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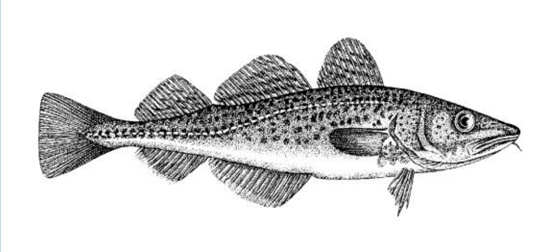
Interreg
Northern Ireland - Ireland - Scotland
European Regional Development Fund



Fisheries and Aquatic Ecosystems Branch

Mission: ***To carry out R&D, monitoring and technology transfer, in support of sustainable management of fisheries and aquatic resources in N. Ireland.***

Shellfish Aquaculture and the Environment

Catchment Investigations & Modelling

The Shellfish Industry in Northern Ireland

In 2016, the aquaculture sector produced 3,438 tonnes of shellfish valued at £4.3 million

46 sites are licensed for the cultivation of shellfish

The main shellfish species cultivated are Mussels and Pacific Oysters.

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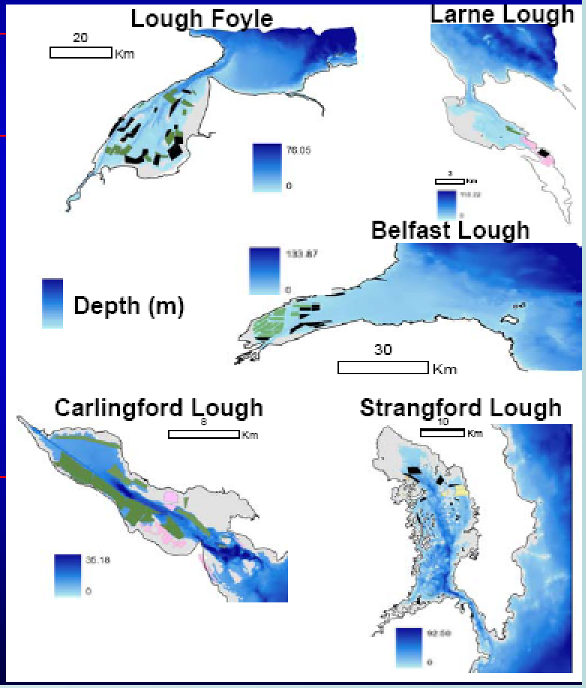
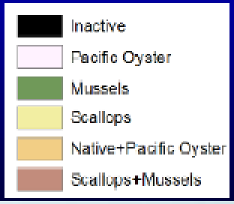
SMILE Loughs - Aquaculture areas (ha)

Lough	Lough area	Mussel area	Oyster area	% of Lough
Foyle	18600	1602.9	0.07	8.6
Larne	800	10.4	59.9	8.8
Belfast	13000	952.6	---	7.3
Strangford	14900	5.9	23.5	0.2
Carlingford	4900	867.5	197.8	21.7
Only NI		167.9	83.2	5.1





Though Lough Foyle has a greater aquaculture area, in Carlingford Lough a higher percentage of the system is occupied by aquaculture.

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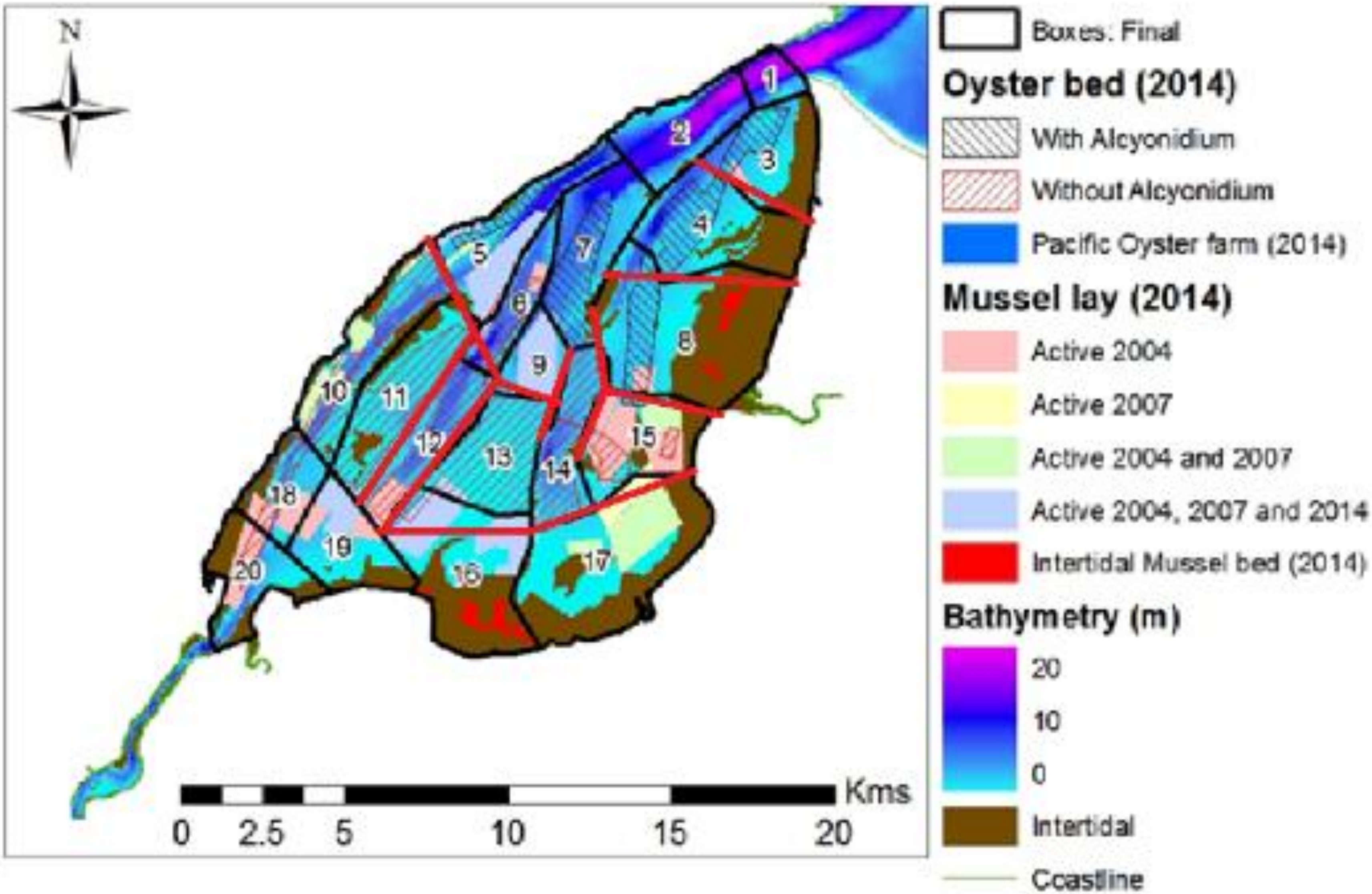
Lough Foyle – EASE



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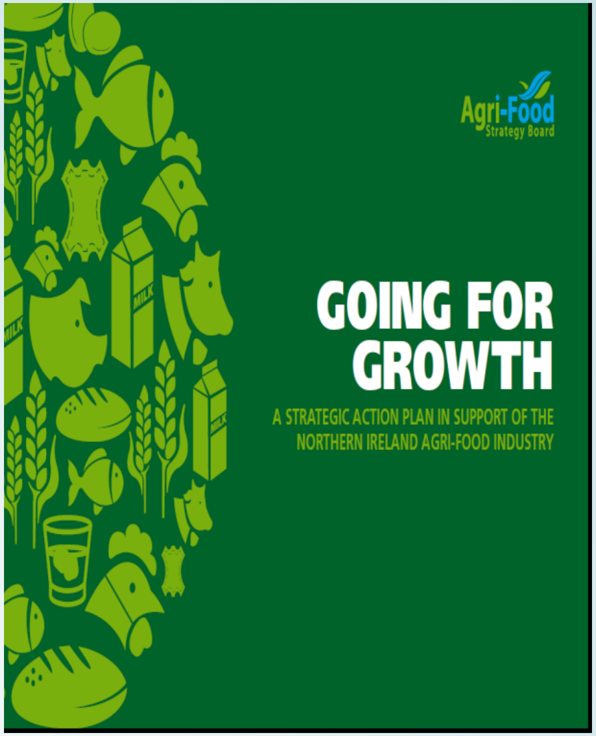
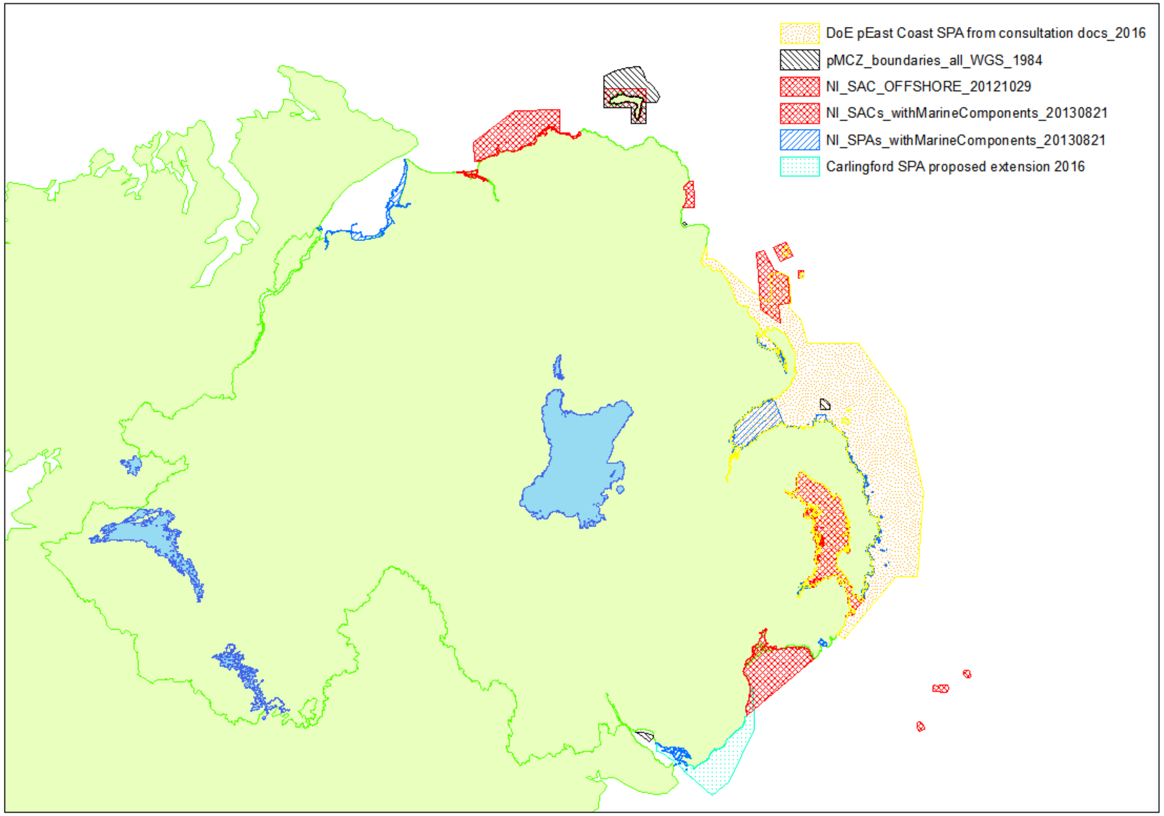
Aquaculture



- Regulatory
- Water Quality
- Access must be facilitated to sites, and opportunities fostered for the sustainable development of aquaculture both offshore and along the Northern Ireland coastline, e.g. By providing access to seed and grow mussels and oysters,:
- to maximise the opportunities presented by the harvesting of seaweed;
- Potential sources of EU funding must be identified which could be used to support the catching, processing and aquaculture sectors;

Habitats Regulations Assessments

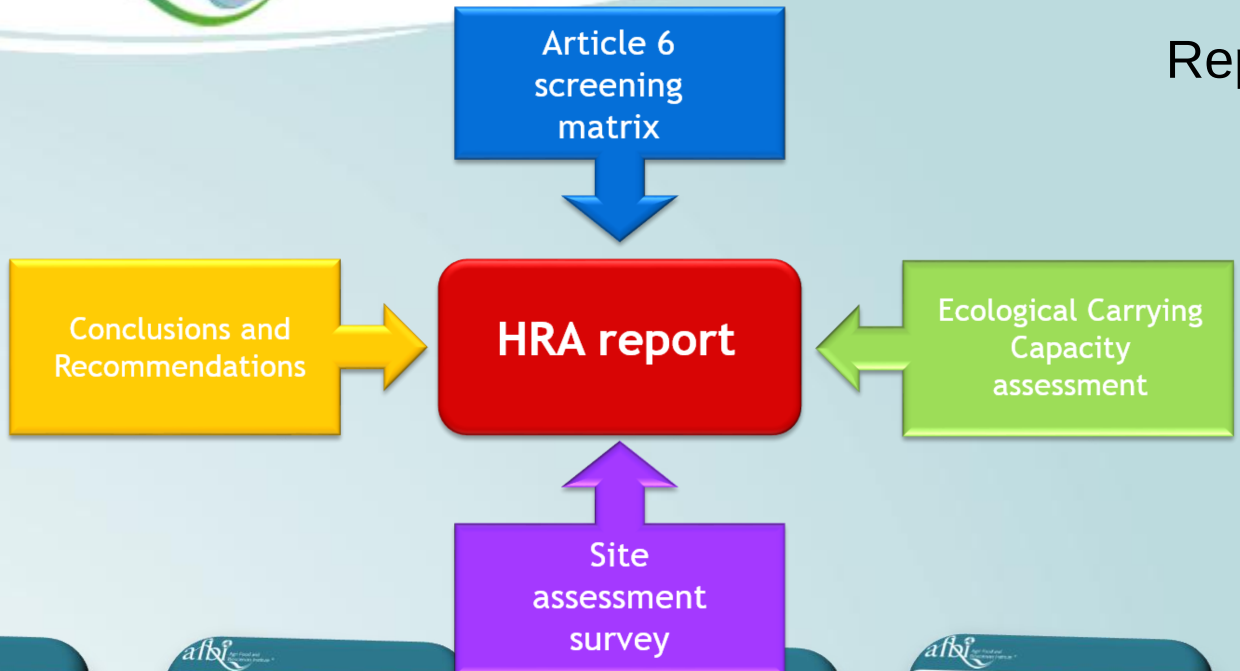
AFBI activity code: 42098



European Council Directive 92/43/EEC (**Habitats Directive**) and European Council Directive 2009/147/EC (**Birds Directives**) were developed with the aims of **protecting habitats and species** considered to be of European interest.

Member states designate sites as Special Areas of Conservation (**SAC**) for the protection of **habitats and species** and Special Protection Areas (**SPA**) for the protection of **wild birds.**

Report Production



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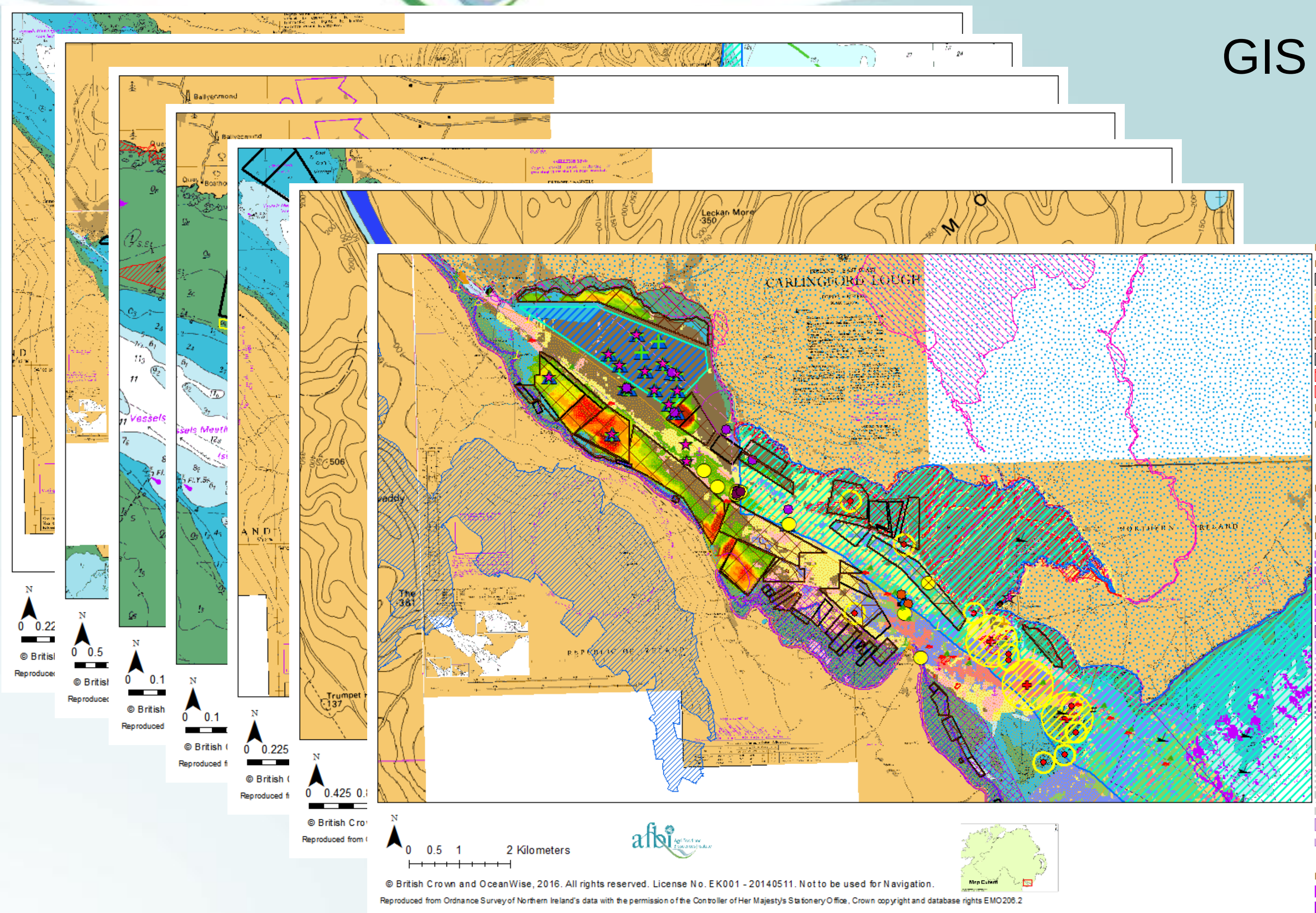
GIS spatial Assessment



Decision Support Tool for Aquaculture management

Can be used to underpin HRA and ASSI assessments

The central goal of the *AquaSpace* project is to provide increased space of high water quality for aquaculture by adopting the Ecosystem Approach to Aquaculture (EAA) using Marine Spatial Planning (MSP) to deliver food security and increased employment opportunities through economic growth

HORIZON 2020

AquaSpace

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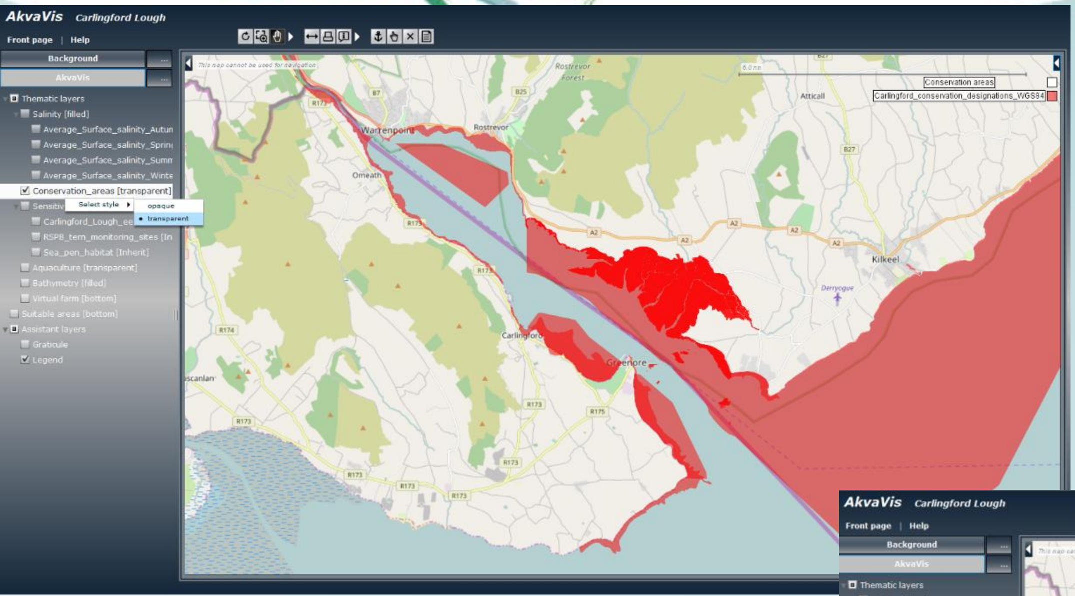
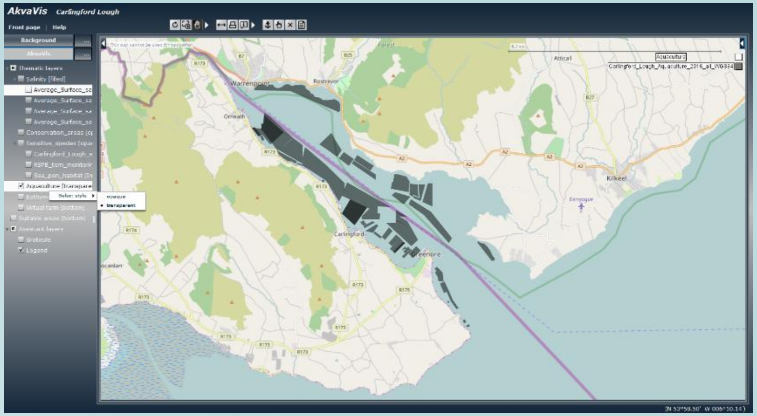
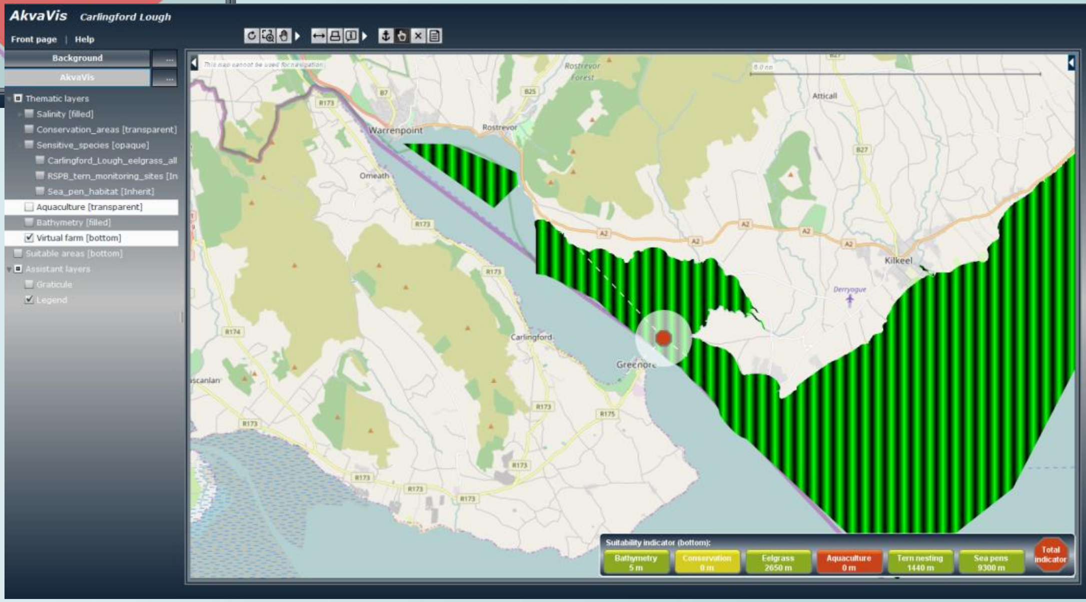






Web-based GIS decision support/risk assessment tool

HORIZON 2020

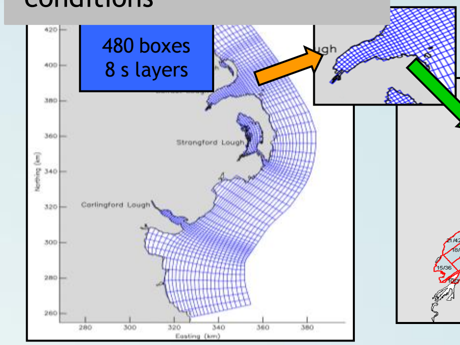
AquaSpace

Sustainable Mariculture in northern Irish Lough ecosystems (SMILE) model

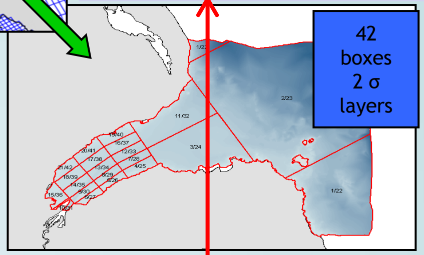
Fine scale hydrodynamics
Fluxes, boundary conditions

EcoWIN.net
Ecological Model
System scale

Individual growth model



Delft3D Hydrodynamic model



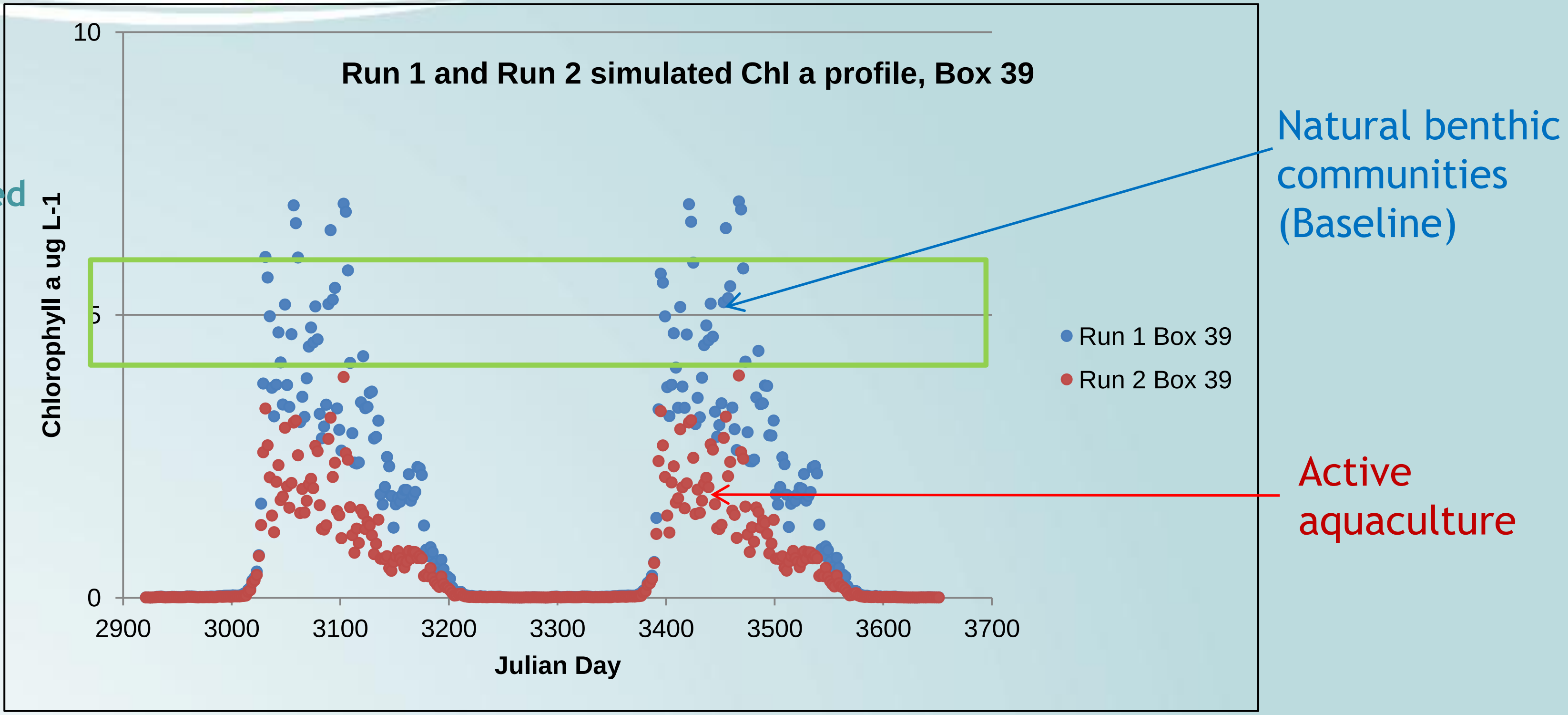
EcoWin ecological boxes

Real time feeding experiments, measure feeding rate – affect of temp & food availability

Measured environmental drivers (survey, moorings)
Shellfish growth trials

Ecosystem health

Chlorophyll a (Chl a) was used as a proxy for phytoplankton biomass



Mussel feeding provides a valuable ecosystem service, reducing Chl a levels and **suppressing eutrophication** during summer months.

Ecosystem Services

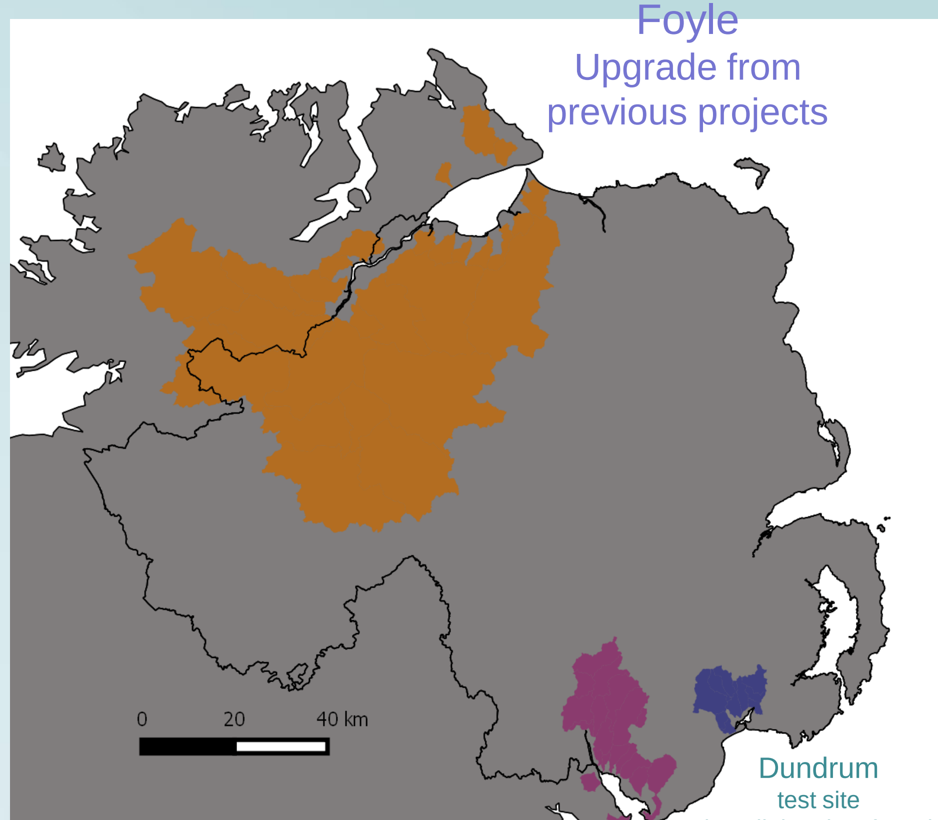
MSFD aims to achieve Good Environmental Status (GES) of the EU's marine waters by 2020. It is the first EU legislative instrument related to the protection of marine biodiversity, as it contains the explicit regulatory objective that "biodiversity is maintained by 2020", as the cornerstone for achieving GES.

Water Framework Directive (2000/60/EC) mandates that the biological quality element (BQE) phytoplankton abundance, biomass, and composition (ABC) must be at Good or High Status. Shellfish aquaculture can assist in organic extraction for top-down control of eutrophication.

Modelling catchment loads to coastal systems

Objective – assess terrestrial loads:

- Water
- Particulate matter
- Nutrients (N&P)
- Bacteria



Modelling catchment loads to coastal systems

Drainage Area Model

Sewage outfall

Direct discharges

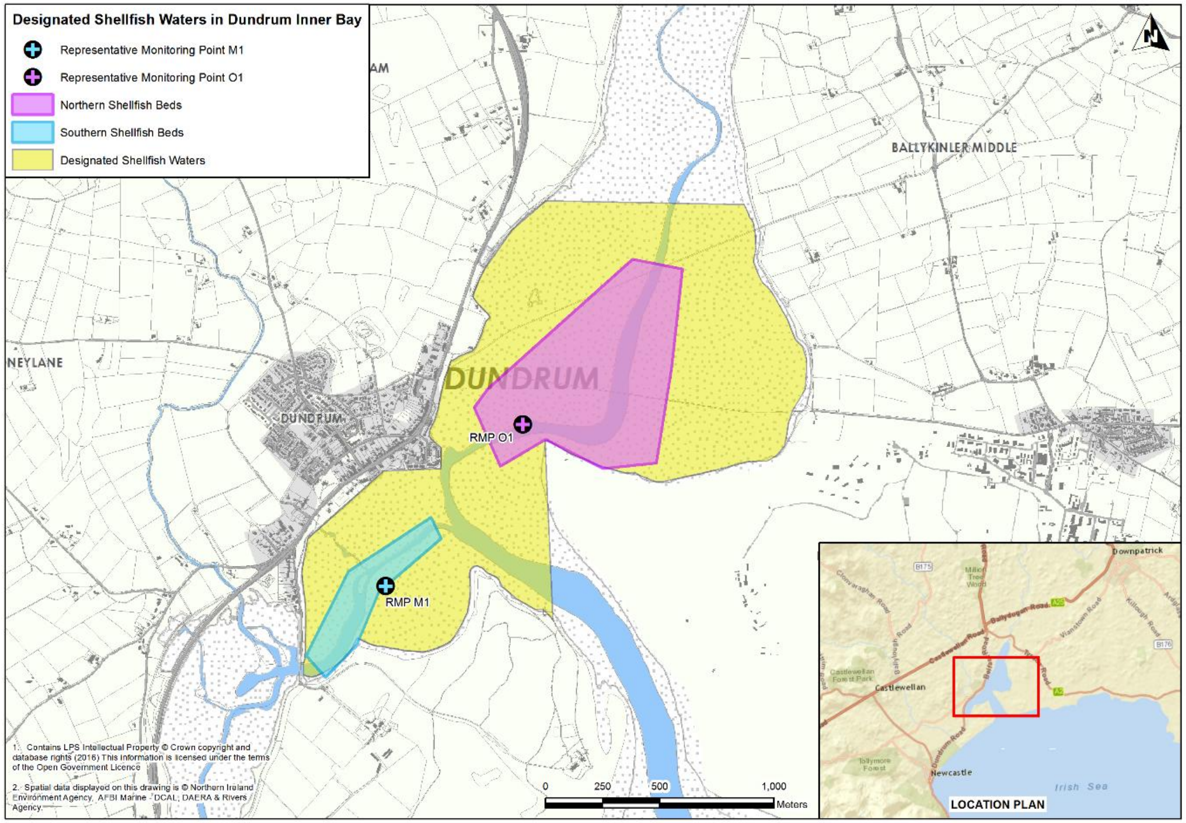
Objective – assess terrestrial loads:

- Water
- Particulate matter
- Nutrients (N&P)
- Bacteria

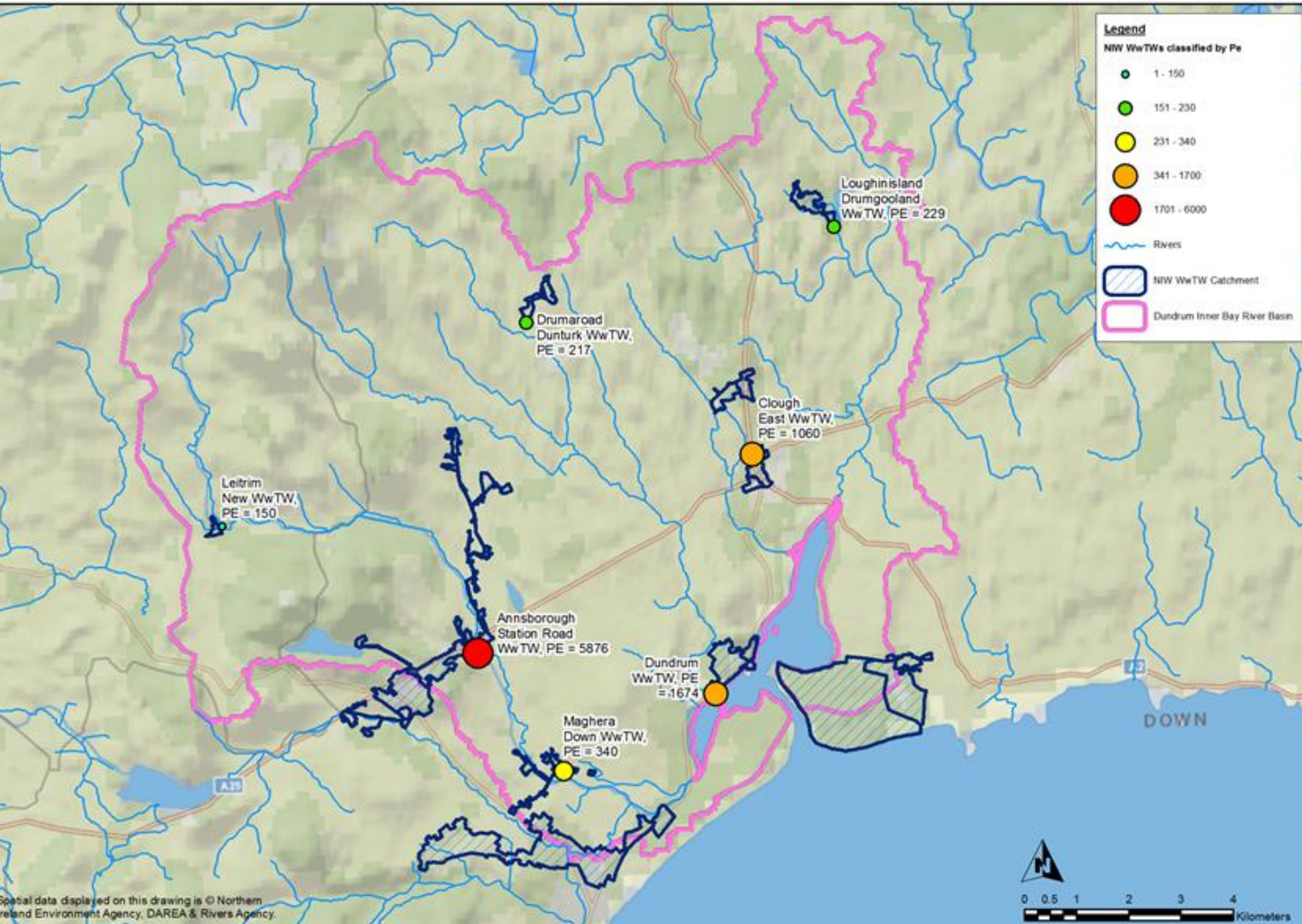
Diffuse pollution

Eco-Hydrological Model

CASE Study 1
Inner Dundrum Bay



- Food Standards Agency (FSA) Food Hygiene Regulations (FHR) compliance testing for microbial levels within shellfish flesh at Inner Dundrum Bay showed elevated levels in the late summer and early autumn testing periods. There was a reported deterioration in water quality within the bay which warranted further investigation.



Legend
NIW WwTWs classified by Pe
1 - 150
151 - 230
231 - 340
341 - 1700
1701 - 6000
Rivers
NIW WwTW Catchment
Dundrum Inner Bay River Basin
Loughinisland Drumgooland WwTW, PE = 229
Drumaroad Dunturk WwTW, PE = 217
Clough East WwTW, PE = 1060
Leitrim New WwTW, PE = 150
Annsborough Station Road WwTW, PE = 5876
Dundrum WwTW, PE = 1674
Maghera Down WwTW, PE = 340
DOWN
A25
A2
0 0.5 1 2 3 4 Kilometers
Spatial data displayed on this drawing is © Northern Ireland Environment Agency, DAREA & Rivers Agency.

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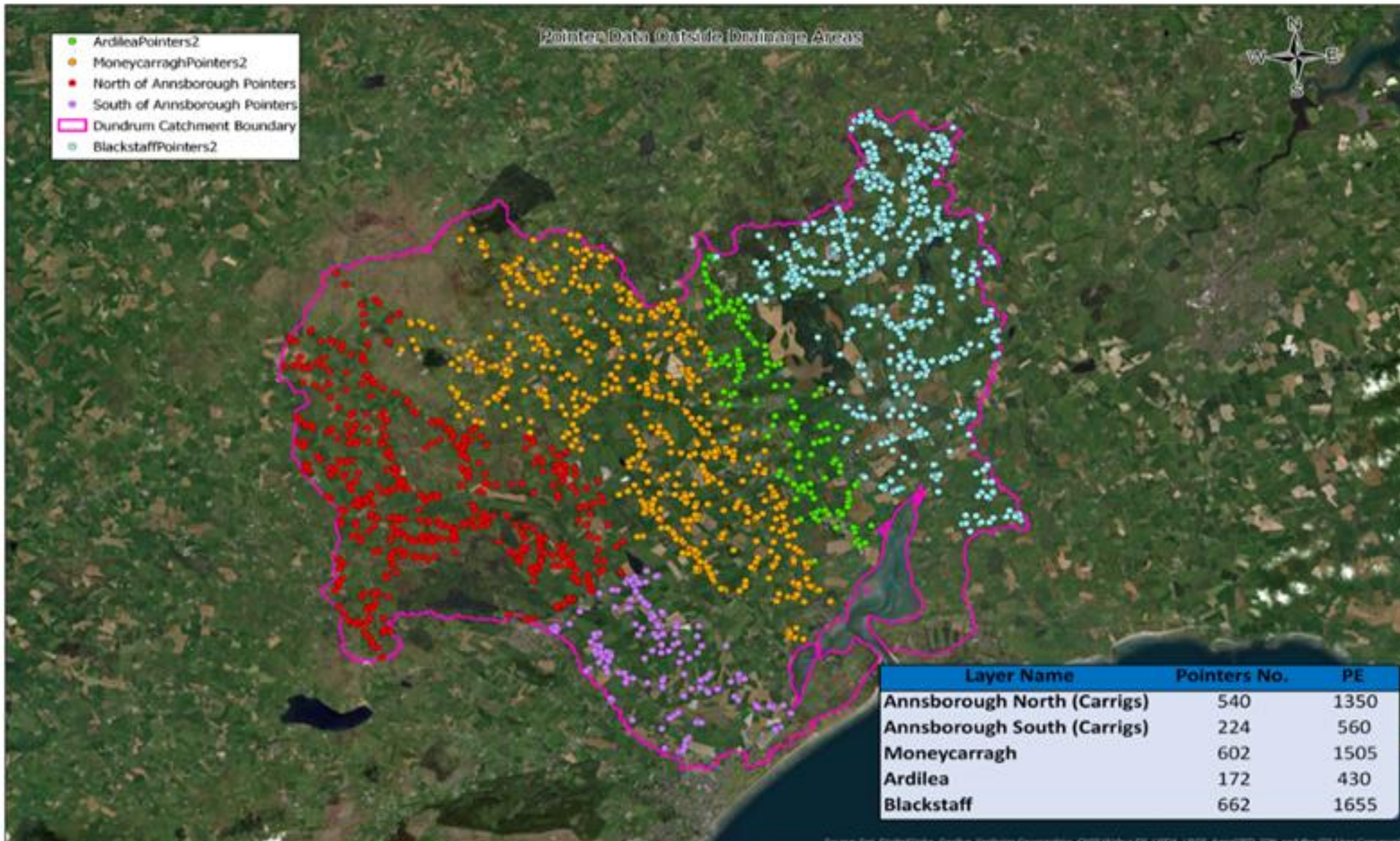
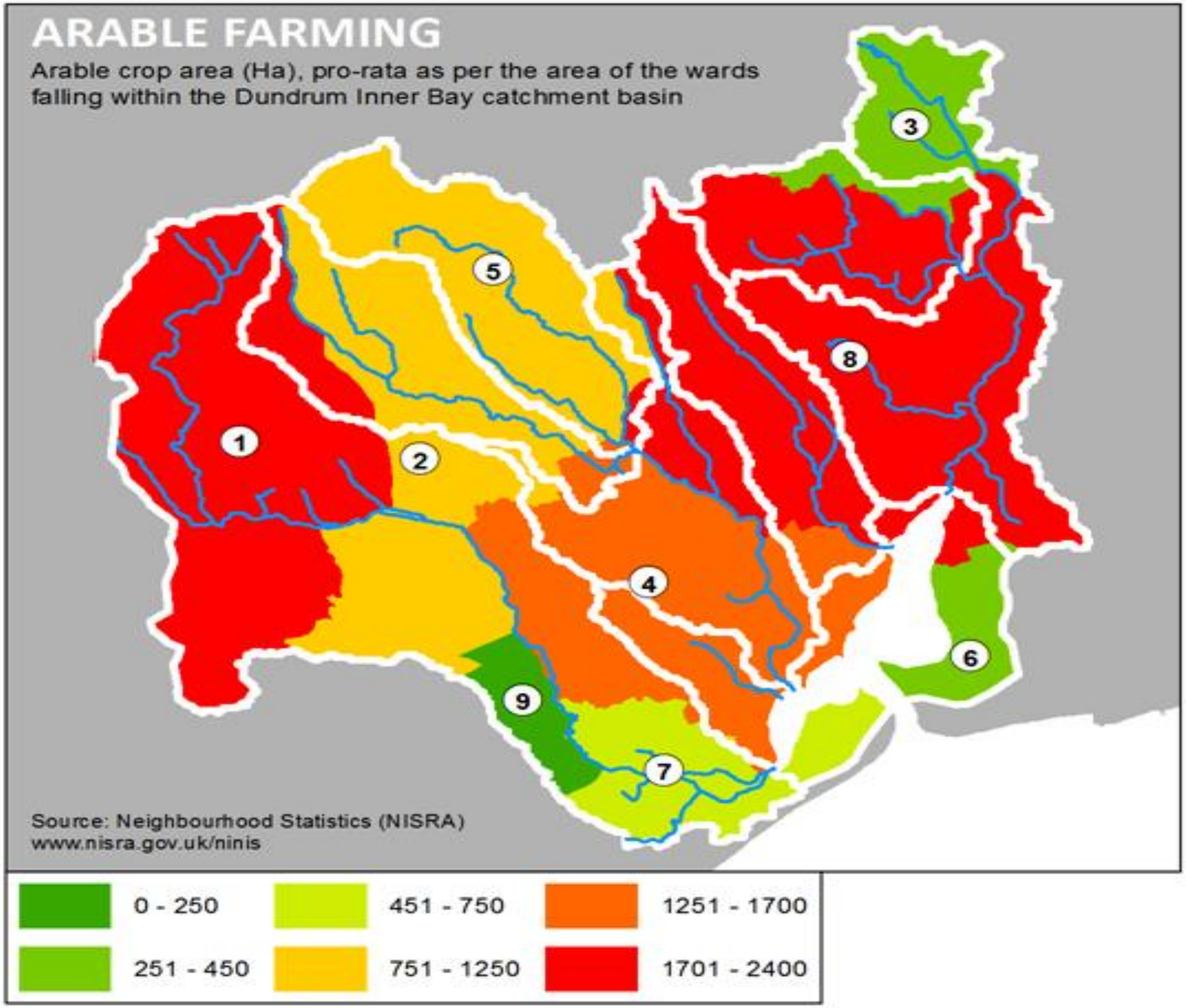
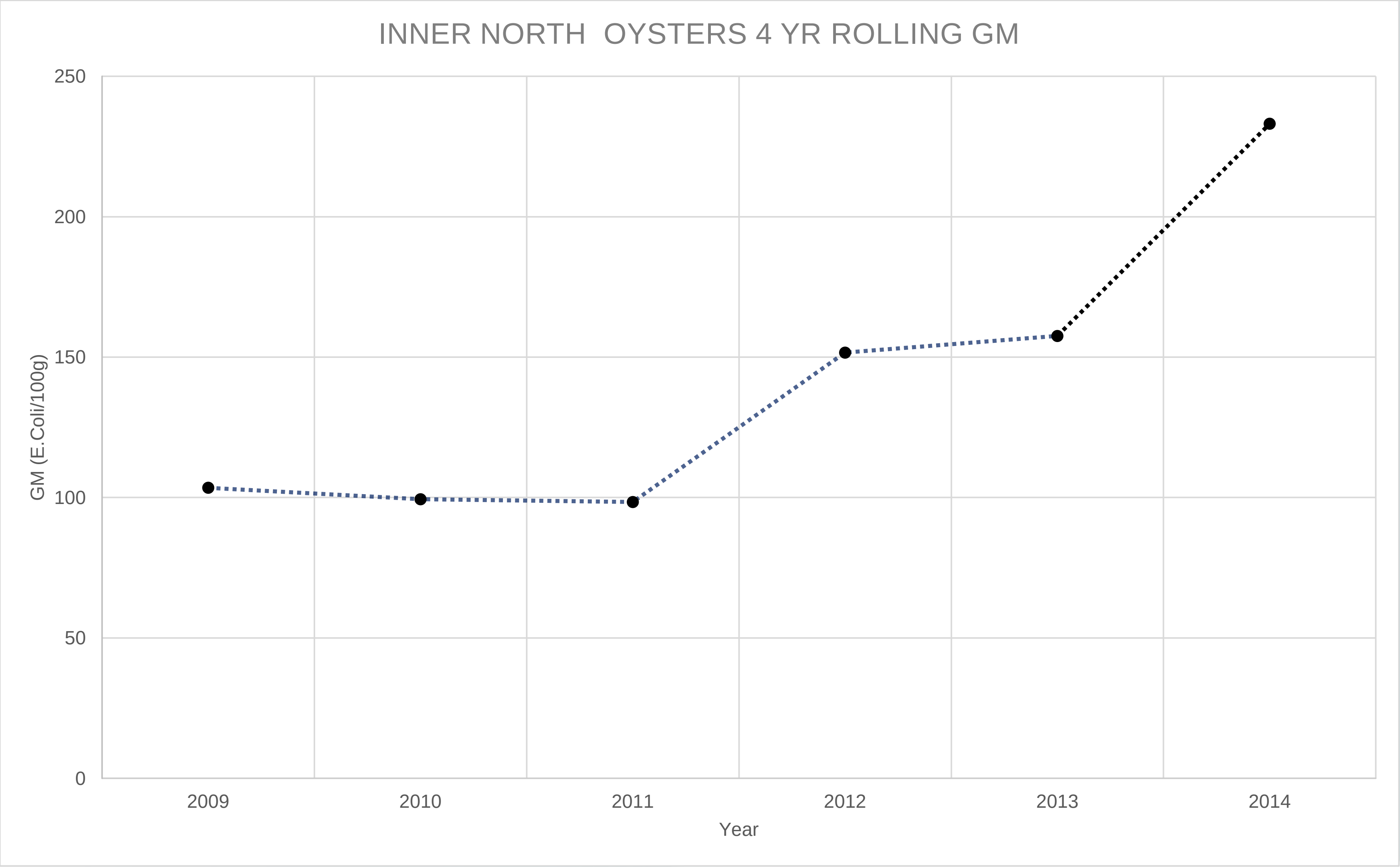


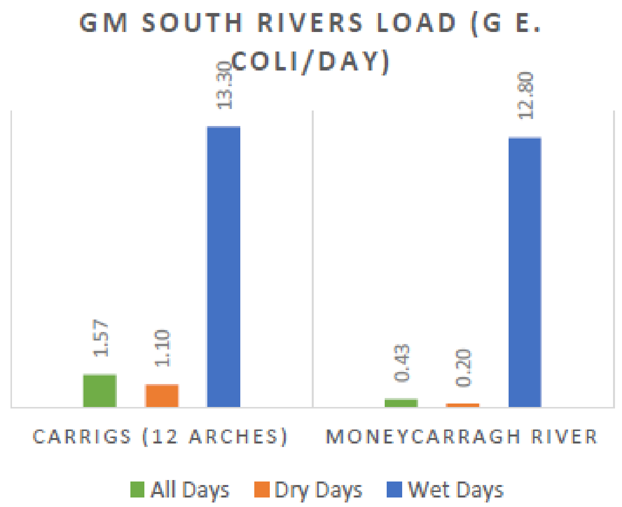
Layer Name	Pointers No.	PE
Annsborough North (Carrigs)	540	1350
Annsborough South (Carrigs)	224	560
Moneycarragh	602	1505
Ardilea	172	430
Blackstaff	662	1655

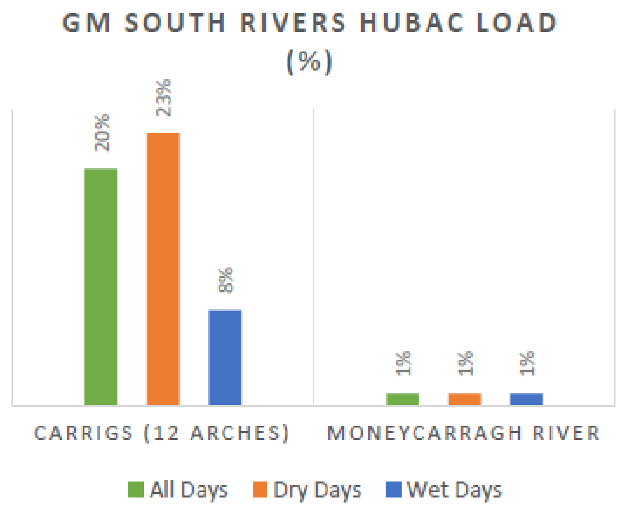


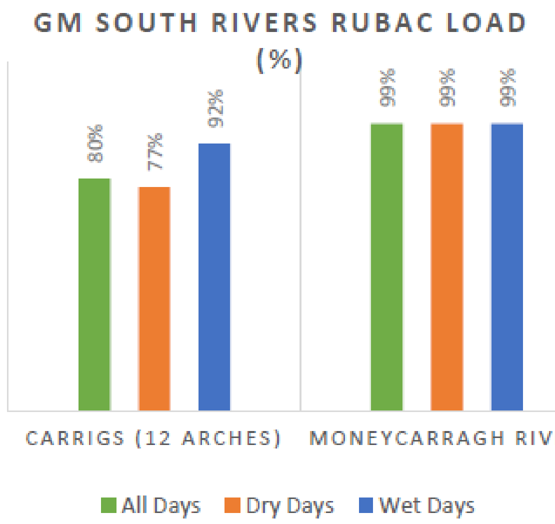
ARABLE FARMING
Arable crop area (Ha), pro-rata as per the area of the wards falling within the Dundrum Inner Bay catchment basin
1
2
3
4
5
6
7
8
9
Source: Neighbourhood Statistics (NISRA)
www.nisra.gov.uk/ninis
0 - 250
251 - 450
451 - 750
751 - 1250
1251 - 1700
1701 - 2400


INNER NORTH OYSTERS 4 YR ROLLING GM
GM (E.Coli/100g)
250
200
150
100
50
0
2009
2010
2011
2012
2013
2014
Year

Inner South Rivers - E.coli & MST Load

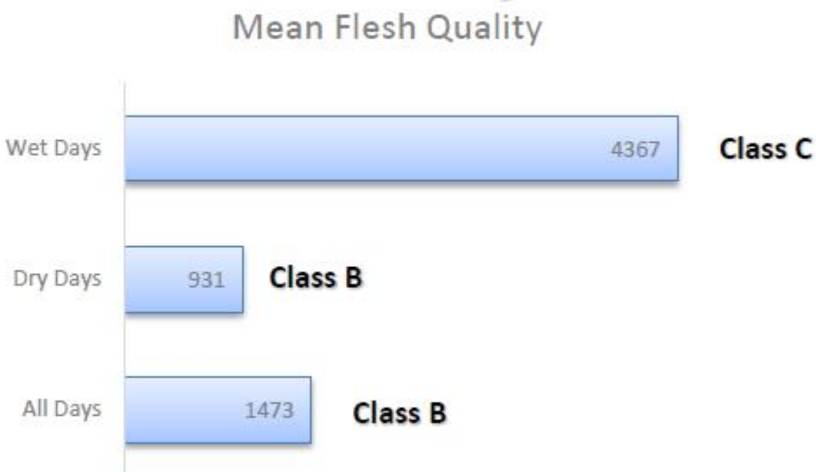


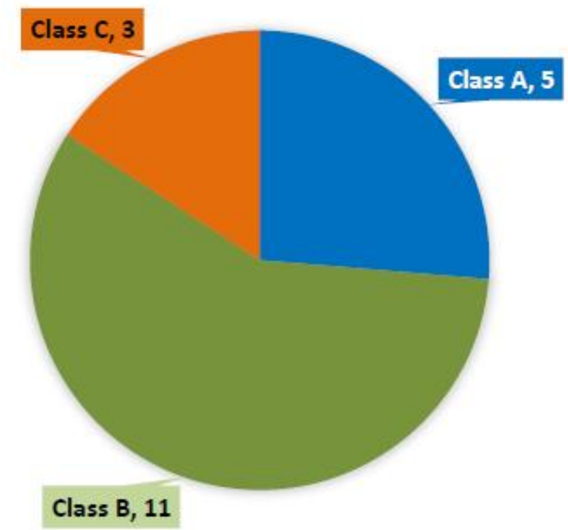




Date	Flesh	Dundrum WwTW	Flynns WwPS	Carrigs (12 Arches)	Moneycarragh River
23rd August	54,000	0%	0	74%	26%
4th September	54,000	0%	<0.4%	64%	36%
21st September	24,000	0%	<0.3%	18%	82%

Inner North Oyster Flesh Results





Generally Good Quality

Worst Result:

- 4th Sept 4,900 *E. coli*/100g

Asset	Geo. Mean Treated Flow (m^3/day)	Max. Treated Flow (m^3/day)	WOC FFT (m^3/day)	Geo. Mean Treated Conc. (E.coli/100mls)
Dundrum WwTw	363	726	953	7
Murlough WwTW	124	161	196	1.0×10^4
nnsborough WwTW	1711	2765	2738	3.3×10^4

te: All flow passed to Dundrum WwTW
m Flynn's WwPS was treated.

	Faecal production (g/day)	Average number (E.coli/g)	Daily load (E.coli)	Rank
Man	150	13×10^6	1.9×10^9	5
Cow	23600	0.23×10^6	5.4×10^9	3
Sheep	1130	16×10^6	18.1×10^9	1
Chicken	182	1.3×10^6	0.24×10^9	6
Hog	2700	3.3×10^6	8.9×10^9	2
Gull	15.3	131.2×10^6	2×10^9	4

: Daily E.Coli loading

Microbial Source Tracking

- Bacteroidetes is an anaerobic bacteria used as a surrogate for differentiation between different sources of Faecal Indicator Organisms (FIOs).
- Bacteroidetes are abundant gut bacteria excreted by most animal species of concern.
- Genetic markers, derived from small segments of the DNA sequence of Bacteroidetes, are specific to the type of animal in whose gut the Bacteroidetes reproduce.
- These may be enumerated are counted as gene copy numbers using a molecular microbiological technique called qPCR (quantitative Polymerase Chain Reaction).

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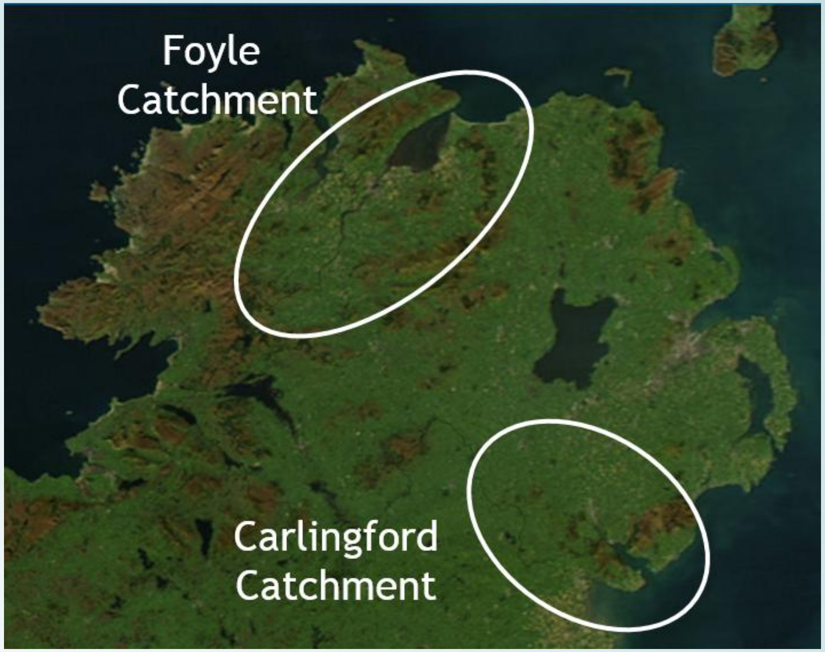
- Integrated Catchment Management is required to properly manage resources

Case Study 2
SWELL Project Summary



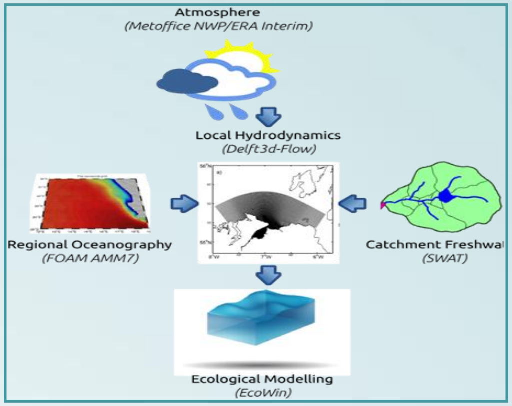
Project Budget

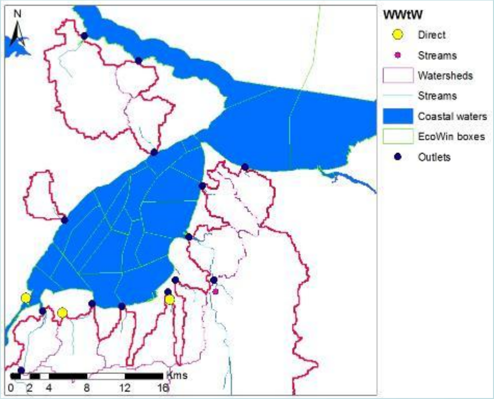
- **SEUPB Funding - €30M (85%)**
- **NIW / IW Funding - €5.29M (15%)**
- **Total Project - €35.29M**
  - **Phase 1 - €3.3M**
  - **Phase 2 – €32.0M**

Outputs

- **Ecosystem Models**
- **Upgraded Wastewater Assets**
- **Improved WFD Water Quality**

Objective

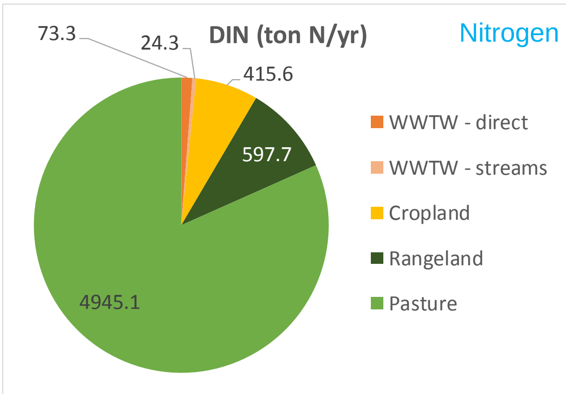


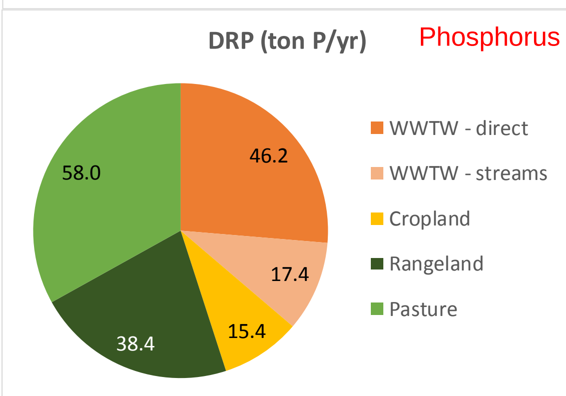


- Examine the interactions between catchment-scale pressures such as nutrient discharge, which are linked to urban and agricultural drivers
- Consider provisioning services (i.e. goods), as well as regulatory and support services (i.e. environmental benefits).
- Apply catchment models to take advantage of the full range of ecosystem services supplied by bivalve filter-feeders including the holistic management of potential eutrophication symptoms

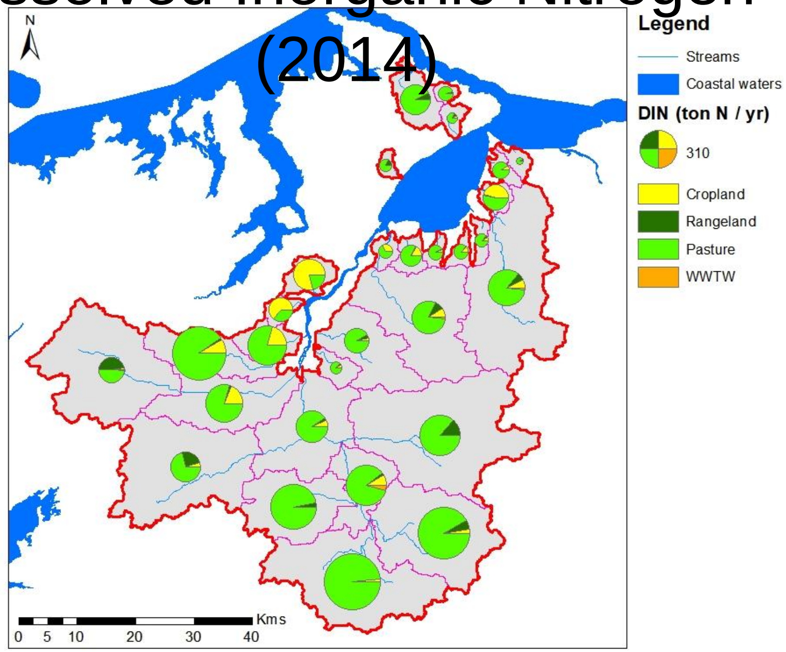
Results: source apportioning

Nutrient loads to Lough Foyle (2014)





Terrestrial sources of Dissolved Inorganic Nitrogen (2014)



Ongoing work:

- Determine for Carlingford Lough
- Update for recent years
- Determine sources of bacteria

Regulatory Ecosystem Services of Shellfish

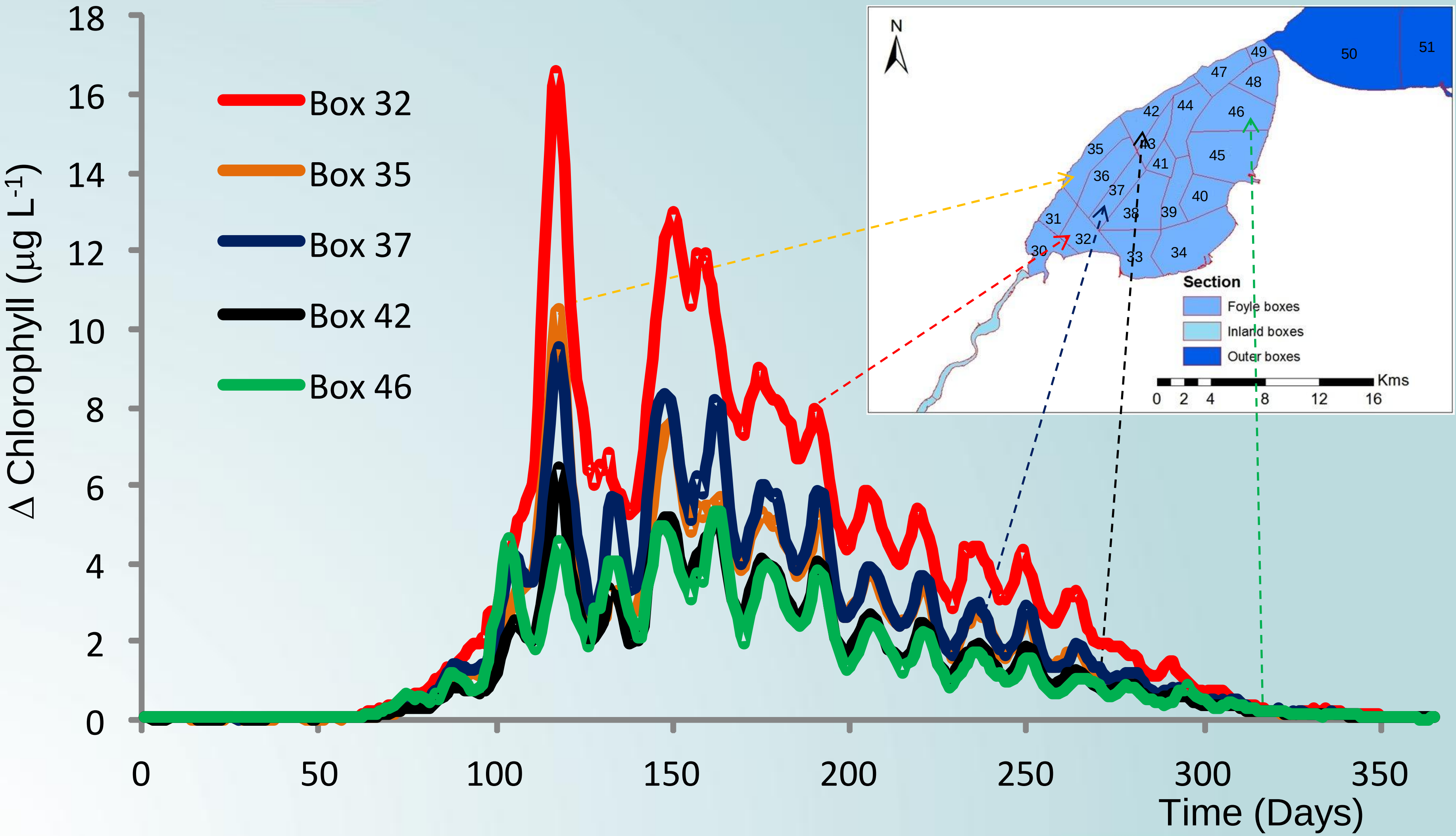
- Nutrient inputs to the coastal zone
- Eutrophication and control mechanisms
- Nutrient credit valuation and trading
- Role of bivalve aquaculture
- Use of alternative indicators
- Final comments

Conceptual model of eutrophication

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.

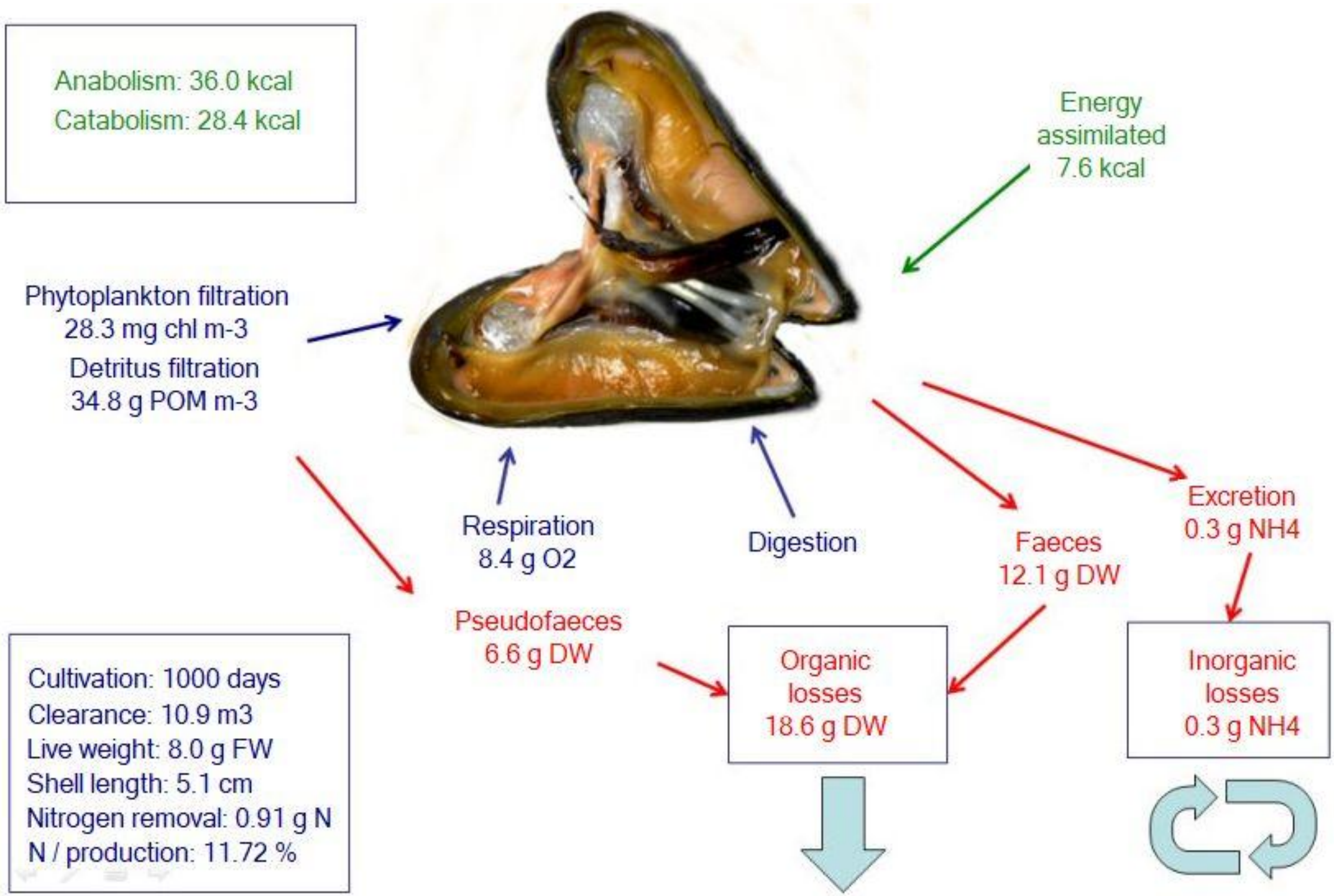
EcoWin.NET Lough Foyle Model
Phytoplankton drawdown – standard model, Year 9



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.

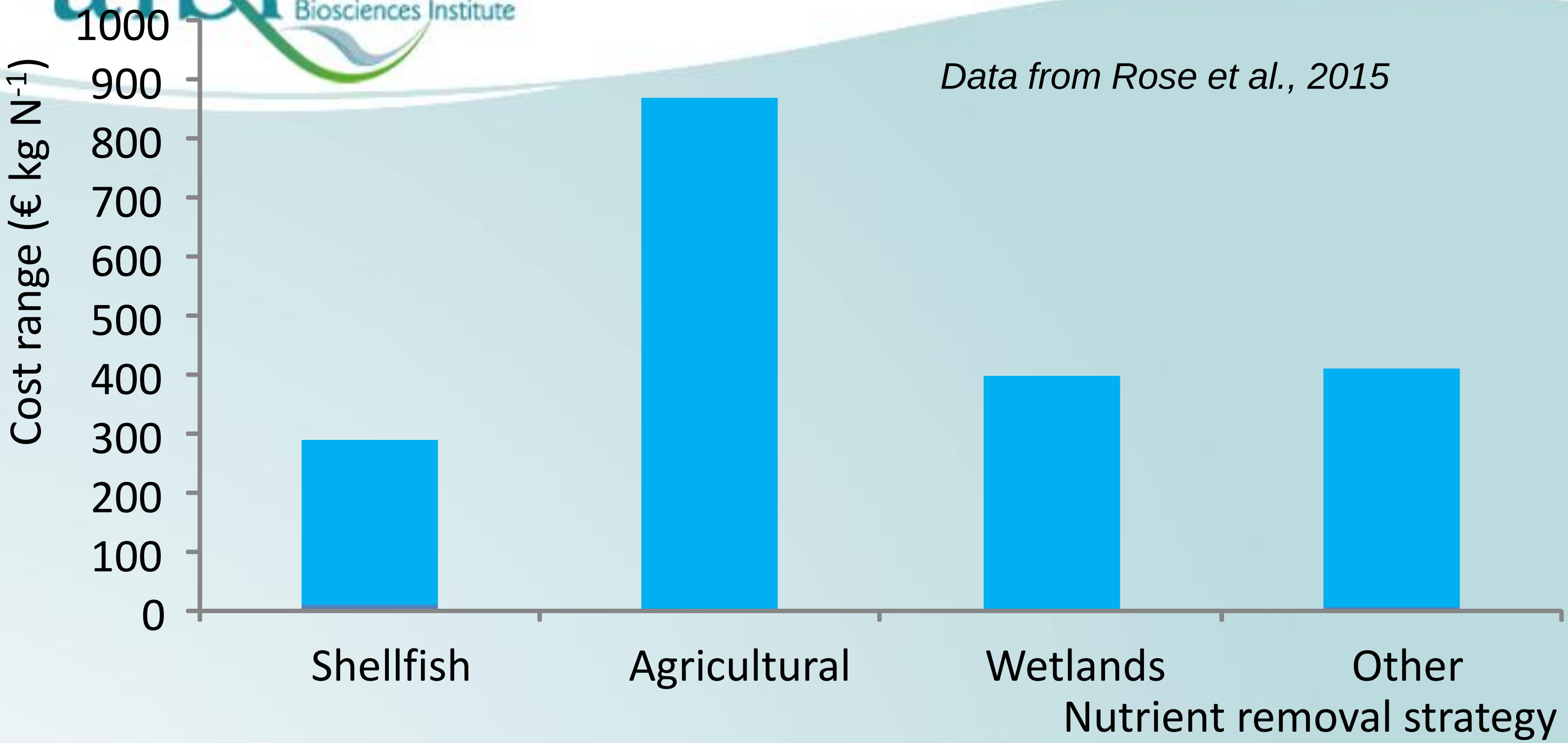
Blue mussel growth model (AquaShell)

Mass balance



Simulation of blue mussel growth for Lough Foyle. End-point weight: 8 g

Nutrient credit valuation and trading



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

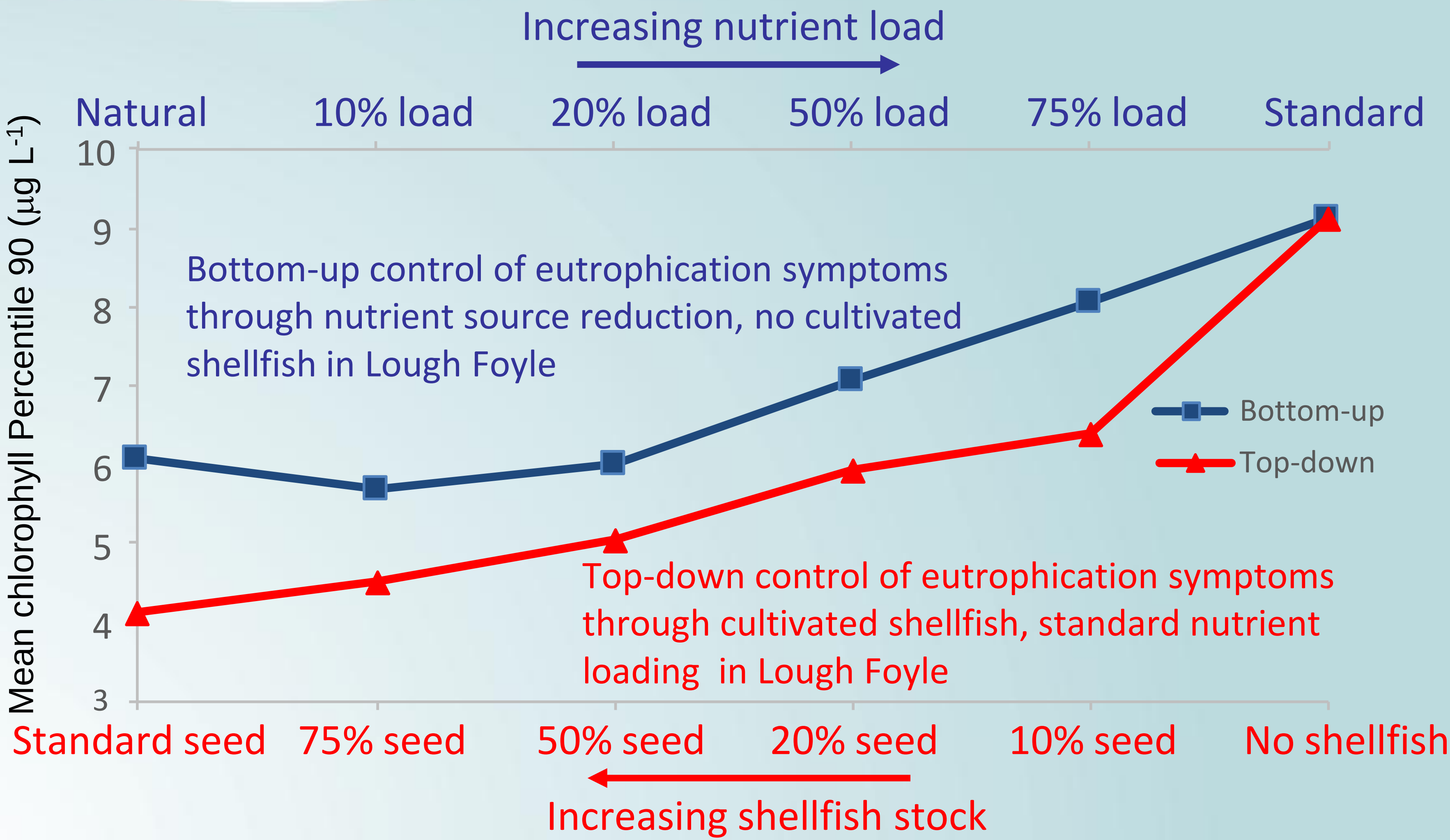
Option 1: Calculate removal from nitrogen content of harvested biomass. For a restored, pristine (unexploited) reef, eutrophication-related <u>ecosystem services will be zero</u>

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.

EcoWin.NET Lough Foyle Model

Chlorophyll drawdown with bottom-up and top-down control



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

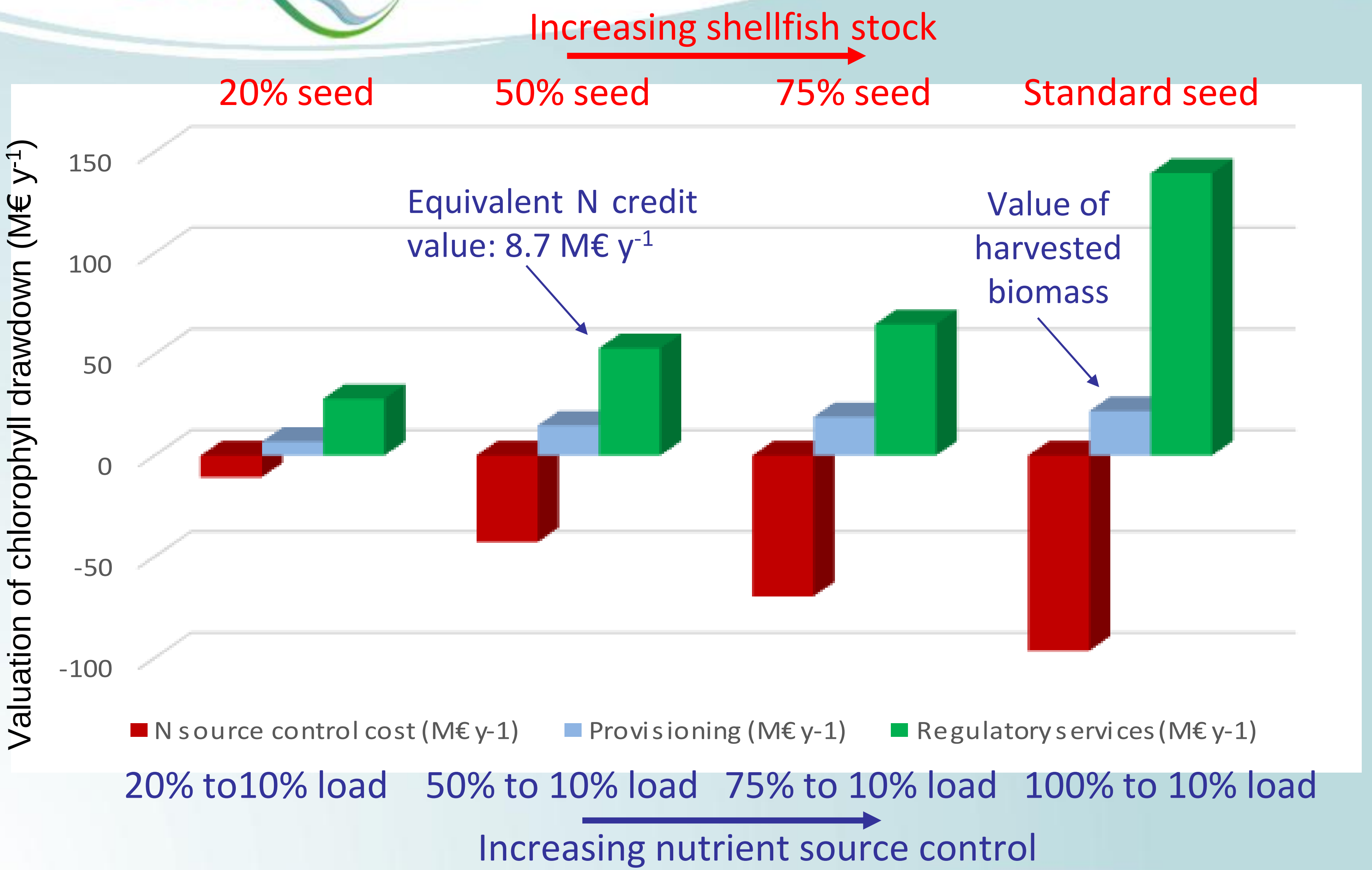
Valuation of regulatory services using chlorophyll

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

- Phytoplankton biomass in the water column depends on several factors;
- In estuaries, transparency is a poor proxy for chlorophyll draw-down;
- 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 chl removal to bottom-up control of primary production.

EcoWin.NET Lough Foyle Model
Valuation of shellfish ecosystem services



The value of the regulatory service of chlorophyll removal by shellfish is far higher than the value estimated through direct nutrient removal.

Bivalve shellfish nitrogen removal calculated with the FARM model for major areas of the world (tonnes N y^{-1})

Group, genus, or species	European Union	United States	Canada	China	Total
Oysters	9461		1287		10749
Cupped oysters (*Crassostrea sp.*)	3439	5045		151110	159595
Flat oyster (*O. edulis*)	105	0.2			105
Mussels (*M. edulis, M. galloprovincialis*)	25341	196	1593	47805	74933
Scallops	2		4	54338	54344
Clams, cockles, arkshells	2418		114		2532
Cockles	311	0.1		19524	19835
Clams	2090				2090
Soft clam	1	48			49
Good clam (*V. decussatus*)	395				395
Carpet shell (*V. pullastra*)	24				24
Manila clam	1670	290		262293	264252
Razor clam (*Solen sp., Sinonovacula sp.*)	0.4			50589	50589
Quahog (*M. mercenaria*)	0.1	1945			1945
Geoduck clam		37			37
Pen shells				1058	1058
Total	37222	7562	2999	586716	634499
Percentage of total (%)	5.9	1.2	0.5	92.5	100

Apply a 'typical farm' approach for different species and regions, then upscale.

Nitrogen loading and offsets for major areas of the world

	Europe	USA	Canada	China	Total
Total N load (10^3 t N y^{-1})	4142.6	3514.0	733.3	2706.0	11095.9
Fed aquaculture N load (10^3 t N y^{-1})	68.8	0.9*a	3.3	32.8*b	105.8
Organic extractive N removal (10^3 t N y^{-1})	37.2	7.6	3.0	586.7	634.5
Proportion of total N load due to fed aquaculture (%)	1.7	0.02	0.5	1.2	
Proportion of fed aquaculture N load offset by bivalves (%)	54.1	870.2	89.6	1790.8	
Proportion of total N load offset by bivalves (%)	0.9	0.2	0.4	21.7	

*a – Only marine aquaculture, mainly salmonids; excludes 229 x 10^3 t live weight y^{-1} freshwater production, of which 67% are channel catfish.

*b – Only marine aquaculture; excludes 27,150 x 10^3 t live weight y^{-1} freshwater production, of which 49% are grass carp, silver carp, and bighead carp

EU shellfish culture offsets half of Norwegian finfish aquaculture;
US and China shellfish offsets greatly exceed finfish loads, but in both cases (on very different scales) there is a freshwater finfish input;
Chinese coastal shellfish culture offsets over 20% of the *total* N load.

Synthesis

- A mass balance approach helps to put nutrient loading, finfish aquaculture, and shellfish offsets in perspective
- 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 and Canada, but are already well-developed in the United States
- The key regulatory ecosystem service is not nutrient removal, but mitigation of eutrophication symptoms
- Mitigation of symptoms can be analysed witth ecosystem model frameworks, but there are few other options
- In the Foyle watershed, 98% of nitrogen loading comes from diffuse sources—there are no easy solutions for reducing chlorophyll in Lough Foyle apart from top-down control
- For the Foyle, a reduction of 1 $\mu g\ L^{-1}$ for chlorophyll P_{90} costs *at least* 30.57 M€ y^{-1} in terms of source control, and the cost ratio of symptom value (chlorophyll) / causative factor value (N) varies between 5.8 and 13.7
- Policy-makers must recognize that bivalve aquaculture should be an integral part of the nutrient economy in catchment management plans

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Task 1.3 Instrumentation of commercial aquaculture facilities

Inner Dundrum Bay Proposed Test Site:
One producer mixed species:
Pacific Oyster and Mussels
Monitored Catchment


Thank you