# Coastal Water Council - Stakeholder Board Meeting

Ringkøbing, April 21st, 2023

## Modelling of Ringkøbing Fjord to support policy-makers for compliance with the EU Water Framework Directive

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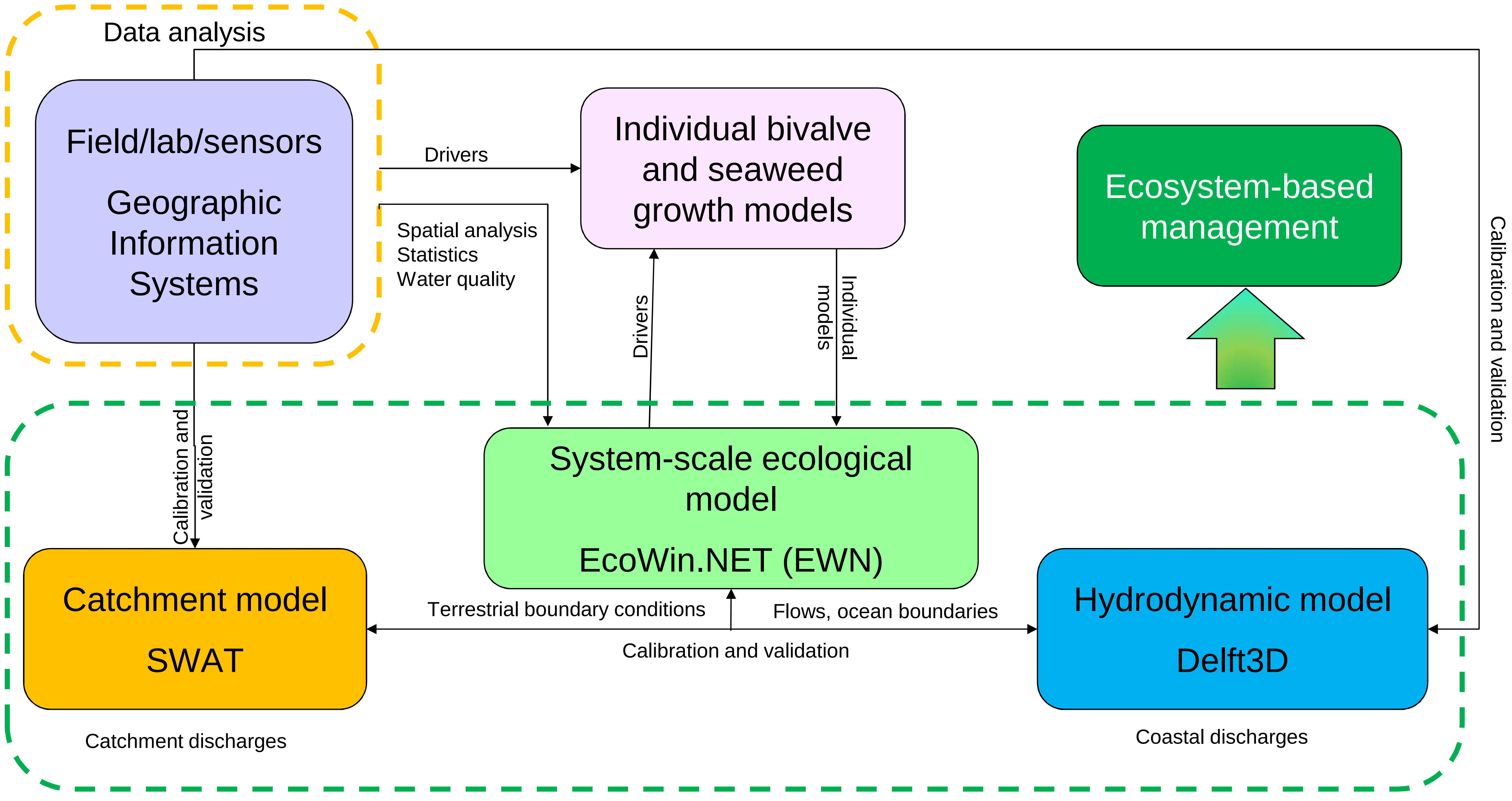



SUCCESS framework – models for integrated management

# Seaweed models

- Longline has modelled various species of seaweed, both for aquaculture (e.g. Nori, the Sushi seaweed) and for bioremediation or environmental pollution work
- We do this by using individual growth models and then scaling to a local area or a whole ecosystem like Ringkøbing Fjord
- Individual models for seaweeds usually apply a two-stage approach:

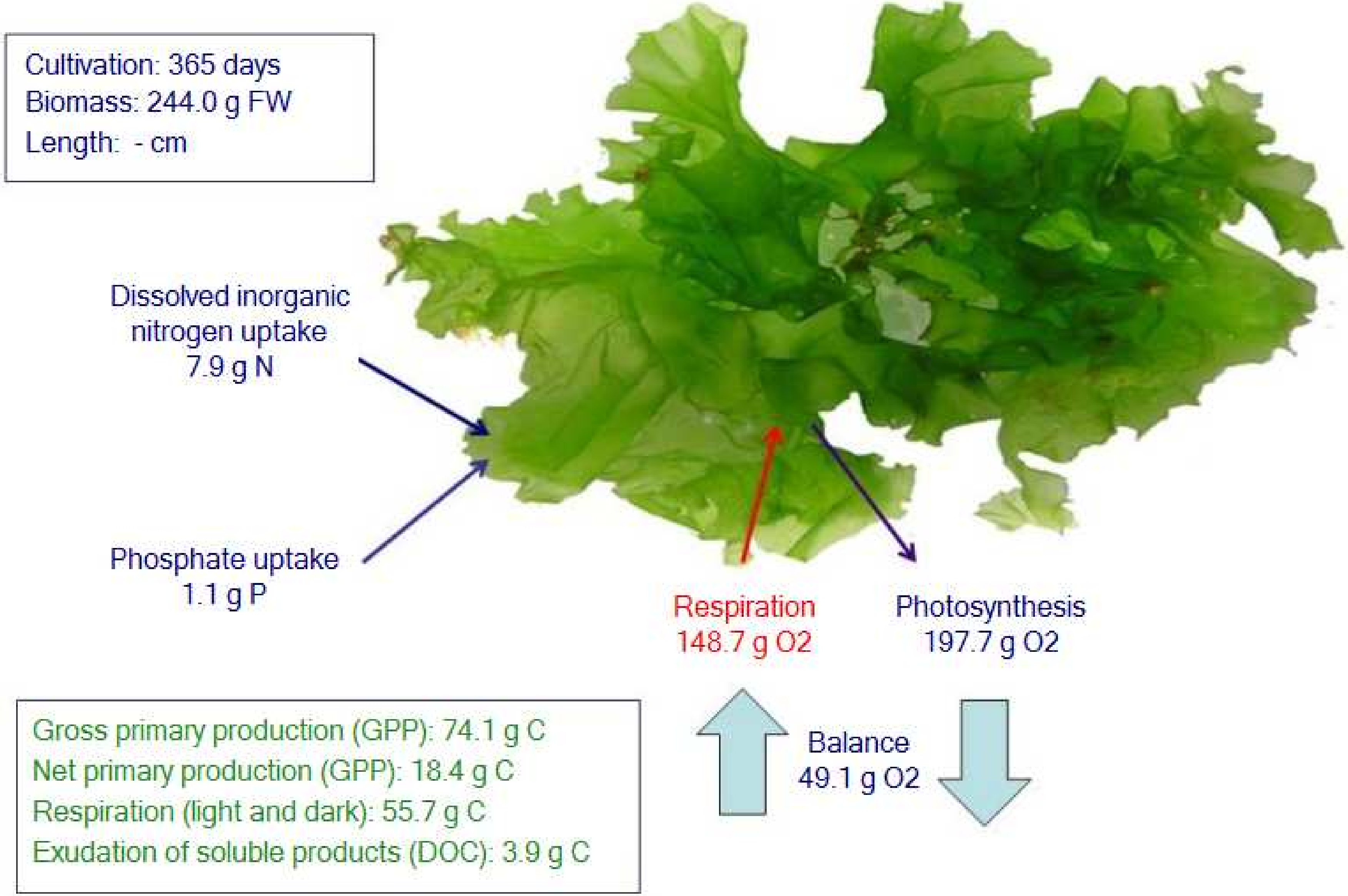
water<->cells<->primary production

- For upscaling to the fjord, it is necessary to know (i) area distribution for *Ulva*; (ii) mortality rates; (iii) starting and peak biomass data for model validation

**If we have gaps in some of the required data, perhaps satellite images can help; we can also use seaweeds as a scenario component of EcoWin, to look at the effect on chlorophyll and nutrient partitioning.**

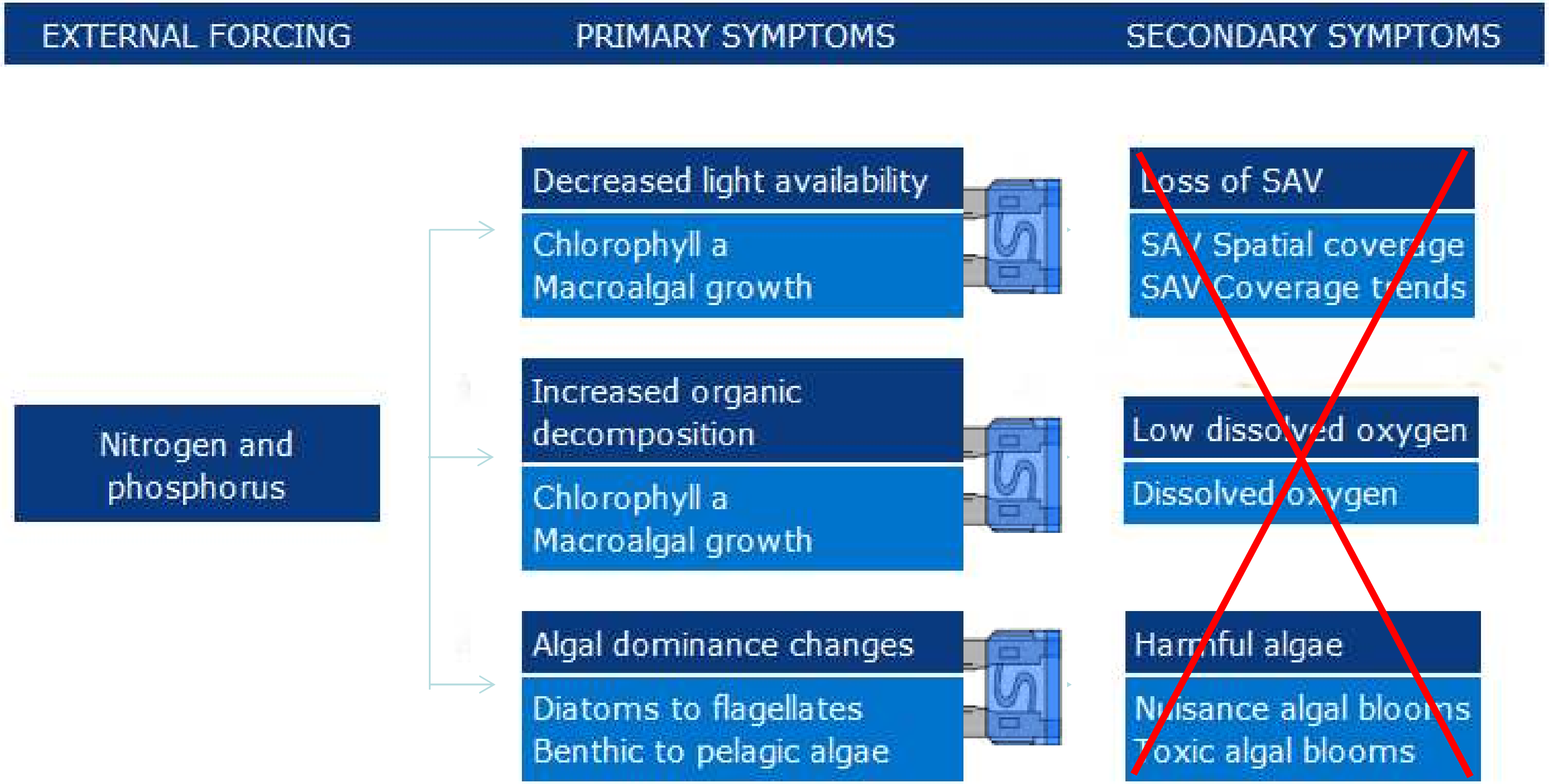
# Mass balance for cell-quota nutrient uptake

## Illustration for *Ulva lactuca*




**Cell-quota models reproduce luxury nutrient consumption for seaweeds.**

# Conceptual model of eutrophication




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

# Top-down control of eutrophication by bivalves

- Bivalves can filter at rates of 1-10 liters per hour—this can play a key role in top-down control of eutrophication, and is a significant ecosystem service
- To illustrate this process for Ringkøbing Fjord, a simple model was developed using the InsightMaker platform (www.insightmaker.com)
- The model uses salinity (wet year/dry year) to simulate the role of the sand mussel (*Mya arenaria*) in controlling algal biomass
- There is no explicit simulation of solar radiation or nutrient input, but the model still shows some interesting properties of the fjord
- If the bivalves are harvested, even for bioremediation (e.g. taking advantage of Omega-3 rich PUFA for fish feed), the nutrients are effectively removed from the system, as are the primary and secondary symptoms of eutrophication

**The general concepts illustrated in the InsightMaker model will be integrated in EcoWin at the scale of the whole ecosystem.**

# InsightMaker model for top-down control of eutrophication

## Physics

Water circulation and renewal, salinity

## Phytoplankton algae

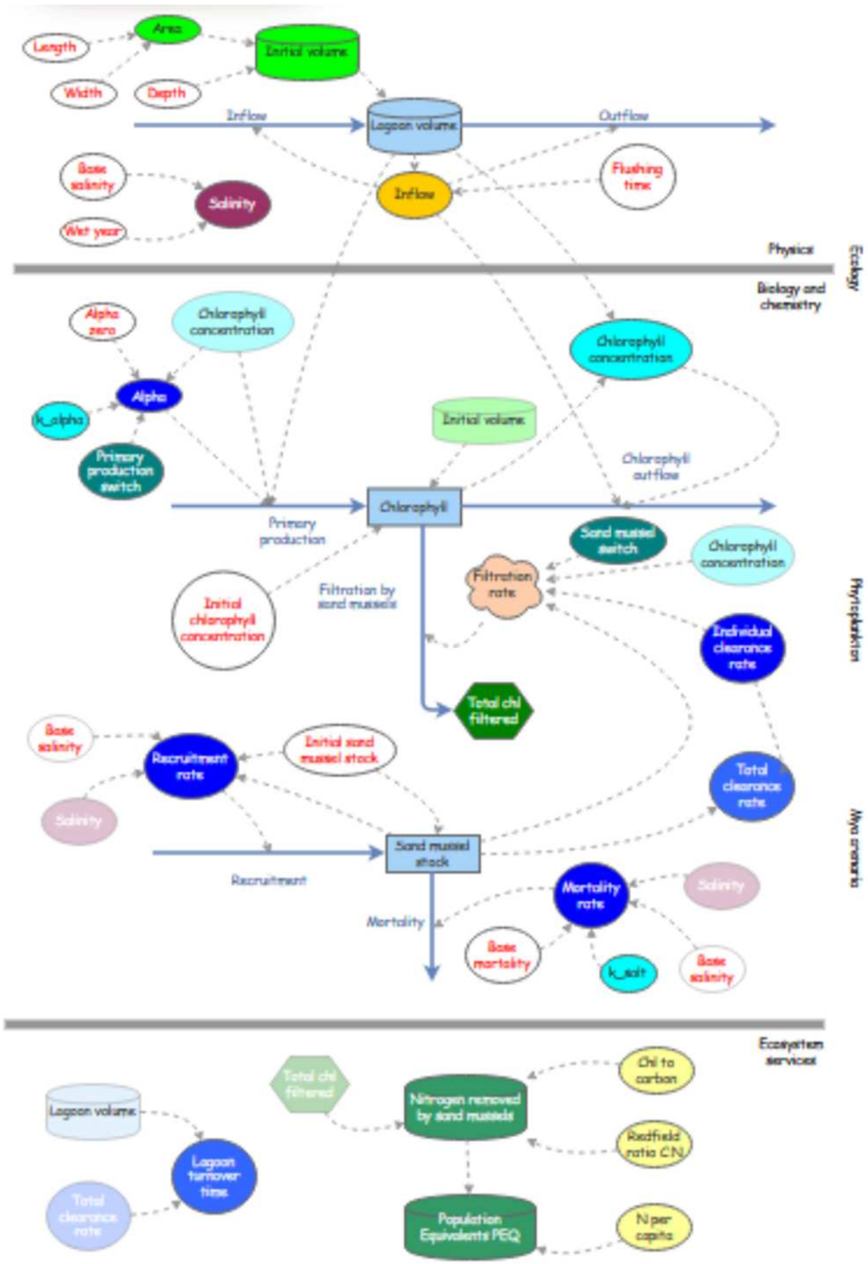
Primary production of phytoplankton, increase in chlorophyll...

## Sand mussels

Filtration, growth, mortality, salinity dependence

## Ecosystem services

Regulatory services due to nutrient removal etc



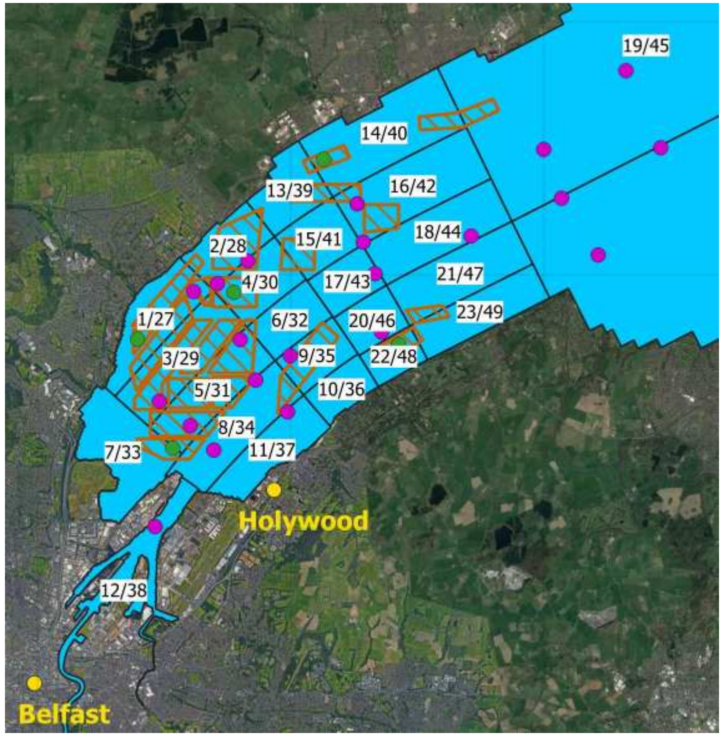
# EcoWin model overview

- EcoWin (EWN) is an ecological model, integrated in the SUCCESS framework; it has been used in many parts of the world, including Europe, US, and China
- EWN will be applied in Ringkøbing Fjord by dividing the system into a number of 2D horizontal boxes and two vertical layers
- The model is driven by physics, provided by a hydrodynamic model (in this case Delft3D) and by the hydrological model for the catchment (SWAT)
- Loading to the fjord will consider exchange of relevant substances (i) at the NorthSea boundary—the sluice; (ii) loading from land sources; and (iii) secondary loading of organic matter from the sediment
- EWN simulates biogeochemistry to predict concentrations of indicators for eutrophication assessment, including chlorophyll, nitrogen and phosphorus
- The model will be tailored to include specific variables relevant to the problem: shellfish (sand mussels) and seaweeds (*Ulva*)

**EcoWin will run a ten-year cycle for Ringkøbing Fjord in under half an hour.**

# EcoWin.NET Belfast Lough – Key indicators for the WFD: Bottom up control scenario (Year 9)

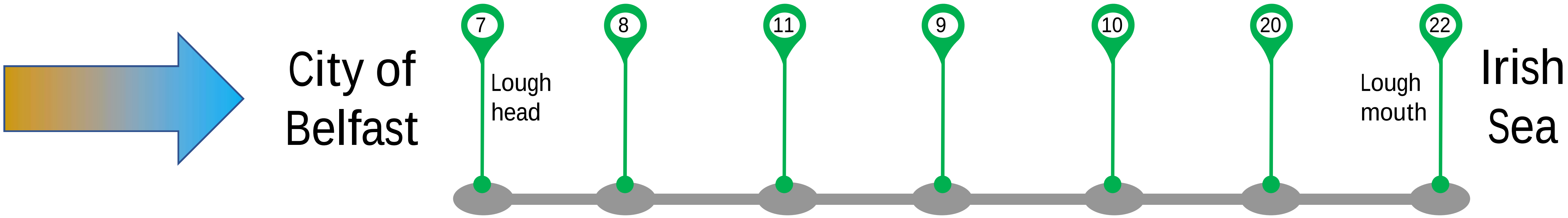
| Mussel harvest (t y$^{-1}$) | Box 27 | Box 28 | Box 29 | Box 30 | Box 31 | Box 33 | Box 34 | *Total* |
|---|---|---|---|---|---|---|---|---|
| Full N load | 18.5 | 184.5 | 291.2 | 315.6 | 815.5 | 80.5 | 603.5 | 2309.3 |
| 50% N load | 8.0 | 122.5 | 158.3 | 262.9 | 643.7 | 50.4 | 489.9 | 1735.7 |
| Difference (%) | -56.5 | -33.6 | -45.6 | -16.7 | -21.1 | -37.4 | -18.8 | -24.8 |




Highest impact on mussel culture

**Bottom-up control of mussel harvest is significant in all the relevant model boxes.**

# EcoWin.NET Belfast Lough – Key indicators for the WFD: Bottom-up control scenario (Year 9)



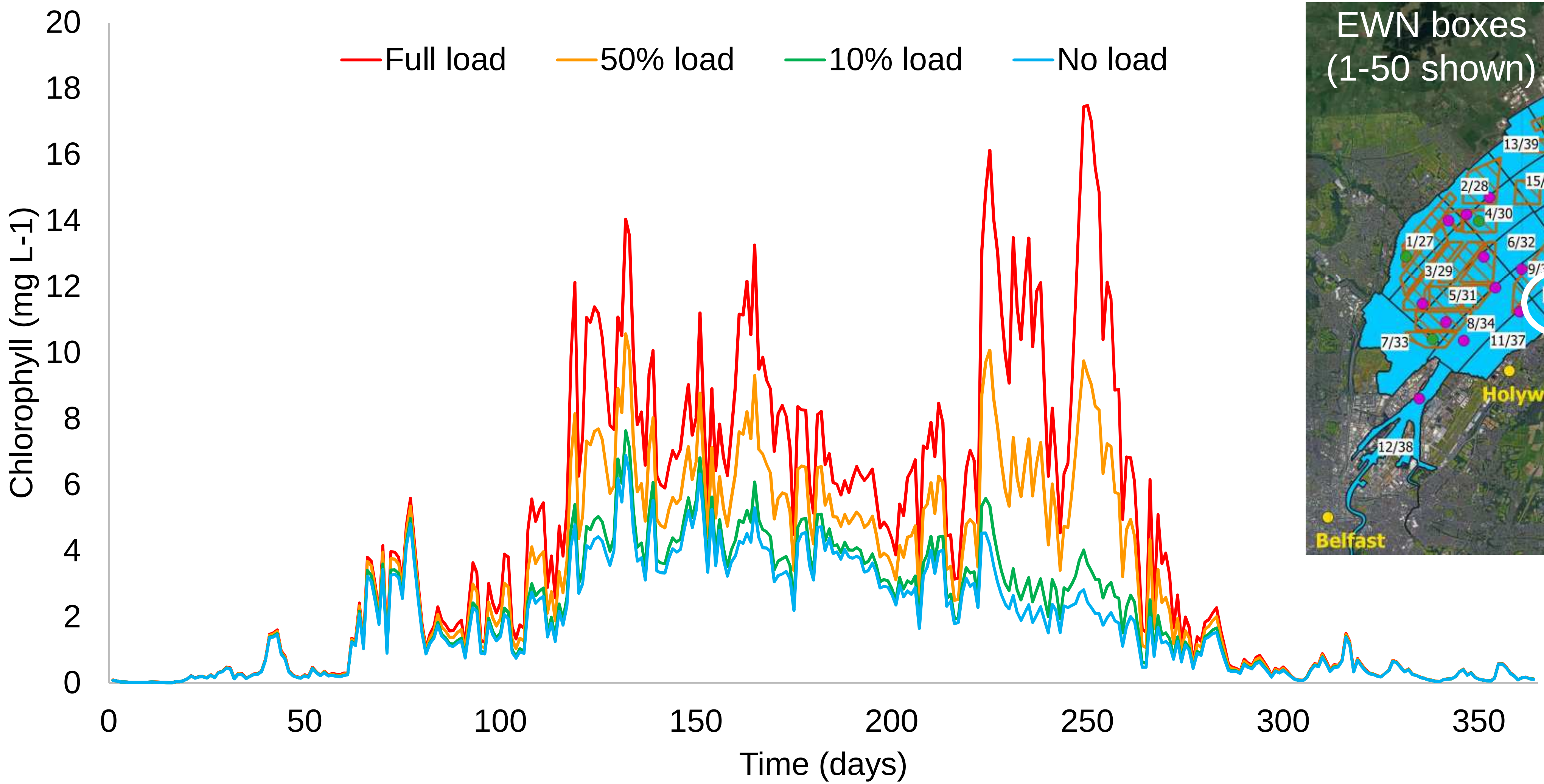

| Chlorophyll $P_{90}$ | Box 7 | Box 8 | Box 11 | Box 9 | Box 10 | Box 20 | Box 22 | Box 38 |
|---|---|---|---|---|---|---|---|---|
| Standard loading ($\mu g\ L^{-1}$) | 6.4 | 14.8 | 13.3 | 9.9 | 10.4 | 7.3 | 8.1 | 13.0 |
| 50% loading ($\mu g\ L^{-1}$) | 4.7 | 9.8 | 8.8 | 7.0 | 7.1 | 5.0 | 5.5 | 8.6 |
| Difference (%) | -26.6 | -33.5 | -33.6 | -29.9 | -32.0 | -32.1 | -31.8 | -33.5 |

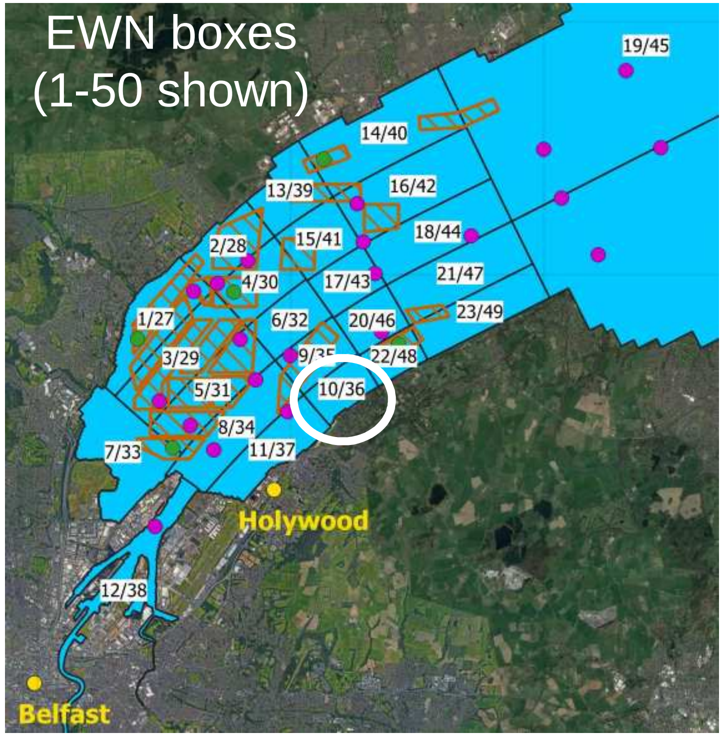
Southern part of the lough shows higher reductions

Bottom box

**Bottom-up control is significant in parts of the lough. Standard model with mussels active.**

# EcoWin.NET Belfast Lough Standard Model
# Effect of nitrogen load reduction on chlorophyll, Box 10, Year 9

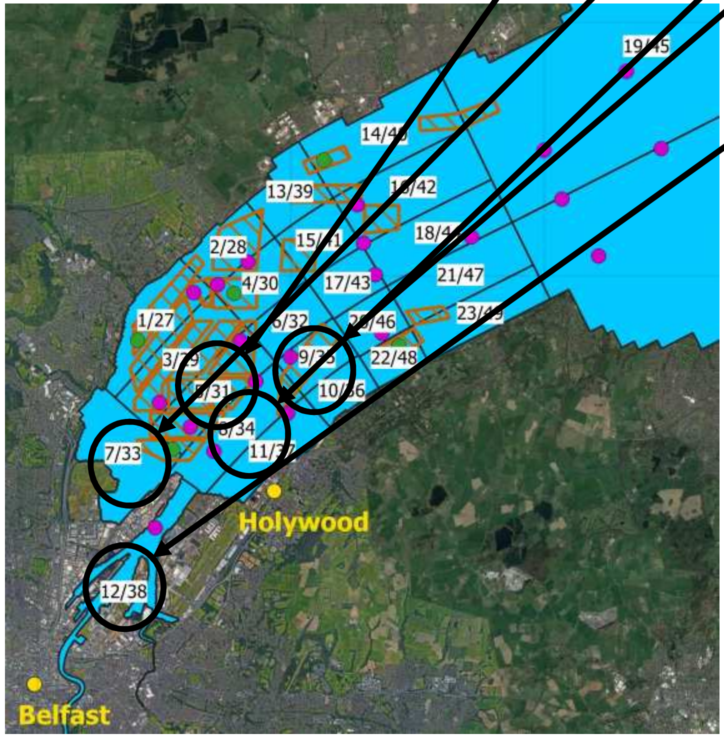



**Reduction in chlorophyll $P_{90}$ of 25% for 50% N load, 44% for 10% N load, and 48% for 0% N load. N remains in the system due to ocean exchange and mineralisation. Chlorophyll with lower N loads is less 'noisy'.**

# EcoWin.NET Belfast Lough – DIN $P_{90}$ compliance(Year 9)

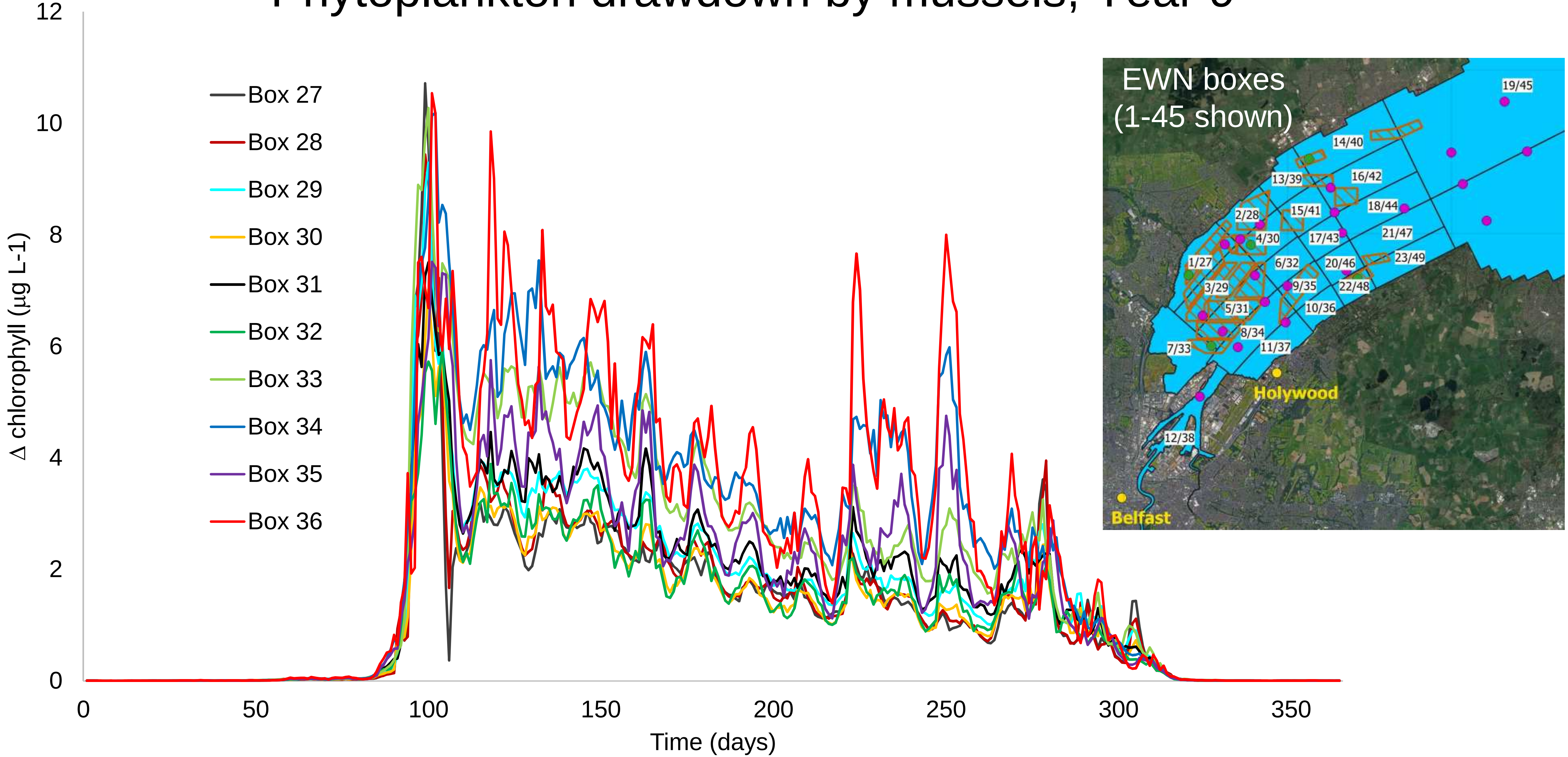
| Box | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Full load P90 DIN | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 50% load P90 DIN | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 10% load P90 DIN | | | | | | | | | | | | | | | | | | | | | | | | | | |
| No load P90 DIN | | | | | | | | | | | | | | | | | | | | | | | | | | |




| WFD categories | Threshold (μM) S: 30-34.5 | Threshold (μM) S<30 |
|---|---|---|
| High | <12 | <20 |
| Good | 12-18 | 20-30 |
| Moderate | 18-27 | 30-45 |
| Poor | 27-40.5 | 45-67.5 |
| Bad | >40.5 | |

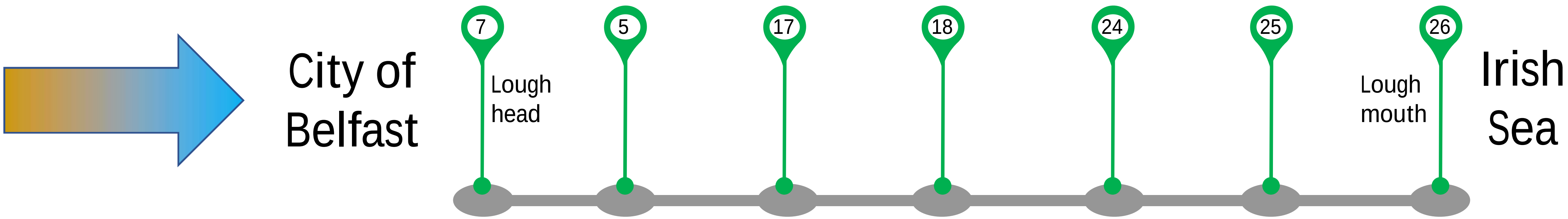
**Bottom-up control of dissolved inorganic nitrogen (DIN). Five surface boxes fail compliance (marine salinity) with present-day loading, one fails with 50% load reduction. None fail with 90% reduction.**

# EcoWin.NET Belfast Lough Standard Model
# Phytoplankton drawdown by mussels, Year 9




**Strongest drawdown is in the central and upper parts of the lough, where blue mussel (*M. edulis*) is grown.**

# EcoWin.NET Belfast Lough – Key indicators for the WFD: Top-down control scenario (Year 9)




| Chlorophyll $P_{90}$ | Box 7 | Box 5 | Box 17 | Box 18 | Box 24 | Box 25 | Box 26 | *Box 31* |
|---|---|---|---|---|---|---|---|---|
| Blue mussels ($\mu g\ L^{-1}$) | 6.4 | 8.2 | 5.2 | 3.9 | 3.0 | 0.9 | 0.8 | 2.7 |
| No top-down control ($\mu g\ L^{-1}$) | 9.2 | 10.9 | 7.0 | 5.0 | 3.5 | 0.9 | 0.8 | 5.1 |
| Difference (%) | -30.7 | -25.1 | -25.4 | -22.2 | -13.5 | -7.9 | -1.0 | -47.7 |

Effect of filter-feeders in boxes with no aquaculture

Big difference between upper and lower box

**Top-down control is significant across all the lough. Reduction of mussel culture will impact chlorophyll.**

# Synthesis

- Scenarios that can be analysed with the SUCCESS framework include (i) agricultural emissions and drivers; (ii) oceanographic and runoff balance as salinity controls; (iii) top-down control by shellfish, and interactions among: nutrients – primary producers (phytoplankton and seaweeds) – sand mussels
- Top-down control of eutrophication by shellfish appears to be a key driver of water quality and potentially of legal compliance
- Sand mussels have significant economic value for regulatory ecosystem services, but may also be of value for protein e.g. in fish feeds (high Omega-3, Omega-6)
- The issue of moral hazard will certainly be raised with respect to top-down control and agricultural emissions. This must be considered with great care
- Longline is committed to help provide realistic solutions to local policy-makers in order to address the ecological, economic, and social sustainability of Ringkøbing Fjord and the associated catchment

http://longline.co.uk/rksk