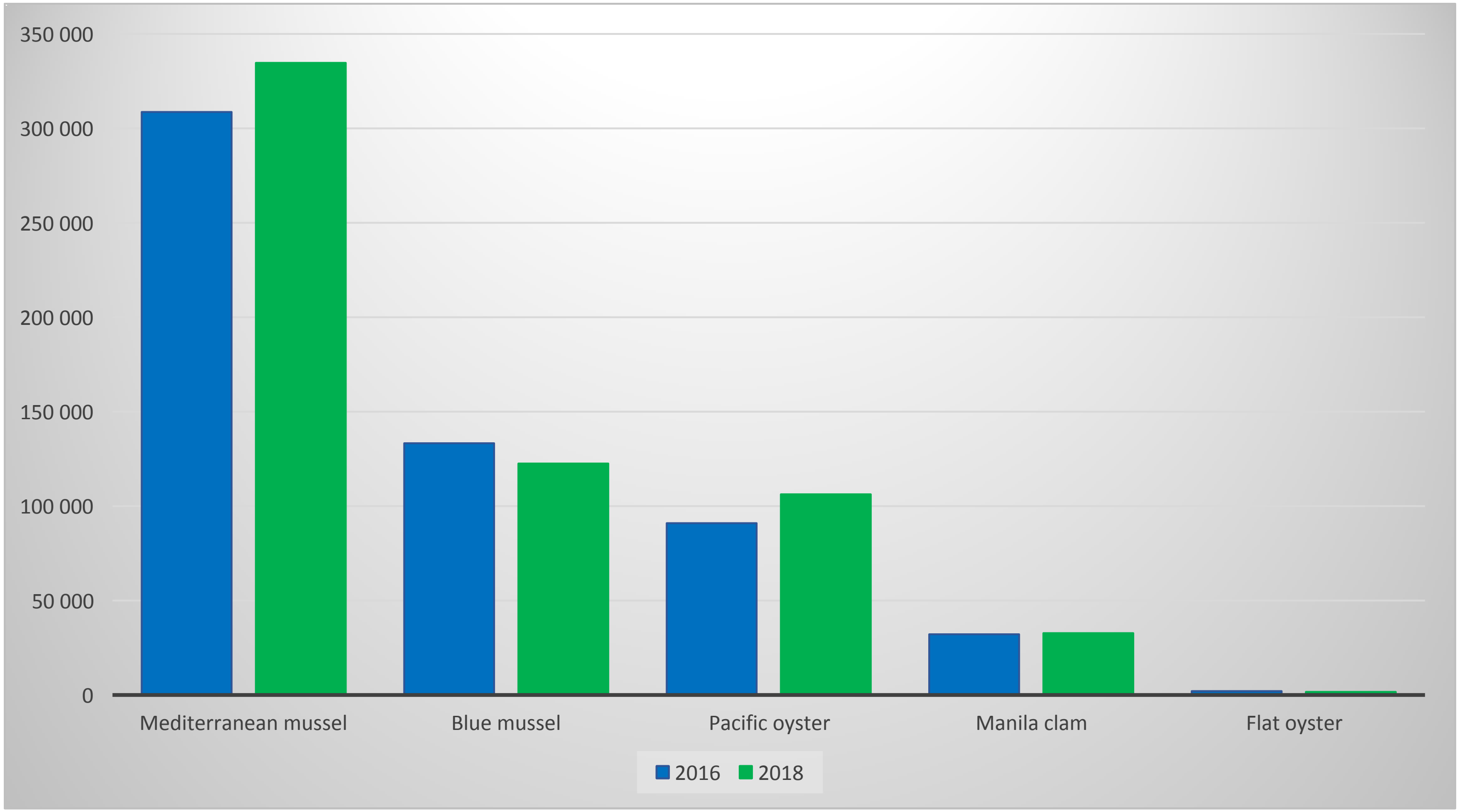
3.5 million tonnes N, i.e. 1065 X 10^6 PEQ, total population: 319 million.

Bivalve production in Europe



The META site at http://longline.co.uk/meta retrieves real-time data on bivalve production from Eurostat.

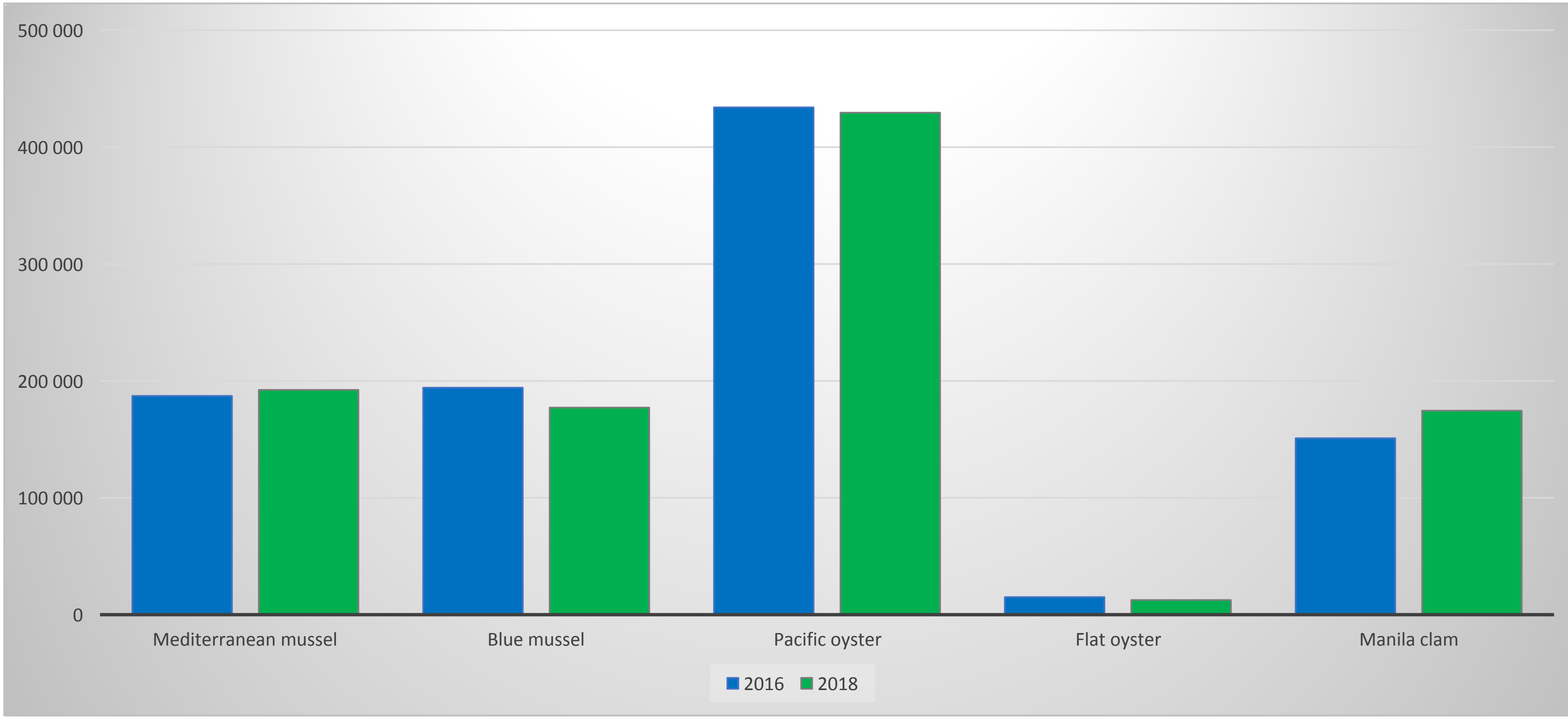
EU shellfish production (t)



- Shellfish production increased by 5.3% between 2016 and 2018
- This was mainly due to the higher production of Mediterranean mussel
- European flat oyster production decreased by roughly 20% - a loss of 421 tonnes
- This species is a valuable niche product, despite not impacting total volume (flat oyster is 3% of oyster production and 0.3% of total shellfish production)

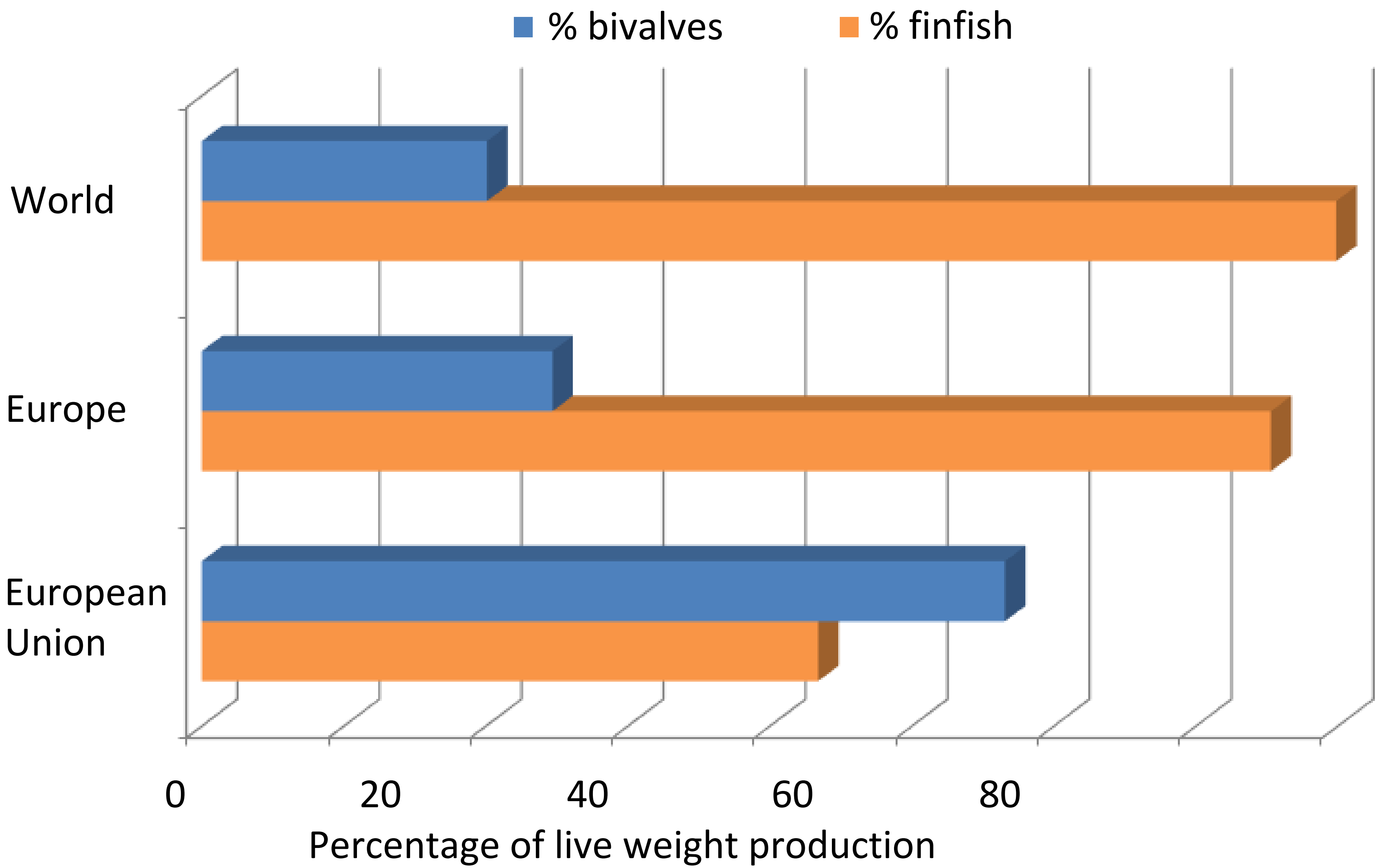
75% of EU farmed shellfish production comes from Mediterranean and blue mussel.

EU shellfish production – value (k€)



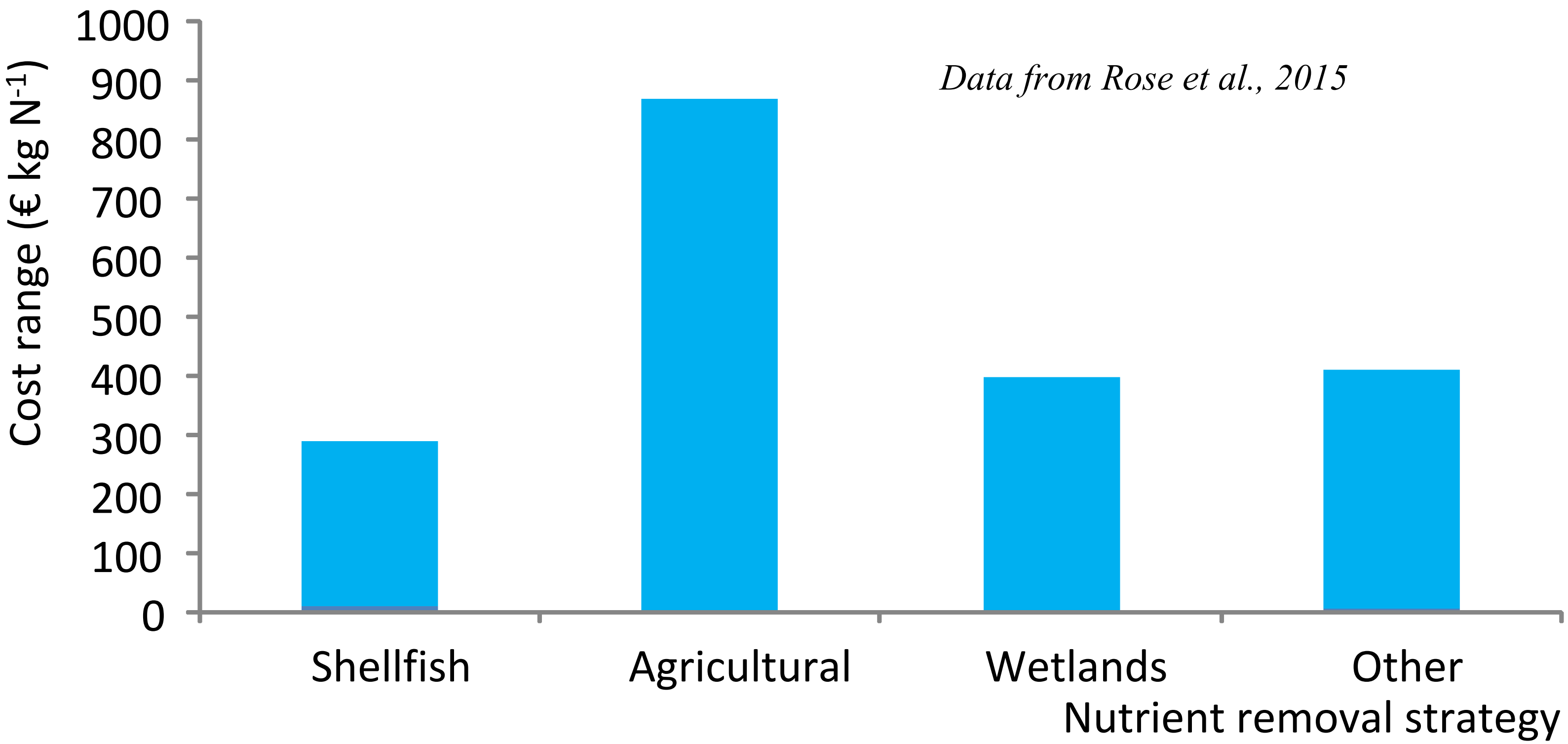
Although most of the volume comes from mussels, oysters are more valuable, and clams also are relatively high value.

Partitioning of aquaculture types in Europe and the world (self-study)



Bivalve aquaculture in the EU is 56% of total production.

Nutrient credit valuation and trading



<u>How much nitrogen do shellfish remove?</u>

Option 1: Calculate removal from nitrogen content of harvested biomass. For a restored, pristine (unexploited) reef, eutrophication-related <u>ecosystem services will be zero</u>

Option 2: Calculate ecosystem services of animals in the water, by modelling the net removal of organic particles, i.e. <u>eutrophication symptoms are not expressed in the water</u>

Modelled ecosystem services (option 2) account for the whole bivalve population's role over the year; typically 2-3X harvest removal in N. Europe & US.

C and N composition – proximate analysis

% of C in Total Fresh Weight (live weight)				
Species	Origin	Min	Mean	Max
Blue mussel	Belfast Lough (NI)	10.1	11.1	14.8
Pacific oyster	Dundrum Bay (NI)	10.8	10.9	11.2
Flat oyster	Lough Foyle (NI)	6.01	8.80	9.97
Mediterranean mussel	Sagres (Portugal)	10.5	10.7	17.4
Manila clam	Venice Lagoon (Italy)	8.15	8.50	11.2
% of N in Total Fresh weight				
Species	Origin	Min	Mean	Max
Blue mussel	Belfast Lough (NI)	0.76	0.88	1.12
Pacific oyster	Dundrum Bay (NI)	0.28	0.37	0.48
Flat oyster	Lough Foyle (NI)	0.19	0.29	0.32
Mediterranean mussel	Sagres (Portugal)	0.96	1.00	1.13
Manila clam	Venice Lagoon (Italy)	0.28	0.32	0.36

This forms the basis for one method of calculation of ecosystem services.

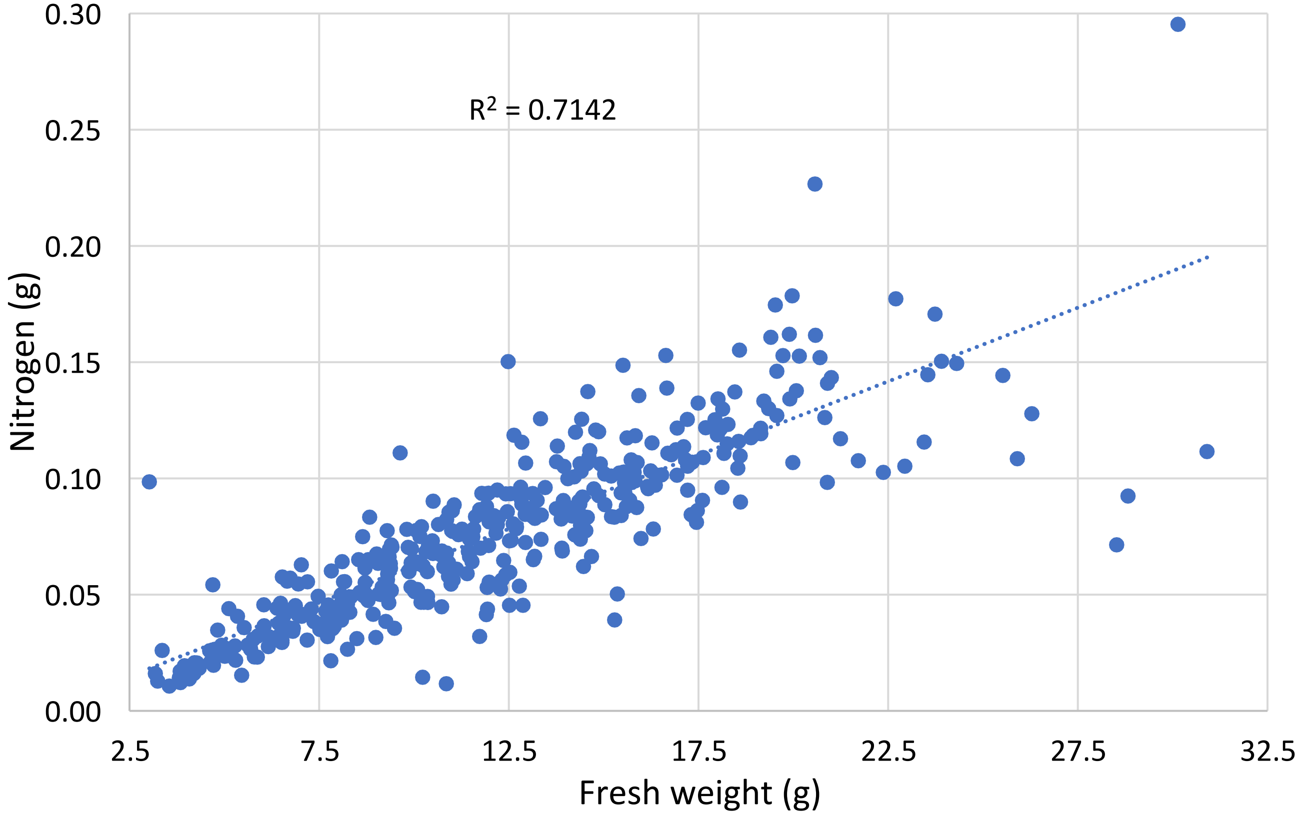
Proximate analysis (self-study)

Proximate analysis for C, N, P burden in blue mussel and Pacific oyster.

Mussels from Belfast Lough n=600, flesh has been analysed for C and N. Shells prepared.

Progress with P protocols with Galway partner, work underway

New data set will be a significant addition to existing literature



Data indicate that the average nitrogen content of blue mussel is 0.6% of total fresh weight.

Individual-based modelling in FARM

- Individual-based models (IBM) are more accurate than the population-dynamics approach historically used in FARM
- This is particularly relevant for (a) a better description of population growth over time; and (b) a better description of environmental effects
- An IBM approach discriminates between net removal of nitrogen through filtration of algae and detritus in both harvested animals and animals below harvest size
- IBM FARM models developed for all key shellfish species grown in Europe: blue mussel, Mediterranean mussel, Pacific oyster, native oyster, and Manila clam
- These models were used for scaling typical farms to European production to estimate net nutrient removal and make management recommendations for a nutrient credit trading framework

IBM models do a better job in simulating growth, harvest, and nutrient dynamics.

EU - Nitrogen removal (tonnes) by bivalves in 2018 determined by proximate analysis and by the FARM model

	Blue mussel	Mediterranean mussel	Pacific oyster	Flat oyster	Manila clam	Total
UK	125-135					125-135
Netherlands	398-430			0.94		399-436
France	386-417	47.3-77.2	338.7-1158	1.87	2.83	777-1687
Ireland	122-131		31.1-106	0.73		153-242
Spain		2426-3955		0.98	2.77	2430-2985
Italy		614-1001			99.1	713-1859
Others	43-46	258-422	23.8-81.2	0.27		325-549
Total EU-28 production	1073-1159	3346-5454	393.5-1345	4.79	104.7	4 922-8893

FARM model estimates given only for major production (mussels and Pacific oysters) and for total removal.

Valuation of regulatory services using chlorophyll

$$\frac{dB}{dt} = P - G_s - G_z - M + \text{advection} \quad \& \text{ dispersion}$$

- Phytoplankton biomass in the water column depends on several factors;
- Local-scale models such as FARM and ABC cannot address the connection between an aquaculture farm and broader-scale, system-wide chlorophyll drawdown;
- An ecosystem model is well suited to this task, but the framework must include the catchment component;
- We are applying such a framework in Lough Foyle, a cross-border Irish estuary, in the Shared Waters Enhancement and Loughs Legacy (SWELL) project.

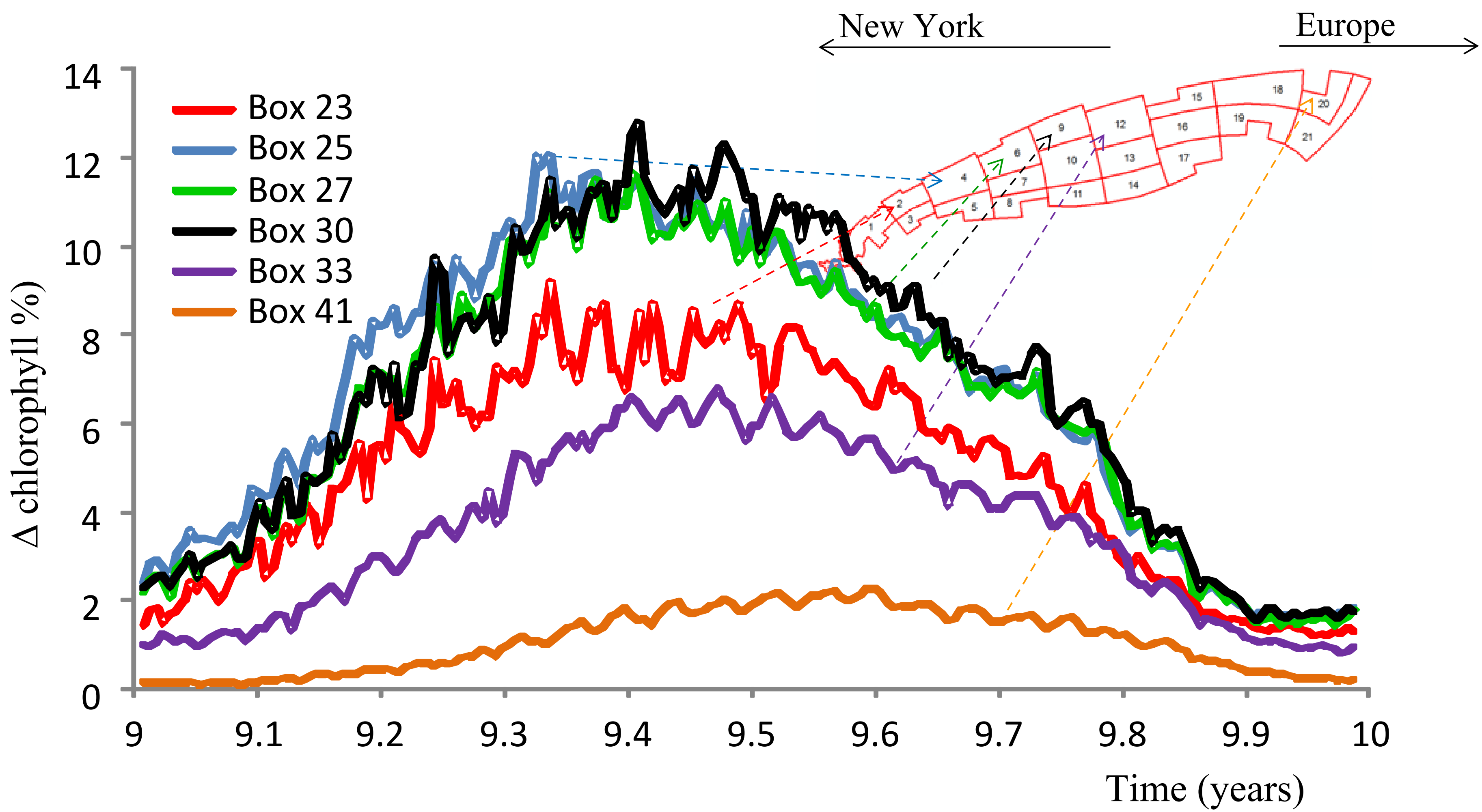
Valuation of chlorophyll drawdown can be estimated by comparing shellfish chlorophyll removal to bottom-up control of primary production.

Beyond nutrient valuation methods (self-study)

- US approach uses BMPs (e.g. for Chesapeake Bay), and tissue content of N at harvest (1% TFW is commonly used);
- If the regulatory service is only determined at harvest, then restored reefs (undisturbed) do not provide a nutrient services;
- Eutrophication control is focused on symptoms—nutrient concentrations are not a symptom (*sensu* ASSETS);
- Nutrient loads are a causative factor (*sensu* ASSETS);
- The WFD, MSFD and US legislation focus more on ecological indicators, such as phytoplankton abundance, biomass, and composition, and less on chemical indicators.

An evaluation of regulatory services directly linked to eutrophication is more ecologically relevant to comparing nutrient loads and nitrogen removal.

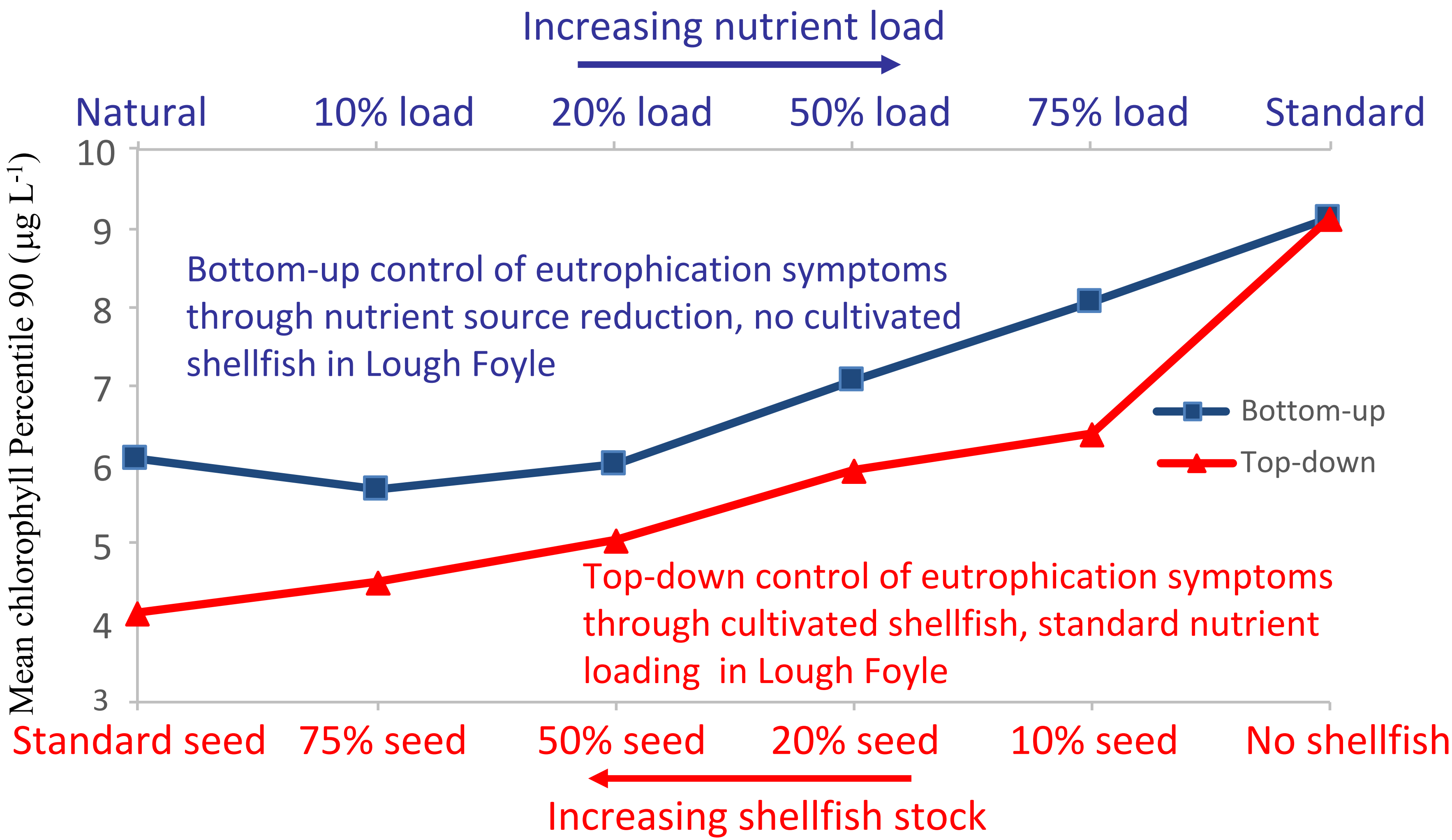
EcoWin.NET Long Island Sound Model
Phytoplankton drawdown – standard model



The strongest drawdown (close to12%) is in box 30 (below box 9), followed by boxes 25 and 27 with a maximum of about 10%.

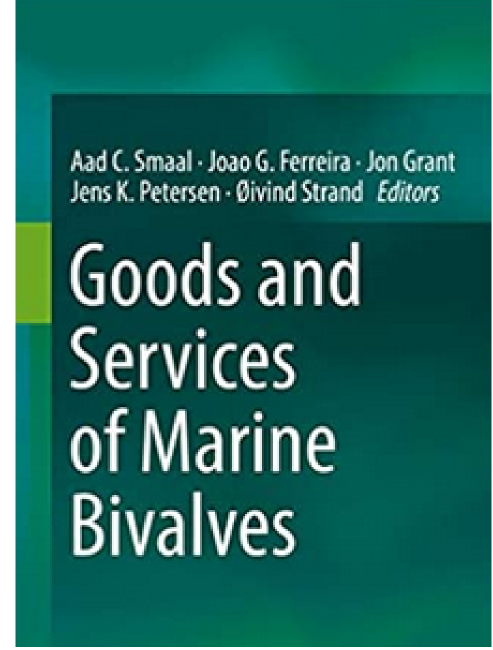
EcoWin.NET Lough Foyle Model (self-study)

Chlorophyll drawdown with bottom-up and top-down control



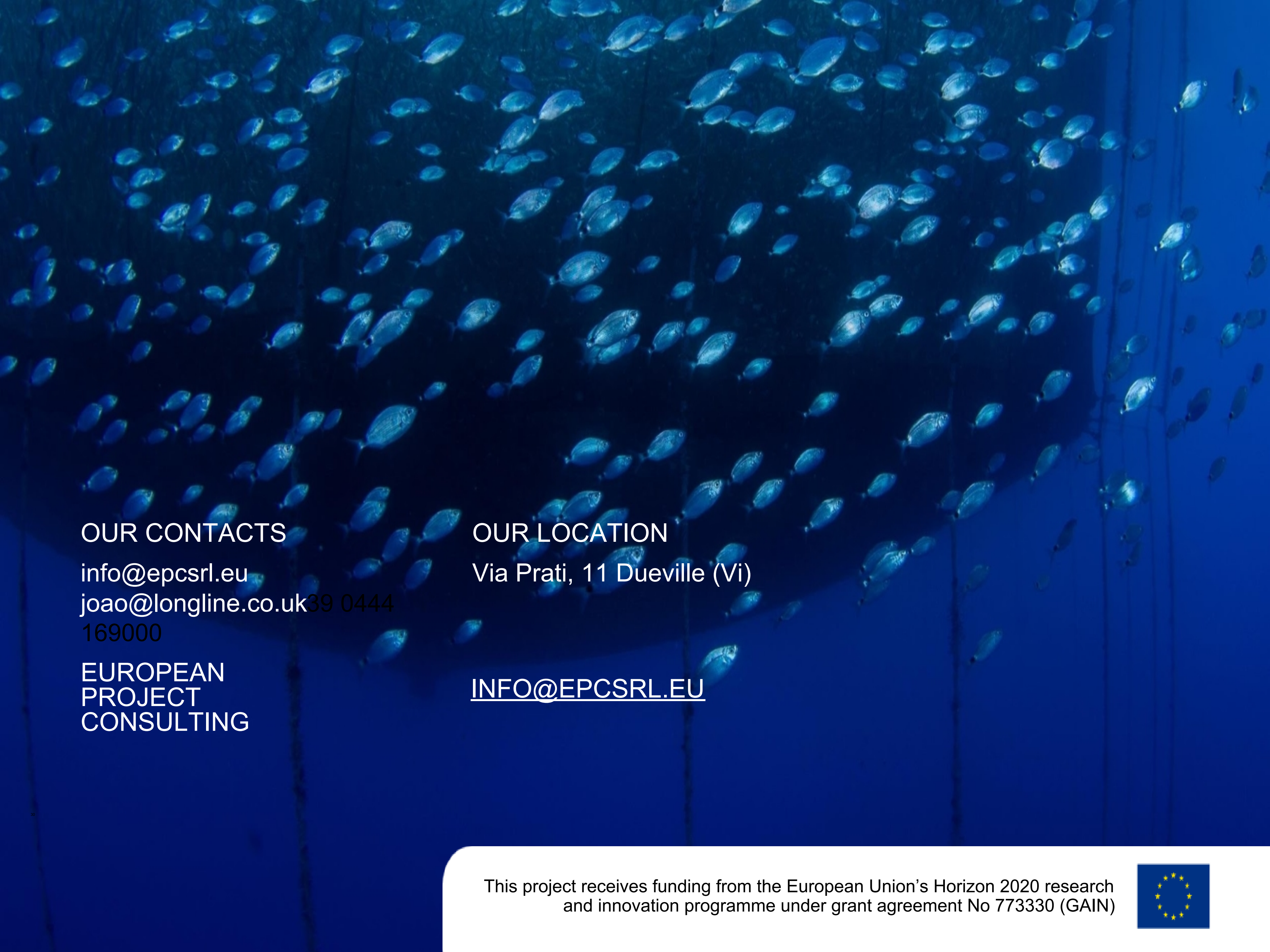
Shellfish culture outperforms source control in controlling eutrophication symptoms, and provides an additional provisioning service.

Conclusions



- Policy-makers must recognize that bivalve aquaculture should be an integral part of the nutrient economy in watershed management;
- In parts of China and Southeast Asia, shellfish can offset a significant proportion of nutrient loads, due to the high culture density and areal coverage;
- In the West, top-down control of eutrophication by shellfish clearly should not replace source control, which is entirely appropriate, not least because of moral hazard;
- The combined modelling approach used in this work suggests that in Europe, shellfish aquaculture removes between 5 and 16 tons of nitrogen per year, with a value between 18 and 30 billion euros;
- Models can make an important contribution to valuation of the role of shellfish in potential nutrient credit trading frameworks – these frameworks are incipient in Europe, but are already well-developed in the United States.

https://www.gain2020.com/credi



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Screenshot of the HYPE model