Modelling the whole-ecosystem impacts of trawling

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Around a dozen main types of fishing gears operate in northern Europe – mobile and static

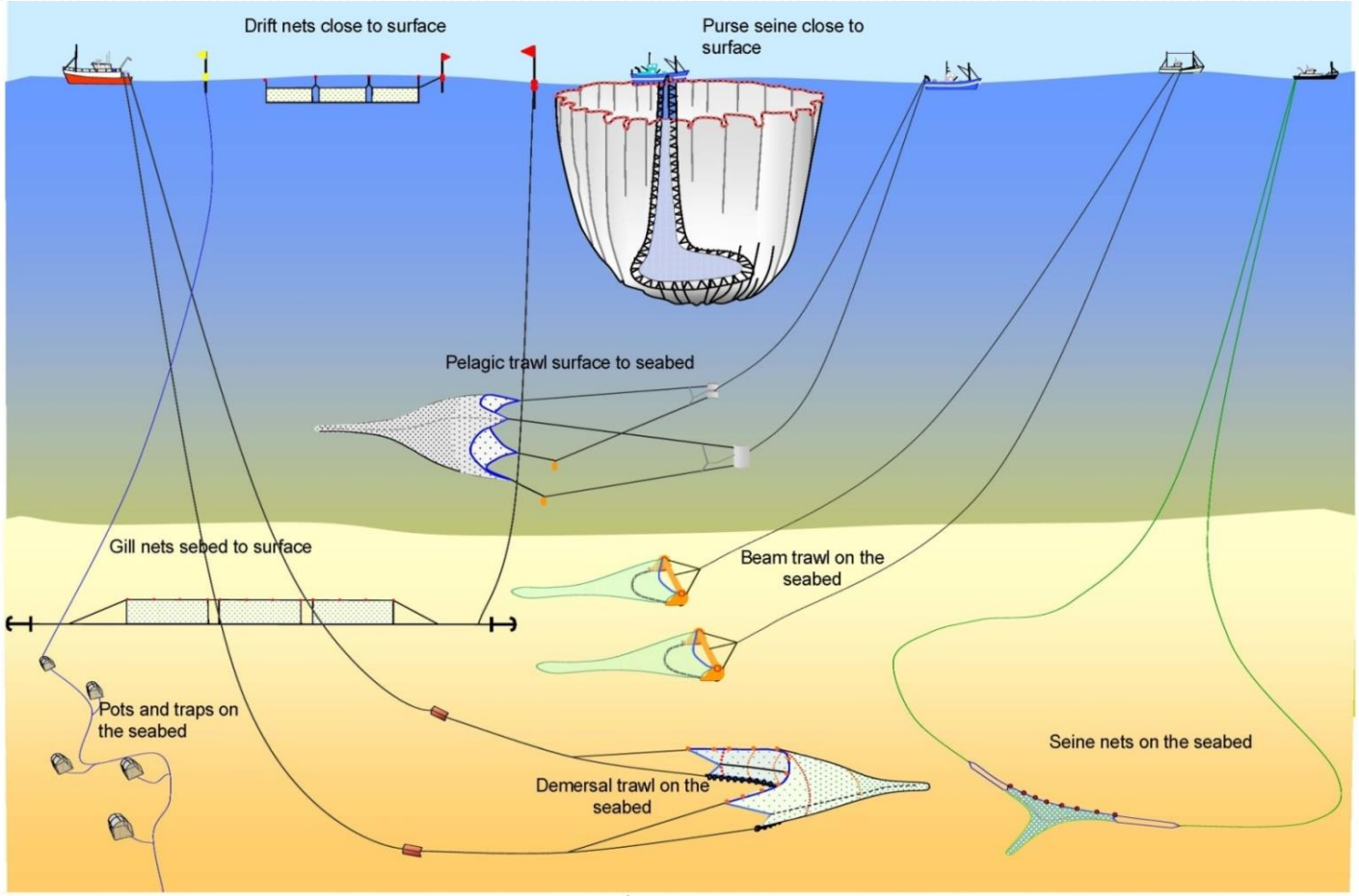

Image from Seafish report 2005

The gears differ widely in their activity rates, catching efficiency, environmental impacts, economics and employment rates.

Various forms of trawling receive a lot of bad-press.

Is this justified?

Complaints about trawling have a long history

1377 – Essex, UK – petition to King Edward III complaining about the 'wondyrchoun' [an early type of beam trawl]:

"… the hard and long iron of the said 'wondyrchoun', destroys the spawn and brood of the fish beneath the said water, and also destroys the spat of oysters, muscles [sic], and other fish by which large fish are accustomed to live and be supported"….

A royal commission was appointed to consider the complaints, but no record of their conclusions or any subsequent action survives

… and continue to the present day…

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Rare Loch Carron flame shell reef 'devastated' by scallop dredger

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Creel fishermen seek inshore trawler ban

Creel fishermen are calling for a change in the way fisheries are managed along the west coast of Scotland. They have put a case to the Scottish government for trawlers to be banned from inshore waters and say the move would create 700 new jobs and 450 new boats.

The Scottish Fishermen's Federation, which represents the inshore trawlers, says that would damage their fleet and does not make economic sense.

BBC Scotland's rural affairs correspondent Kevin Keane reports.

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So, what is it about trawling that attracts so much criticism ?

- **Social conflict** – competition for space; static gear is easily damaged or towed away by trawls

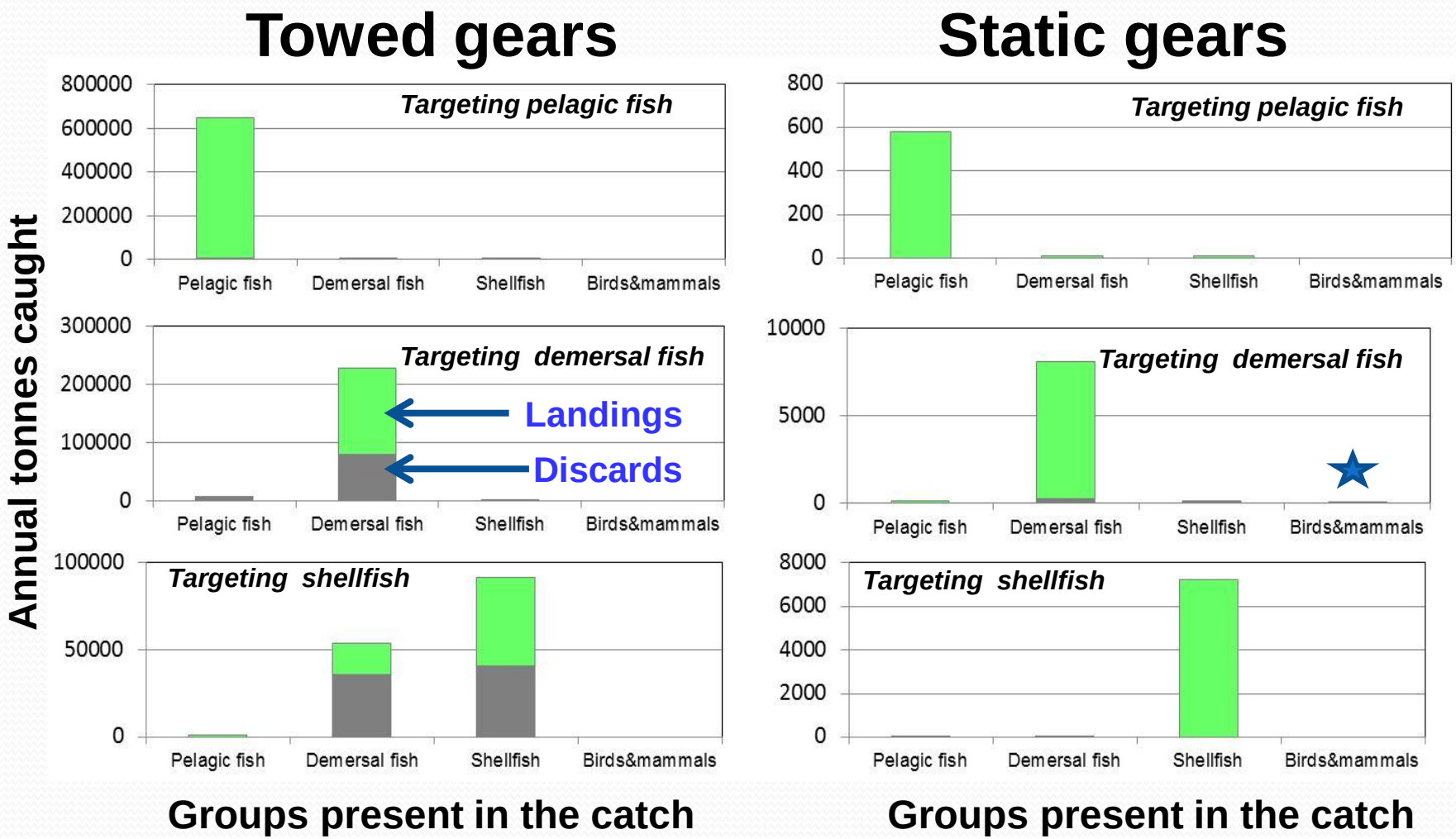
- **Wealth and power** - trawling is highly efficient at catching fish – outcompetes ‘artisanal’ methods.

- **Selectivity** – trawling seen as indiscriminate compared to static gears – and wasteful due to consequent discarding of undersize fish and unwanted species

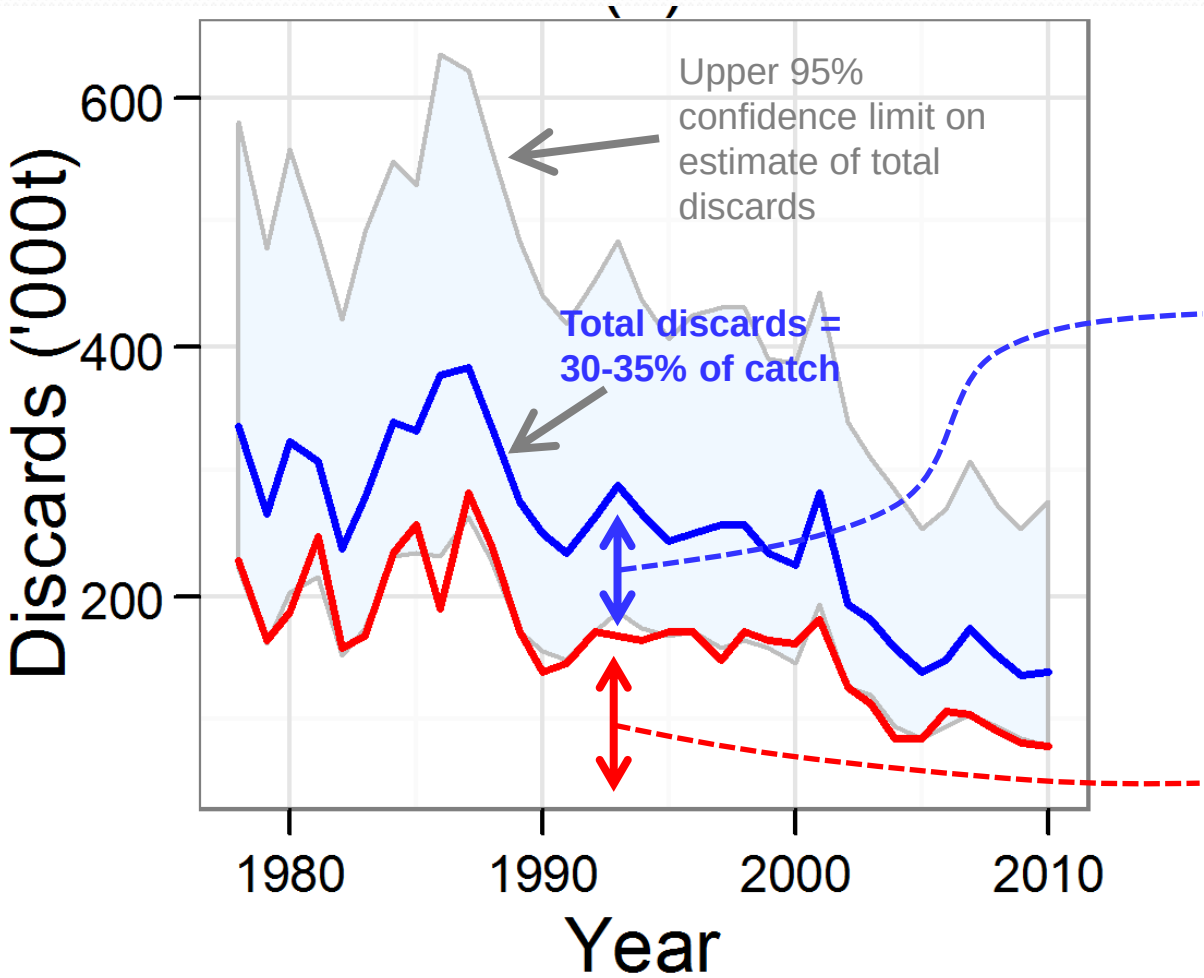
- **Physical damage to seafloor habitats and fauna** – seabed scarring, destruction of biogenic structures and essential habitat, sediment suspension, nutrient release, benthos mortality leading to changes in community composition

How ‘clean’ are trawl catches?

EU STCF landings and discards data for the North Sea, 2003-2013



Discards of trawl-caught demersal fish in the North Sea, 1978-2010



Regardless of cause, dead discarded catch re-enters the food web via scavengers

Discarded due to insufficient quota, or species of low/no market value

Discarded due to being too small (below legal or marketable landing size)

Non-target by-catch in Nephrops trawl fisheries - discarding of undersize, low value, or over-quota fish

Norway lobster

How do trawls impact on the seabed?

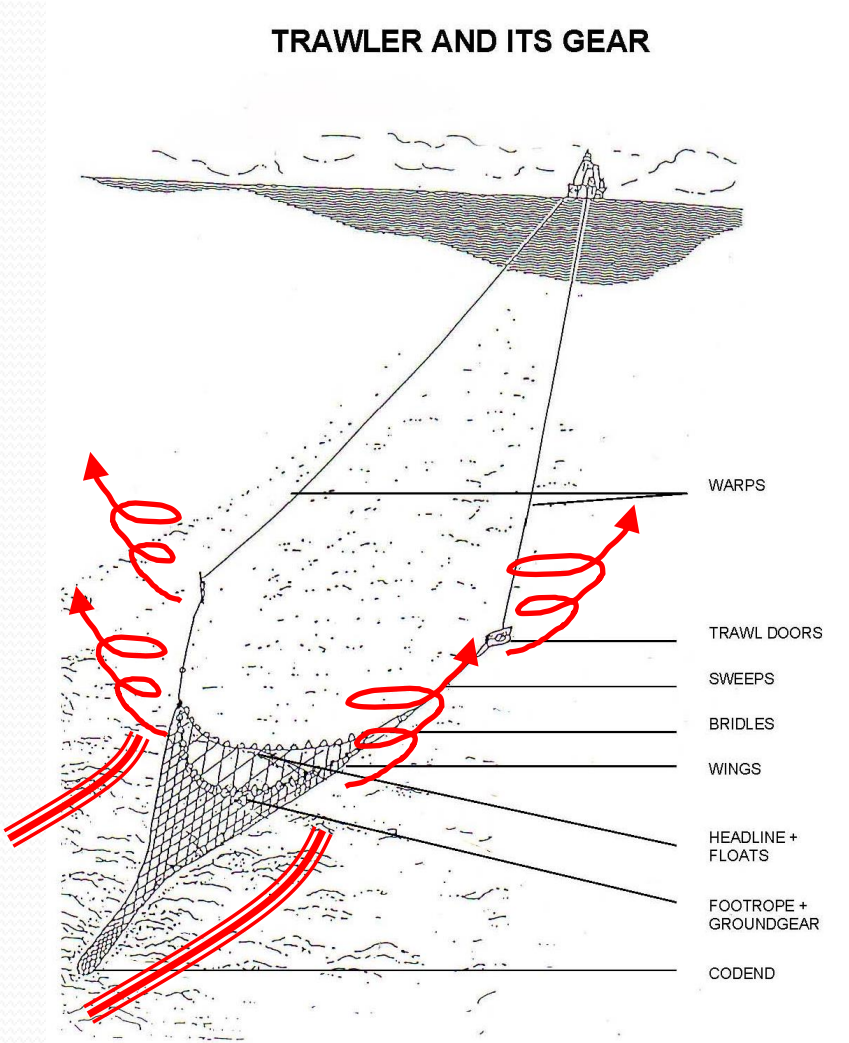


Image from Scallish report 2005

Otter boards, sweeps, wing-end weights, and foot-chains penetrate the seabed, causing:

- ***Furrows, scrape marks and scarring***
- ***Relocation of bounders and stones***
- ***Suspension of sediment***
- ***Release of pore-water nutrient***
- ***Sediment oxygenation***
- ***Mortality of benthos infauna and macrobenthos***
- ***Destruction of fragile species and biogenic structures***

It's been argued that this is a good thing, like ploughing the fields:

- ***Makes more food available to benthivorous fish***
- ***Stimulates primary production***

Purpose of this modelling study… focus just on the ecology…

- ***How significant are trawling-specific impacts at the scale of a whole regional ecosystem?***
  - Specifically…
    - **Selectivity**
    - **Discarding**
    - **Seabed abrasion**

Linked features

- **Any substance to the 'ploughing the fields' argument?**

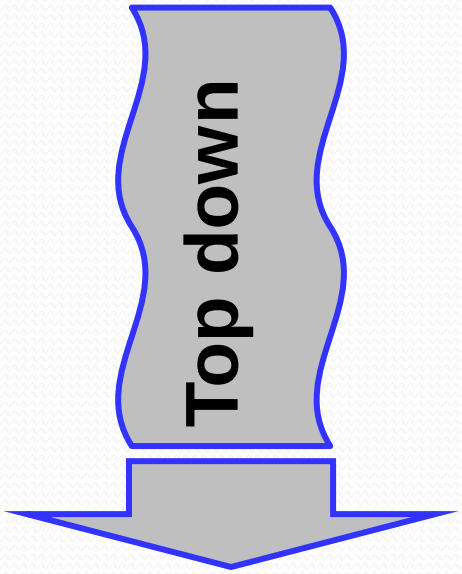
- **Case study region: North Sea**

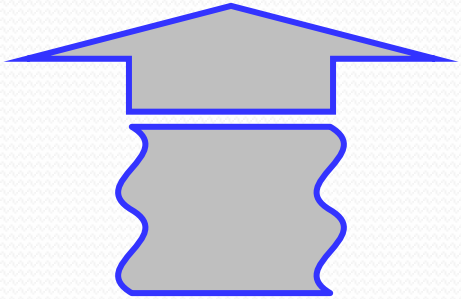
Its not about harvesting biomass from the sea *per se* – its about the manner in which this is carried out

Answering this question needs a model scheme capable of seamlessly simulating end-to-end trophic cascades

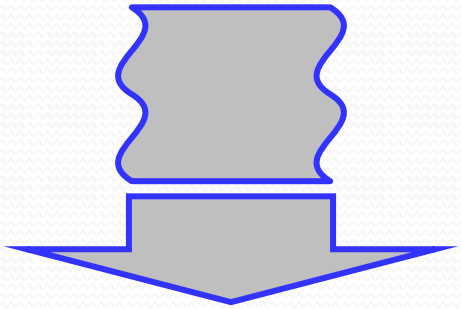
"Middle-out" cascade

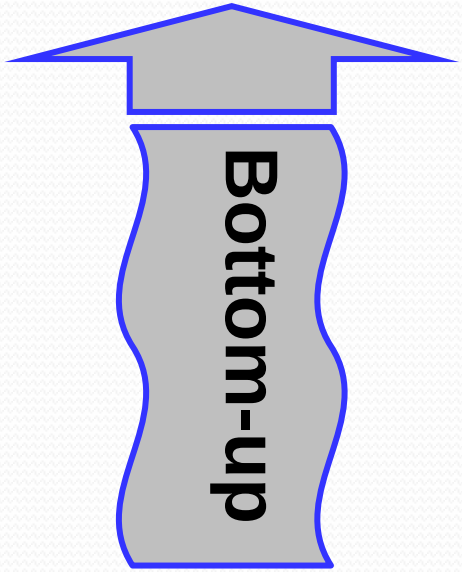
Harvesting of top predator species





- **Harvesting of mid-trophic level species,**
- **Benthos mortality**





- **Nutrient release,**
- **Discards,**
- **Sediment suspension**

Nuts and bolts of the StrathE2E ecosystem model…

- **Coupled ODE box model** of the rate of change of nitrogen mass of food web components (nutrients-mammals), with full conservation of mass
- **Advection, mixing and active migration** between vertical & horizontal spatial compartments
- Explicit representation of **seabed sediment biogeochemistry *and* disturbance** processes
- **External drivers** – temperature, irradiance, SPM, ocean boundary inputs, river and atmospheric inputs; fishery harvest, discard & seabed abrasion rates
- **Export fluxes** – nitrogen gas, advection fluxes, fishery landings
- Coded in C, solved using R-deSolve function, fast (<0.25 sec per year), daily interval outputs
- **Computational parameter optimisation** to fit the model to observed data

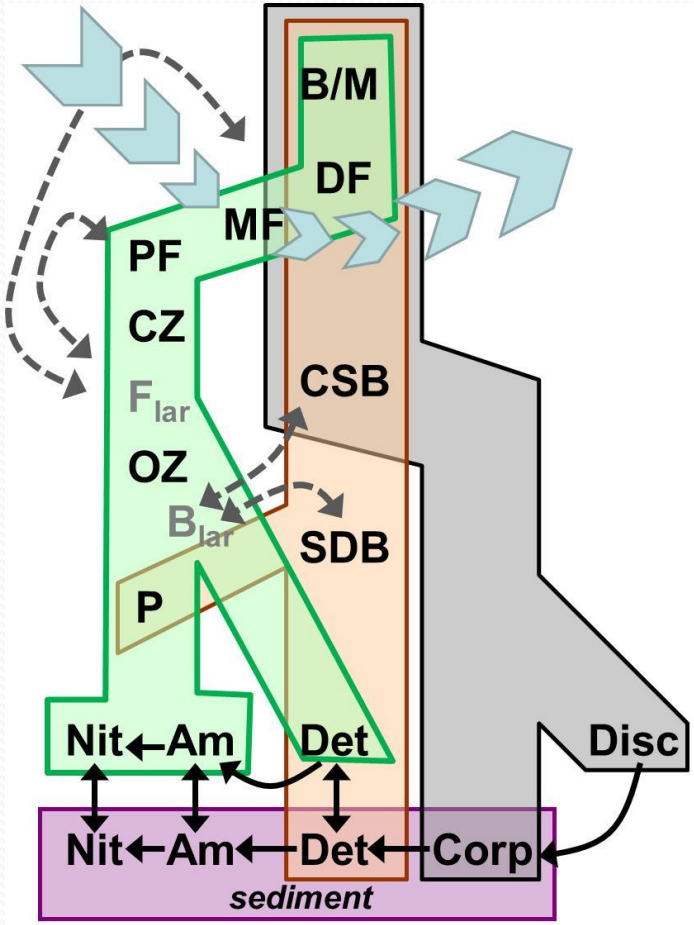
Schematic of the StrathE2E 'ecology'

Four interconnected compartments: Pelagic, Benthic, Scavenging, and Sediment

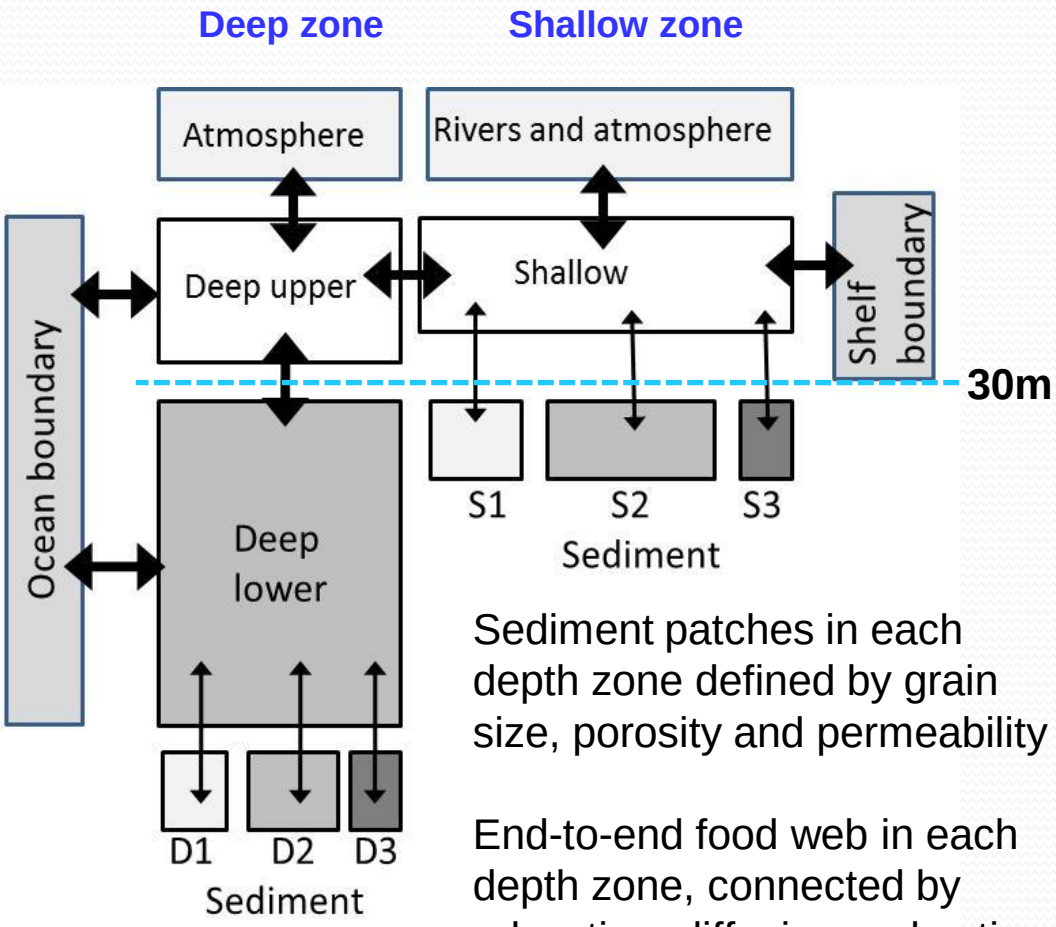
Birds & mammals (B/M)
Demersal fish (DF)
Ocean migratory fish (MF)
Planktivorous fish (PF)
Carnivorous zooplankton (CZ)
Carnivorous/scavenging benthos (CSB)
Fish larvae (F_{lar})
Omnivorous zooplankton (OZ)
Benthos larvae (B_{lar})
Susp/deposit feeding benthos (SDB)
Phytoplankton (P)
Nitrate (Nit)
Ammonia (Am)
Detritus (Det)
Corpses (Corp)
Discards (Disc)

Fishing :

- Catches fish, benthos, carnivorous zooplankton, birds&mammals
- Produces discards
- Affects the sediment-water nutrient & detritus exchange
- Inflicts mortality on benthos

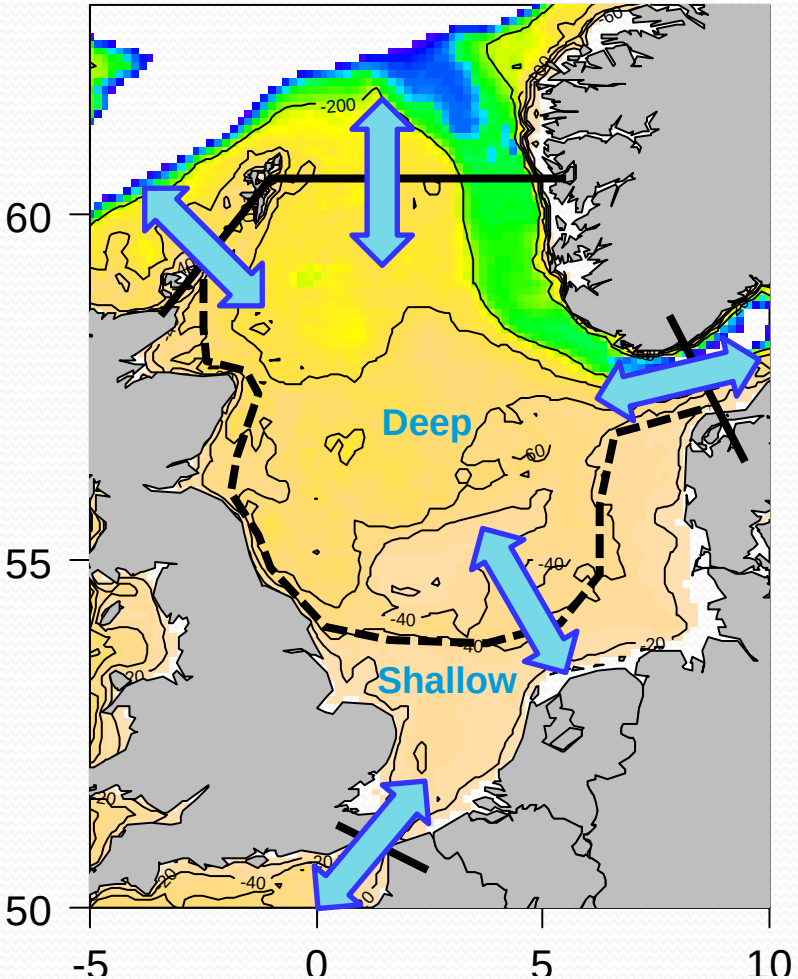


Physical and spatial context for the ecology model



Sediment patches in each depth zone defined by grain size, porosity and permeability

End-to-end food web in each depth zone, connected by advection, diffusion and active migrations



Fishery driving parameters for the ecology model generated by a separate 'fishing fleet model'

Fishing fleet model → Ecology model

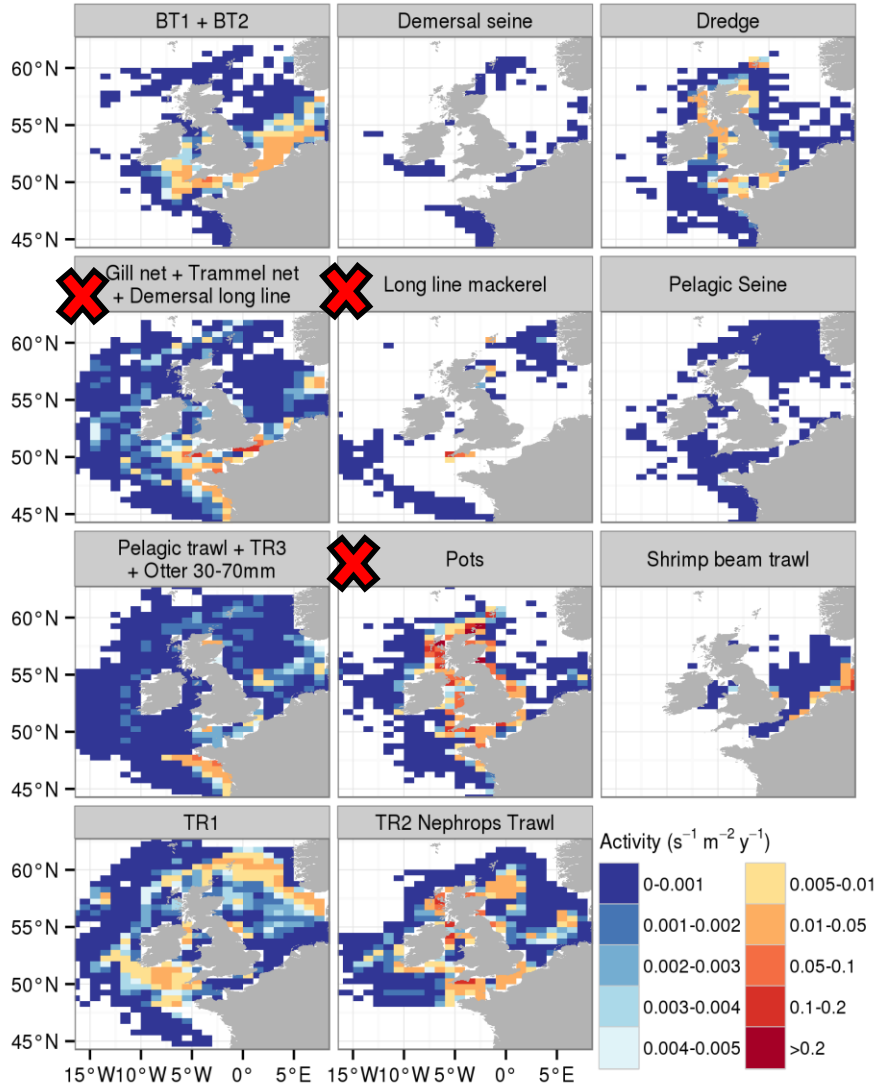
INPUTS: For each gear type:

- Spatial distribution of activity rate
- Selectivity pattern (catching power) w.r.t each exploited resource group
- Discard rate w.r.t each exploited resource group
- Seabed abrasion rate and penetration depth

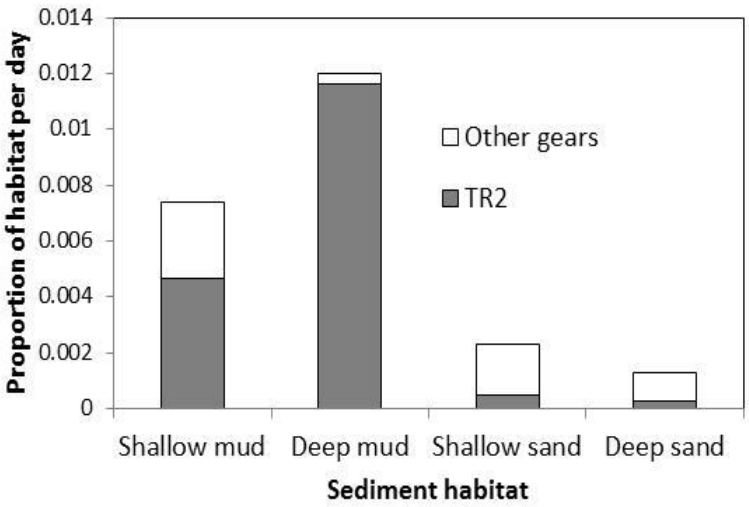
INPUTS: For each spatial compartment:

- Proportion of seabed sediment volume ploughed per day
- **Harvest rates** – proportion of mass each exploited resource group caught per day
- **Discard rates** – proportion of captured mass each exploited resource group returned to the sea as discards
- Parameters for density dependent **size and species composition** of demersal fish catch

Fishing gears vary in their spatial distributions, levels of activity, and seabed abrasion rates



Abrasion intensity – proportion of habitat abraded per day in the North Sea



= static gear

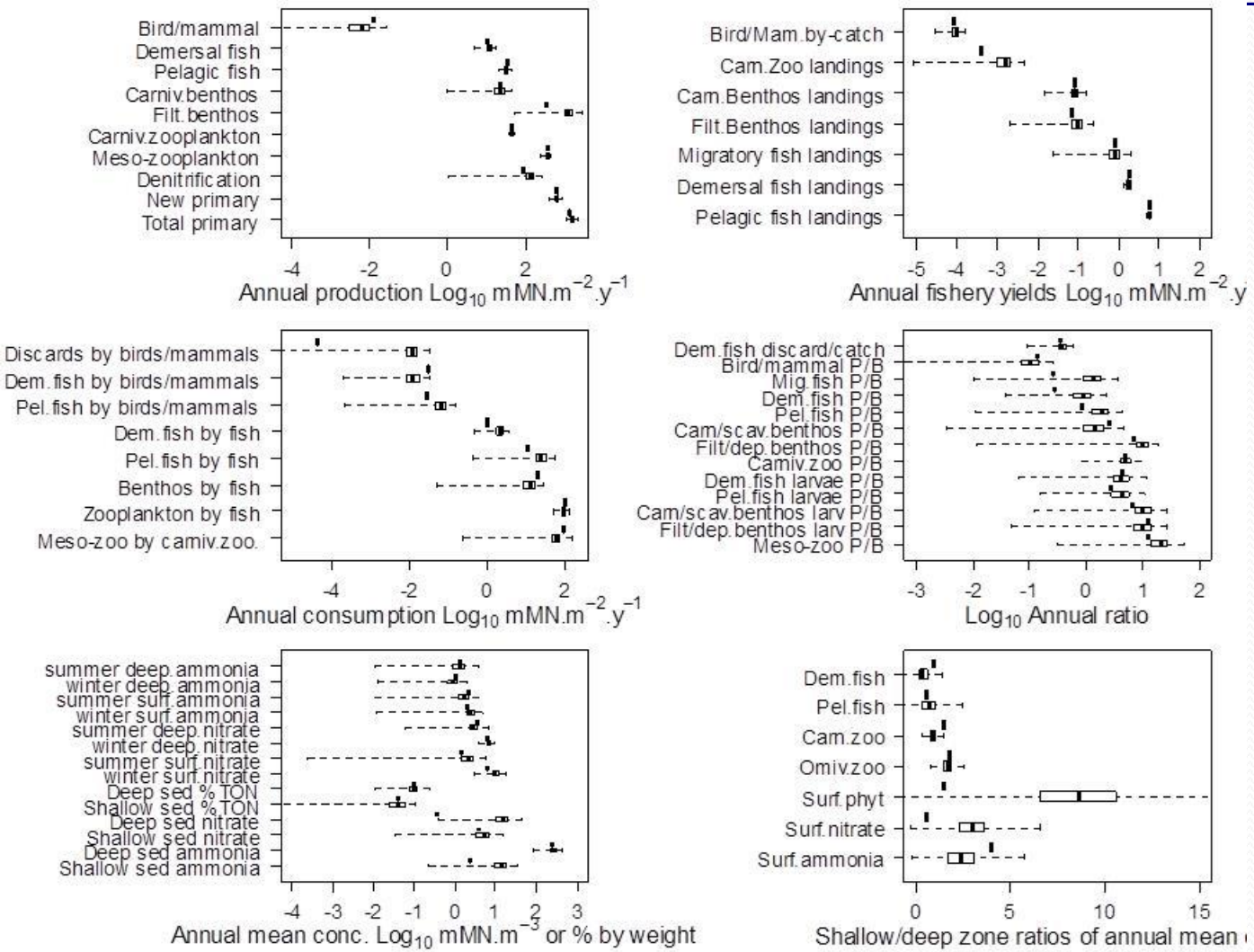
Baseline model for the North Sea

- 11 types of fishing gears; 1970-1999 climatological average annual cycle of oceanographic inflow rates from POLCOMS, temperature, river inflows and atmospheric inputs from data analyses.

- Run to a repeating annual cycle (stationary state) with repeating annual cycles climatological drivers and fishing activity rates

- Simulated annealing used to find the maximum likelihood parameter set for the model, given an array of 1970-1999 observed data on biomass densities, production rates and feeding fluxes

Fitted model with 1970-1999 climatology driving data, relative to observed ecosystem metrics



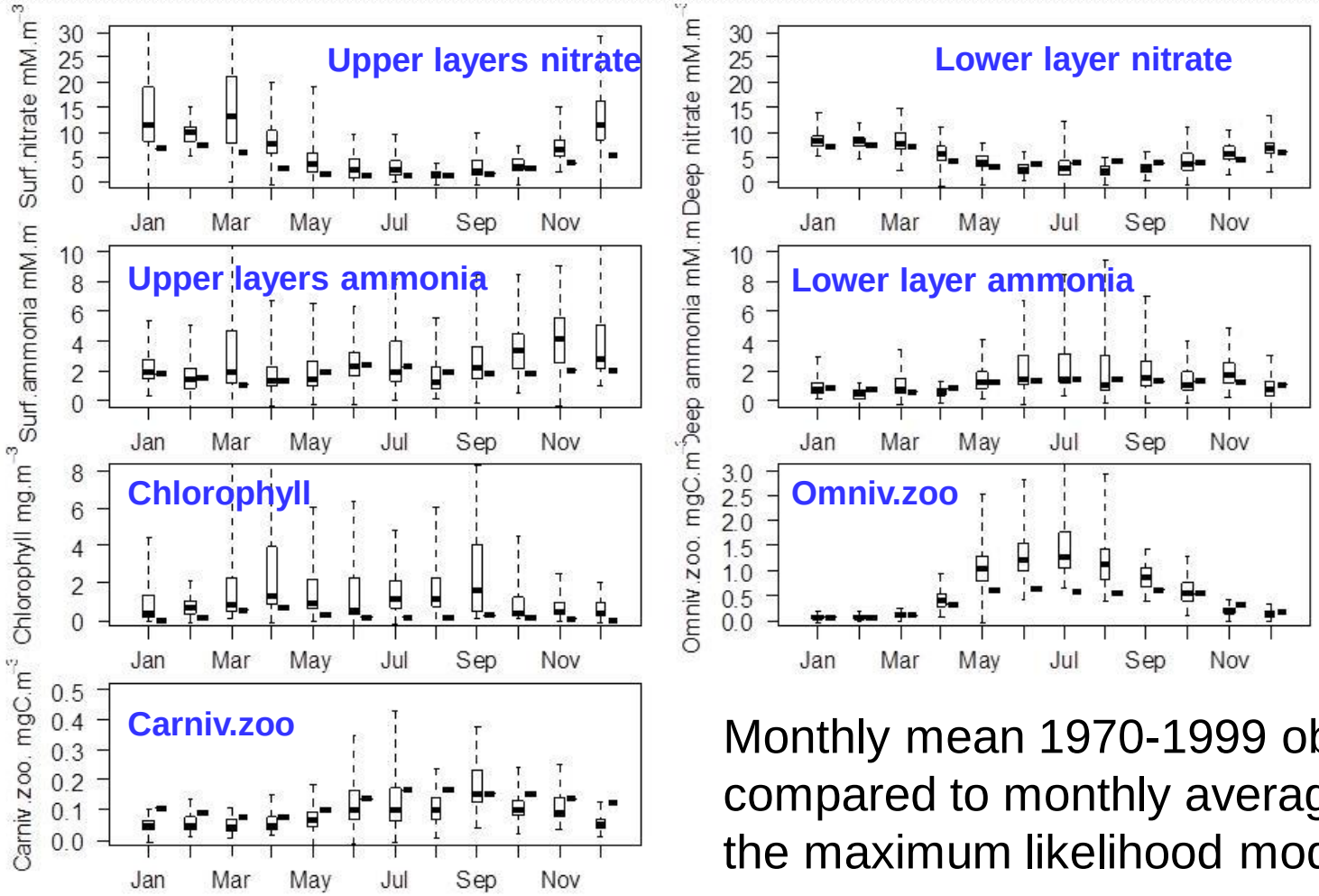
Computational fitting (simulated annealing)

Seeks the maximum likelihood parameter set given the external driving data and the (observed) target data

Box-and-whisker plots: median, uncertainty in observed target data; **tick marks**: maximum likelihood model

120 parameters fitted; 10,000 model runs of 100 years each.

Credibility check of the fitted model – how well does it represent the annual cycle



Monthly mean 1970-1999 observed data compared to monthly averaged data from the maximum likelihood model

Sensitivity to contentious features of trawl gears

- **Selectivity scenario** – harvest rates reduced commensurate with no by-catch of non-target model groups, and no catch of undersize demersal fish, by any towed gears

- **Discard scenario** – no discarding of any catch by any towed gears

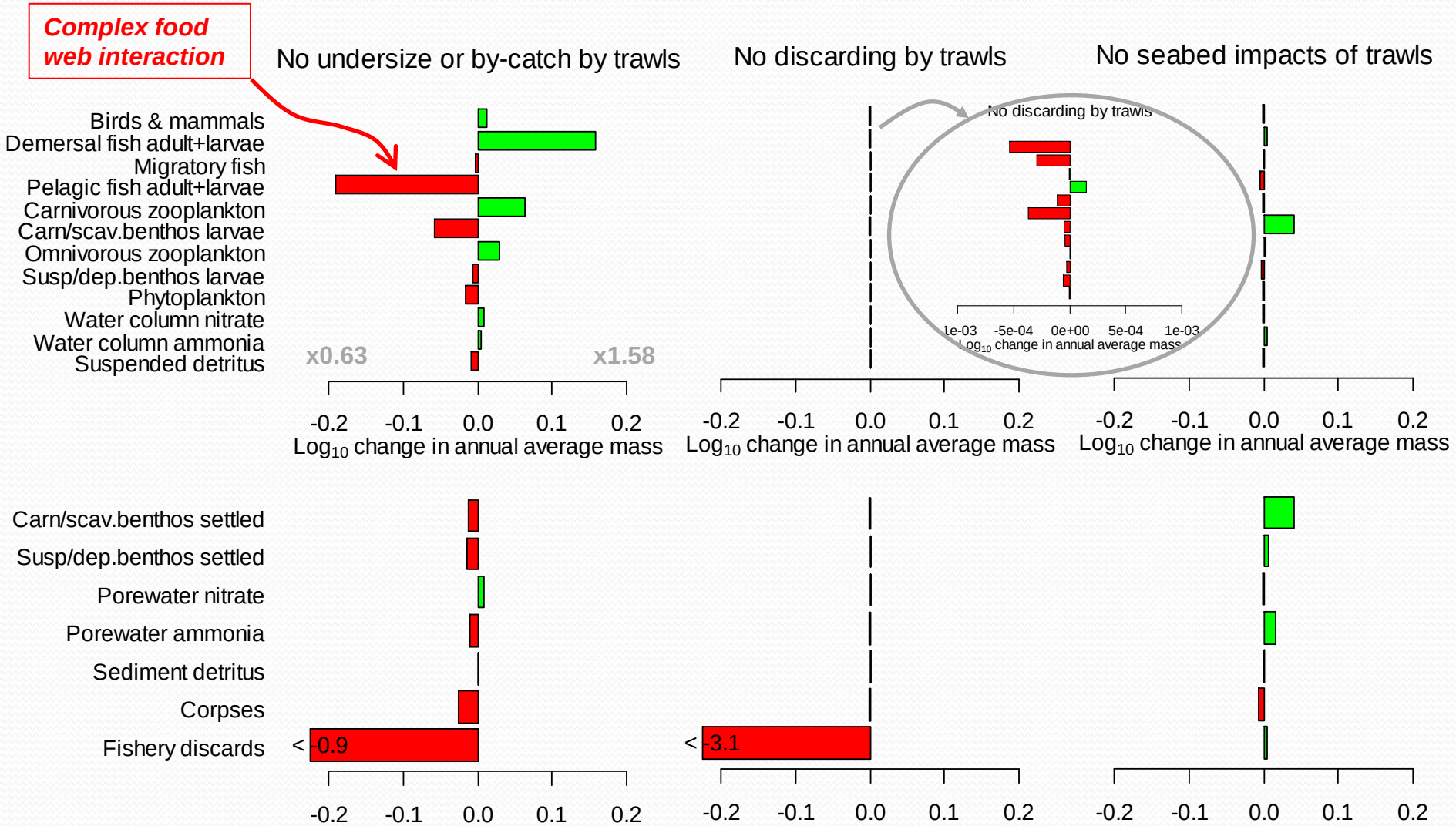
- **Seabed impact scenario** – no seabed penetration by any towed gears

- **All combined** – selectivity, discard and seabed impact scenarios combined for all towed gears

- Run each scenario to a stationary state with the same environmental drivers, same activity rates of each fishing gear, and fitted ecology parameter values.

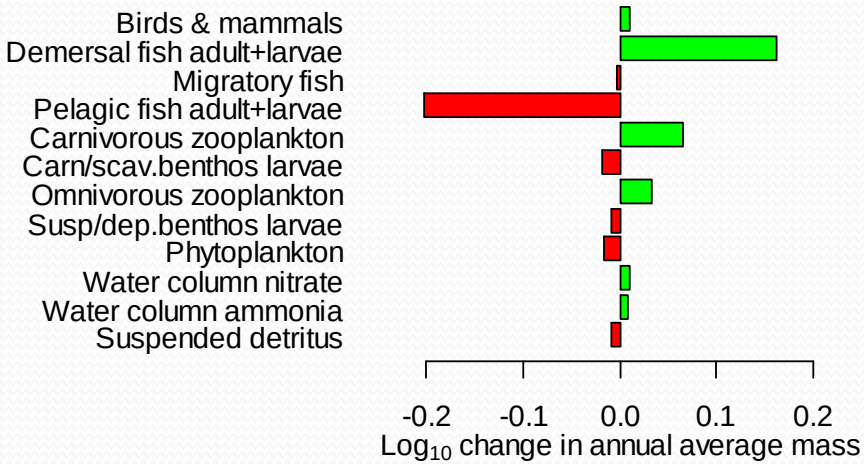
- Compare each scenario simulation to the baseline model

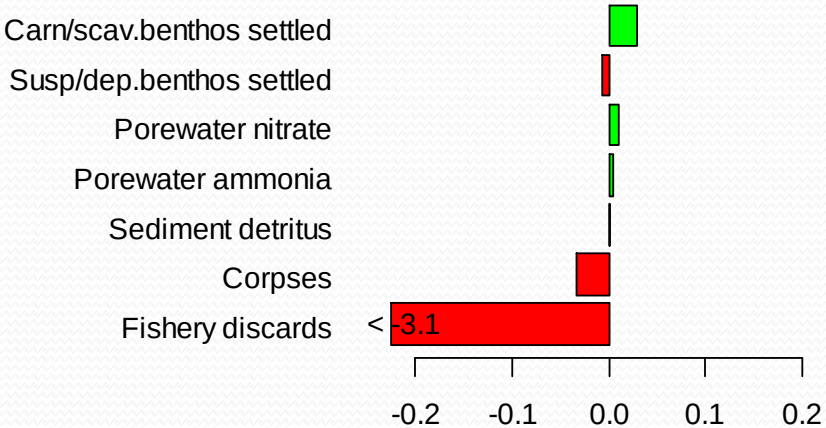
Whole model region - ecosystem sensitivity to main features of trawling (scenario – baseline)



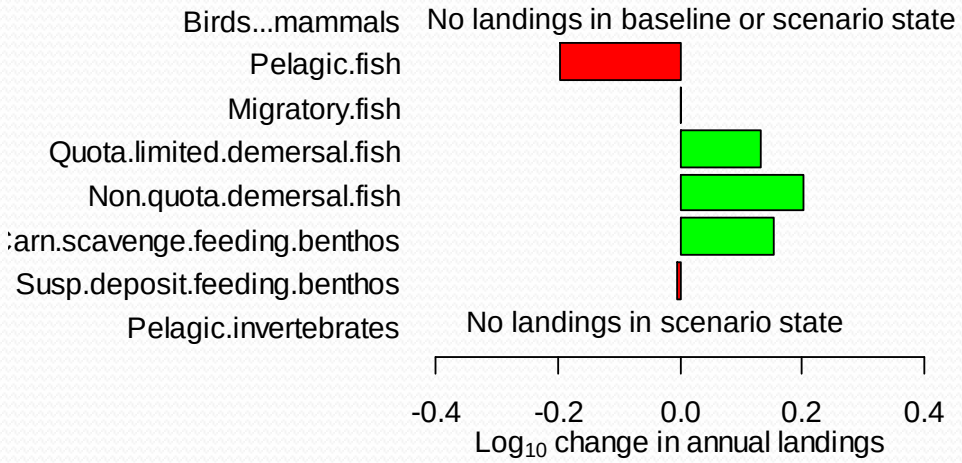
Whole model region – sensitivity to combined properties of trawls (scenario – baseline)

Effects on the ecosystem





Effects on landings



Conclusions according to the model

At the regional ecosystem scale:

- Poor selectivity is by far the most ecologically impactful feature of trawling gears
- In comparison, we find very little support for the ‘ploughing the fields’ argument
- Enforcing a landing obligation (discard ban) without tackling selectivity is futile. No conservation benefits.

None of this should detract from the potential for serious habitat damage at local scales (e.g. Loch Carron flame shell reef), or cumulative effects on benthos biodiversity

- *and note that any survival premium for eg juvenile fish due to some fragile habitats is not recognised by the model*

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After-thoughts and discussion points

- We should not be over-critical of trawling – static gears are not all rosy either - cetacean mortality due to entanglement; plastic debris; ghost fishing.

- The density of static gear required to match the yields generated by trawling would be unimaginable.

- Model results are sensitive to how we represent active migrations of fauna between spatial compartments
  - Next big challenge in ecosystem modelling
  - Need to represent the behavioural responses which lead to emergent movements, if we can, rather than just pre-programme ‘clockwork’ animals to move around.

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