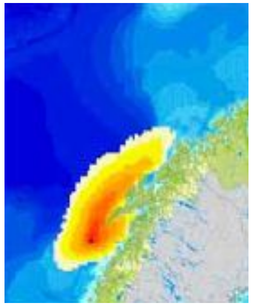
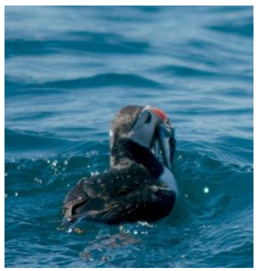
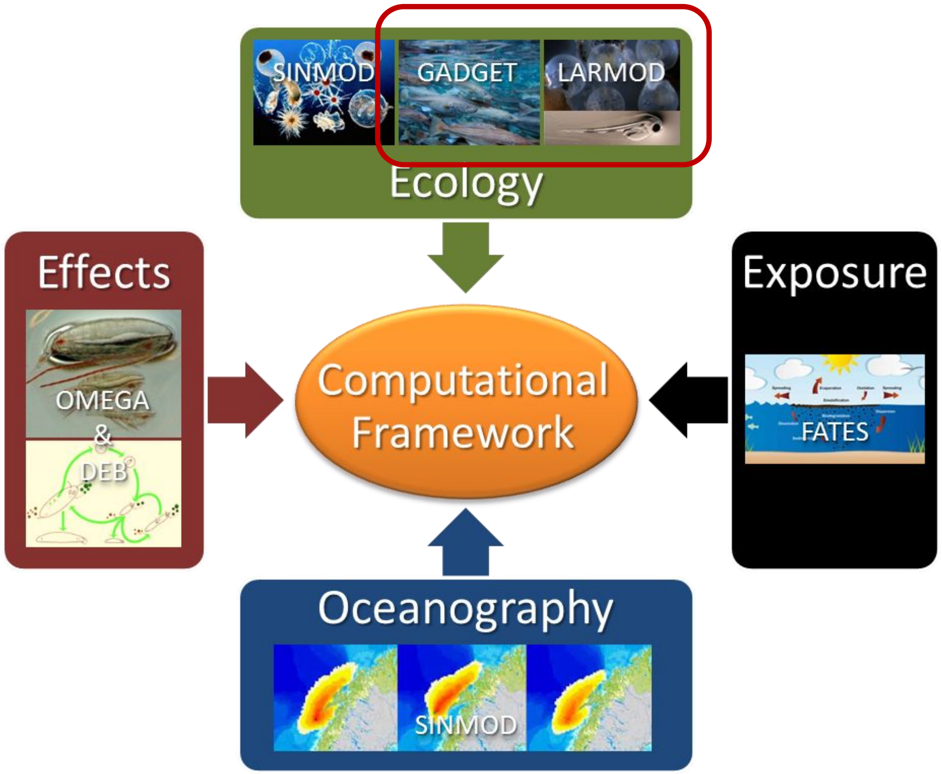
SYMBIOSES

An integrated modeling framework for decision support in marine ecosystem based management





Larval and adult fish modelling



In order to evaluate effects on fish populations we need to model:

Eggs and Larvae

Where they spawn

How the move, feed, grow, and die

Fish

How many larvae become fish

How does the fish population develop

What happens when you add oil

We take the oil concentrations and impact on the plankton and on to fish larvae and fish populations

Eggs and Larvae: LARMOD

- **Individual Based Model**
- **Runs in high resolution in the Lofotens**

Fish: Gadget

- **Statistical multispecies fisheries model**
- **Barents Sea**
- **Not spatially detailed**

We take the oil concentrations and impact on the plankton and on to fish larvae and fish populations

Eggs and Larvae: LARMOD

- Individual Based Model
- Runs in high resolution in the Lofotens

0-group (”swimming larvae”)

Fish: Gadget

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- Barents Sea
- Not spatially detailed

LARMOD

Models eggs through to the end of the drifting larval stage

Individual Based Model (IBM)
depth and position

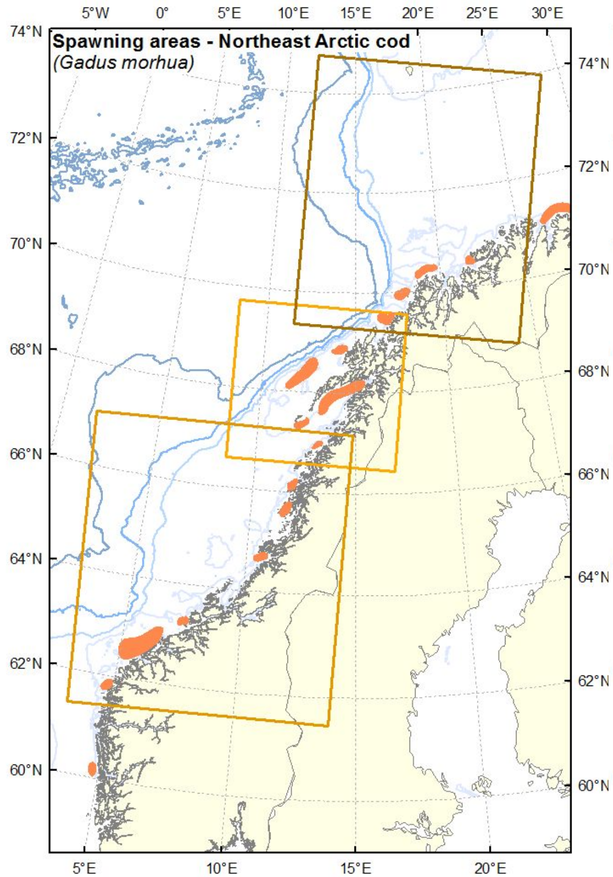
Models vertical destribution, horizontal drift, growth (temperature and food dependent), feeding and mortality

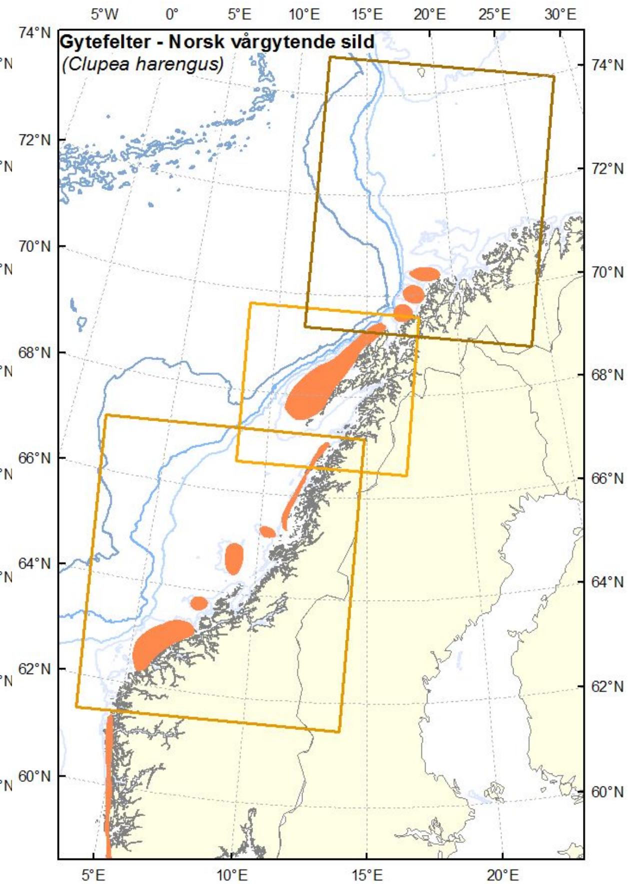
- Location, timing and abundance of eggs.
- Ocean circulation model covering the larval areas
- Spatiotemporal food and predator abundance.
- Spatiotemporal concentrations of oil components.
- Body burden model, effects of egg and larvae exposure to oil.

- Model drift, growth and survival
  - Until the larvae stop drifting

Requirements

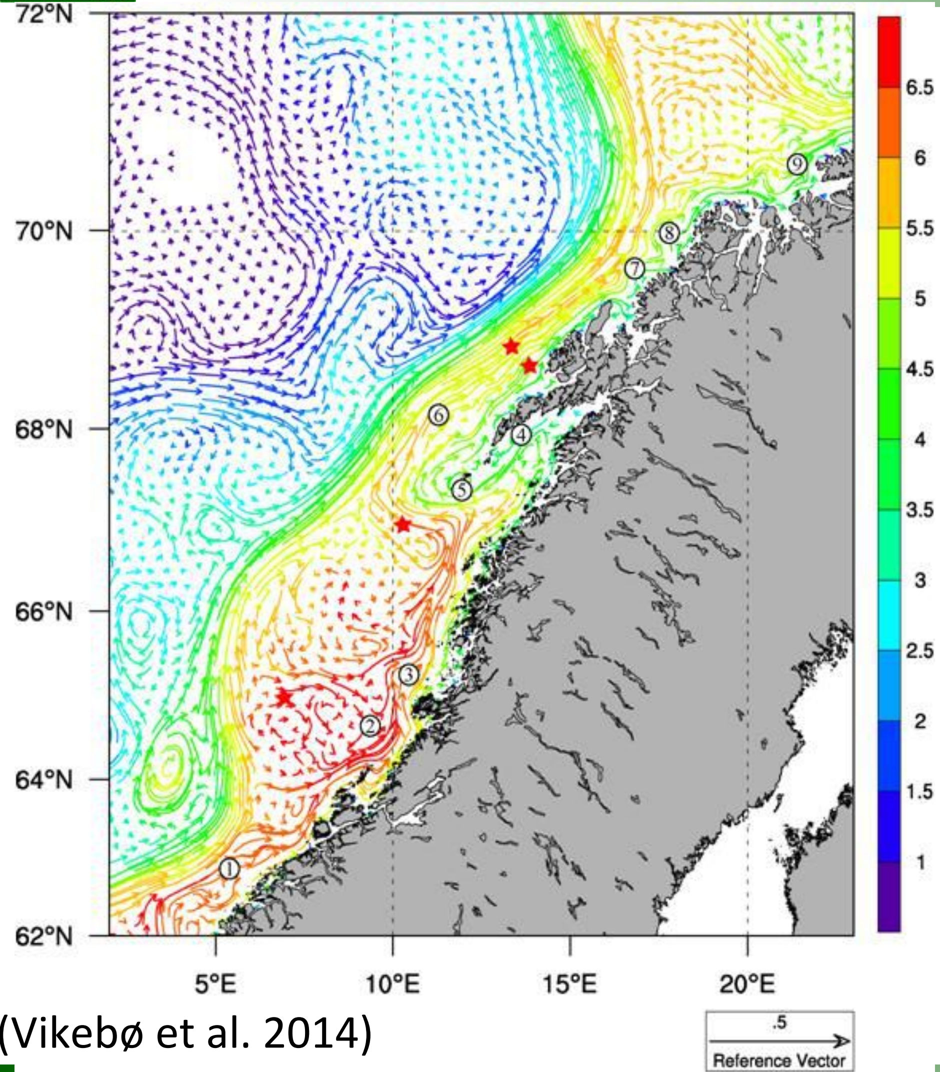
Fish eggs and larvae





Spawning grounds based on observations

Numerical ocean model



(Vikebø et al. 2014)

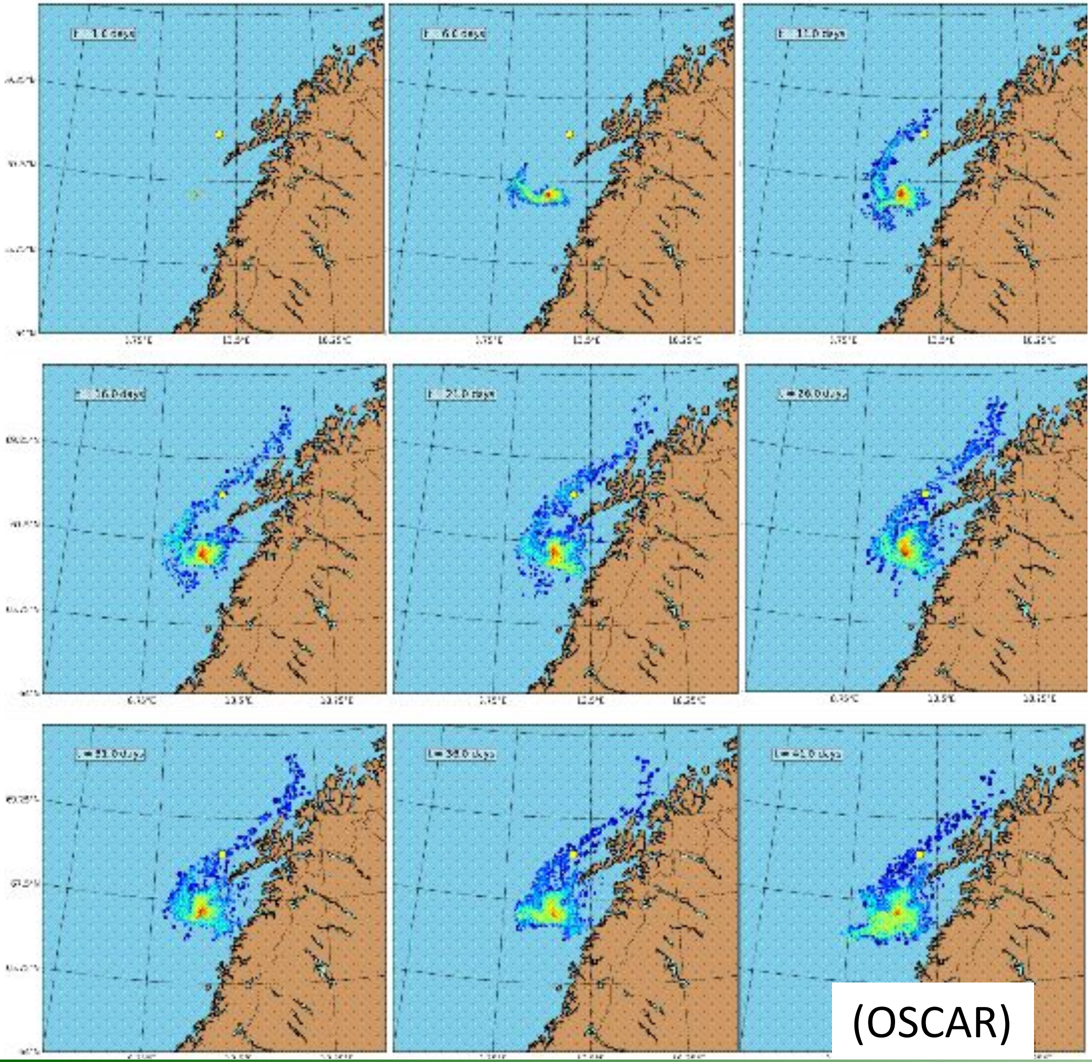
★ Hypothetical oil spill

(3) Spawning ground number 3

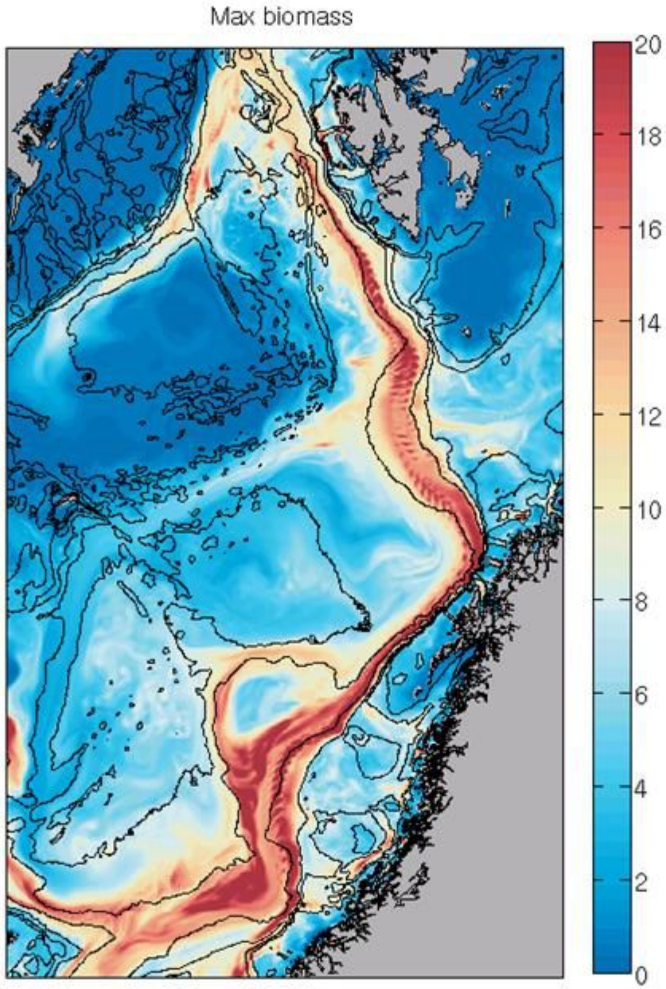
- Oil spills can be placed in the model at hypothetical locations.
- Spawning location of fish in accordance with observations.
- The spatiotemporal circulation allows quantification of individual egg and larvae exposure to toxins aswell as prey and predators.

Oil, eggs, larvae and larval prey dispersal by simulated currents

Oil concentrations and larval prey availability updated every 6 minutes



(OSCAR)

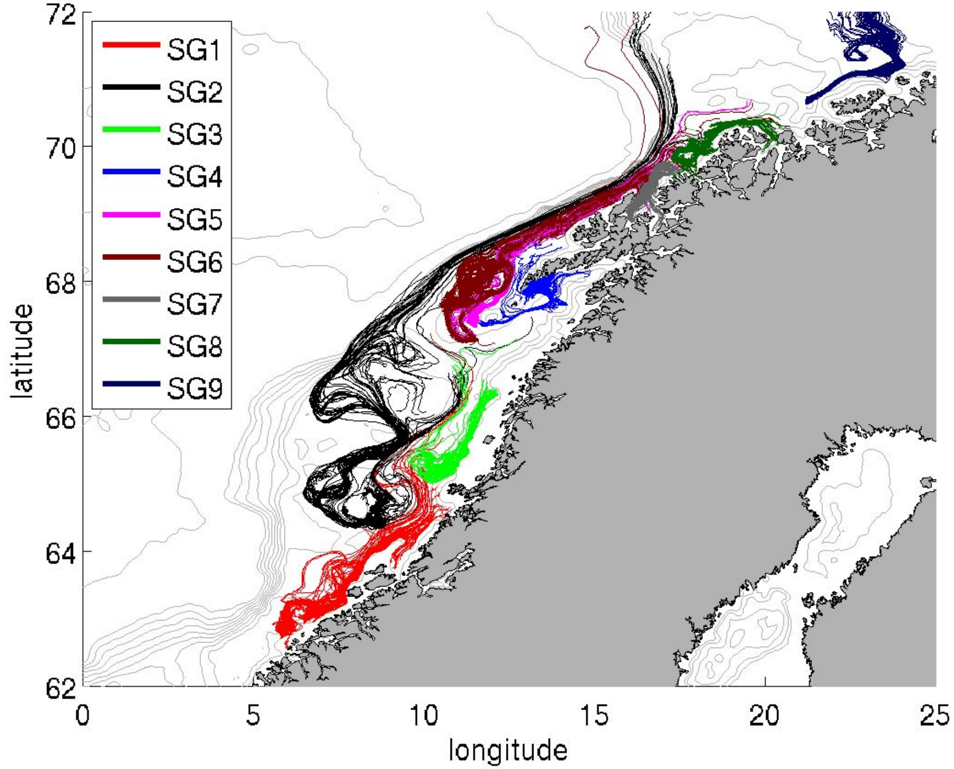


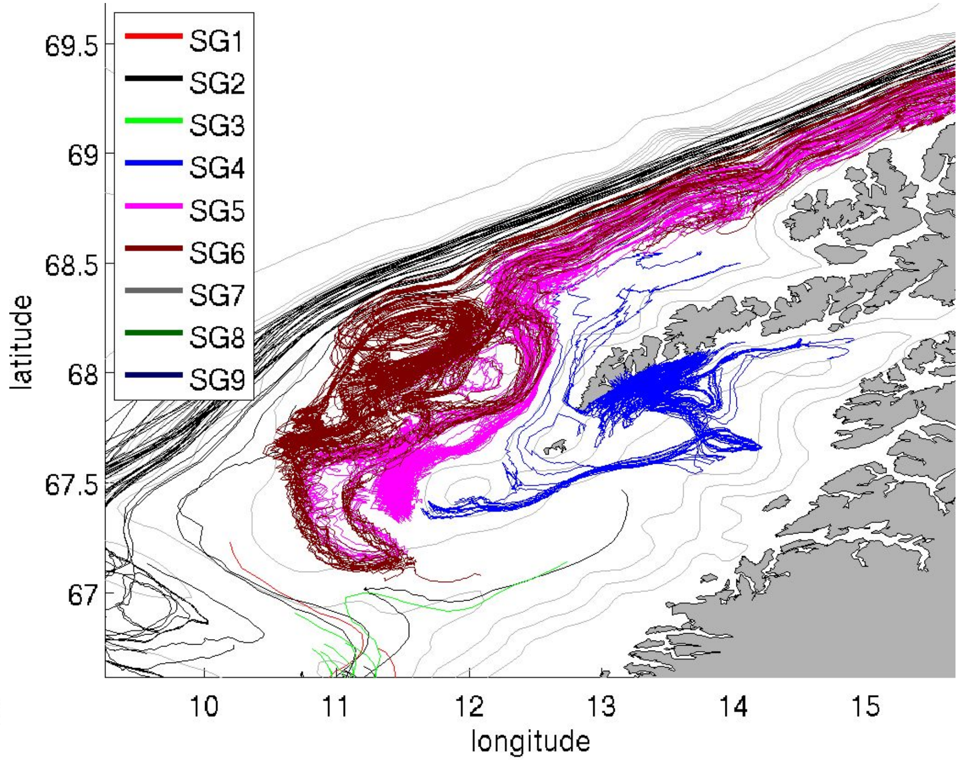
(SINMOD)

g C m^{-2}

Larval prey and toxins

100 days of drift of eggs and larvae spawned end of April

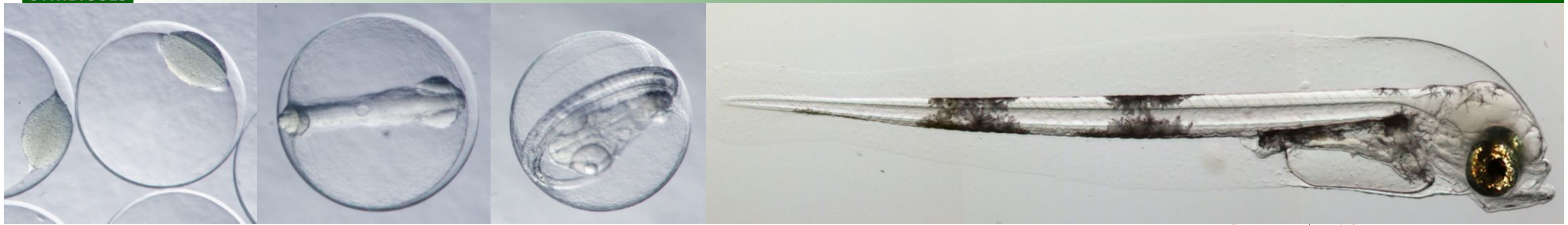


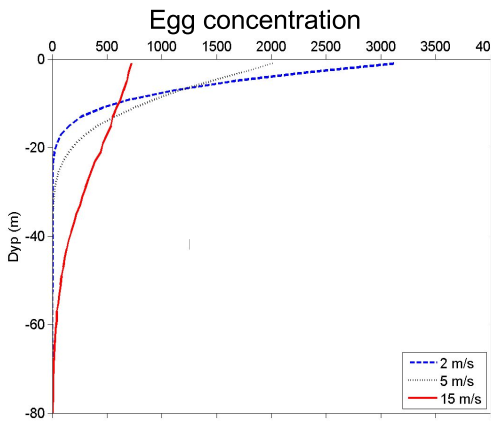


The trajectories of the 100 particles released from each of the 9 spawning grounds belonging to batch 6 (released 19 days after the simulation start, April 7th). The simulation period is 100 days, enabling 81 days of drift for these particular individuals.

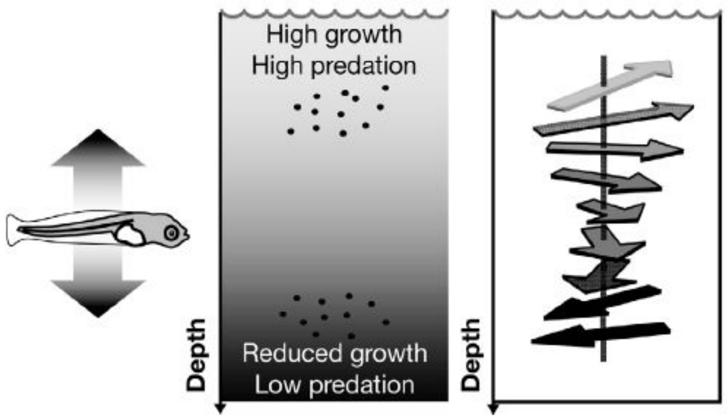
Different spawning grounds

Vertical distribution of fish egges and larvae affect dispersal

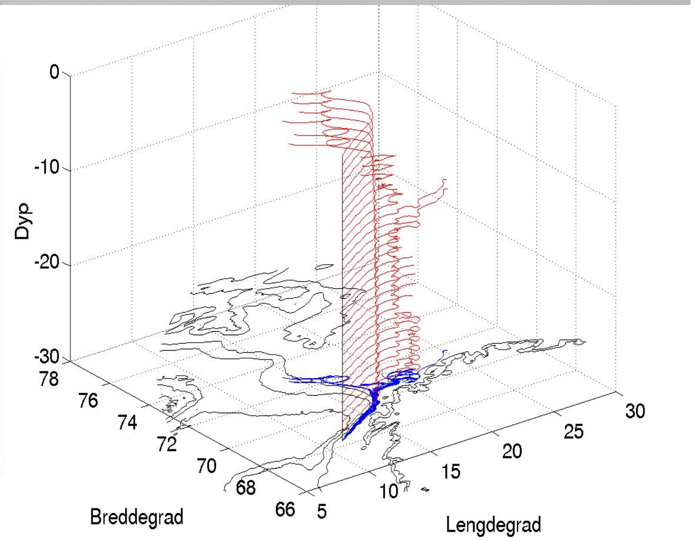




(Rohrs et al. 2014)



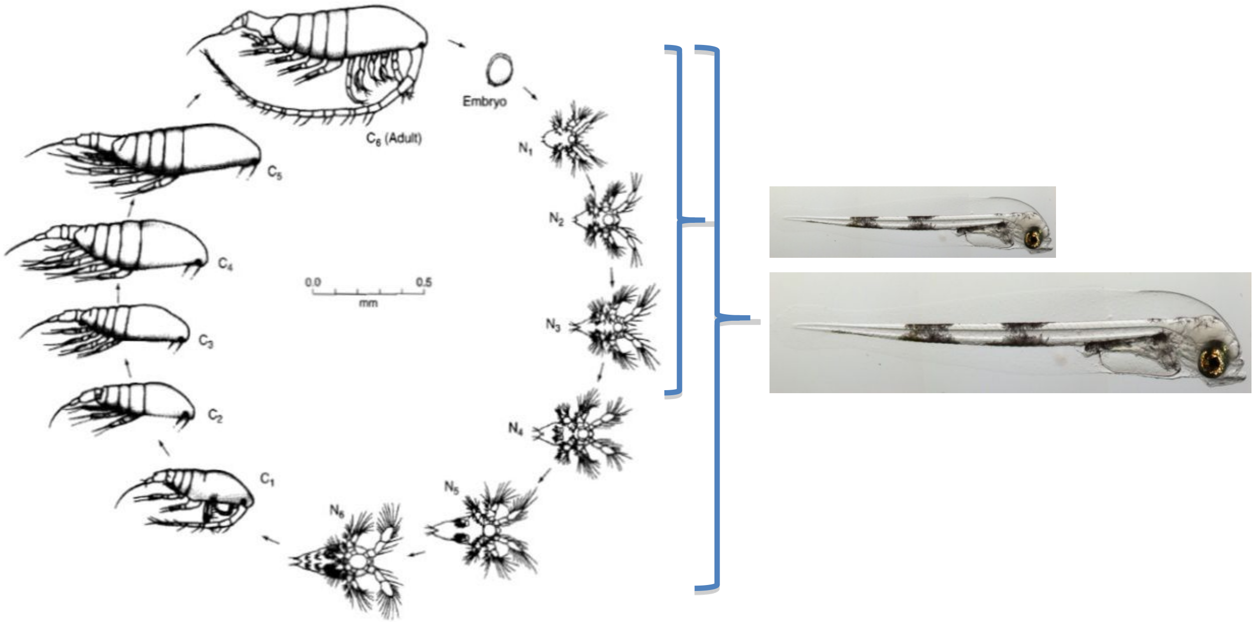
(Fiksen et al. 2014)



Light is a key determinant for encounter rates of larval fish with both prey and visual predators, and it decreases with depth. Hence, vertical positioning affects immediate growth and survival, but also large-scale and long-term drift and dispersal.

Dynamic vertical positioning of eggs and larval migration

Fish larvae feeding

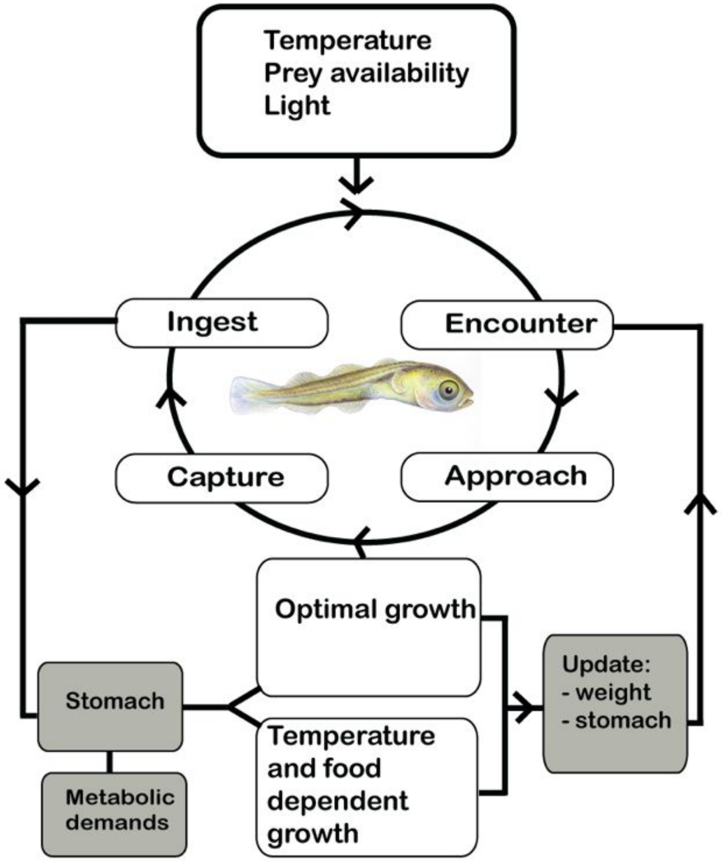


Indvidual larvae in LARMOD sample the modeled calanus fields from SINMOD. Larval size determines which nauplii and copepod stages they can eat.

Growth dependent on food availability

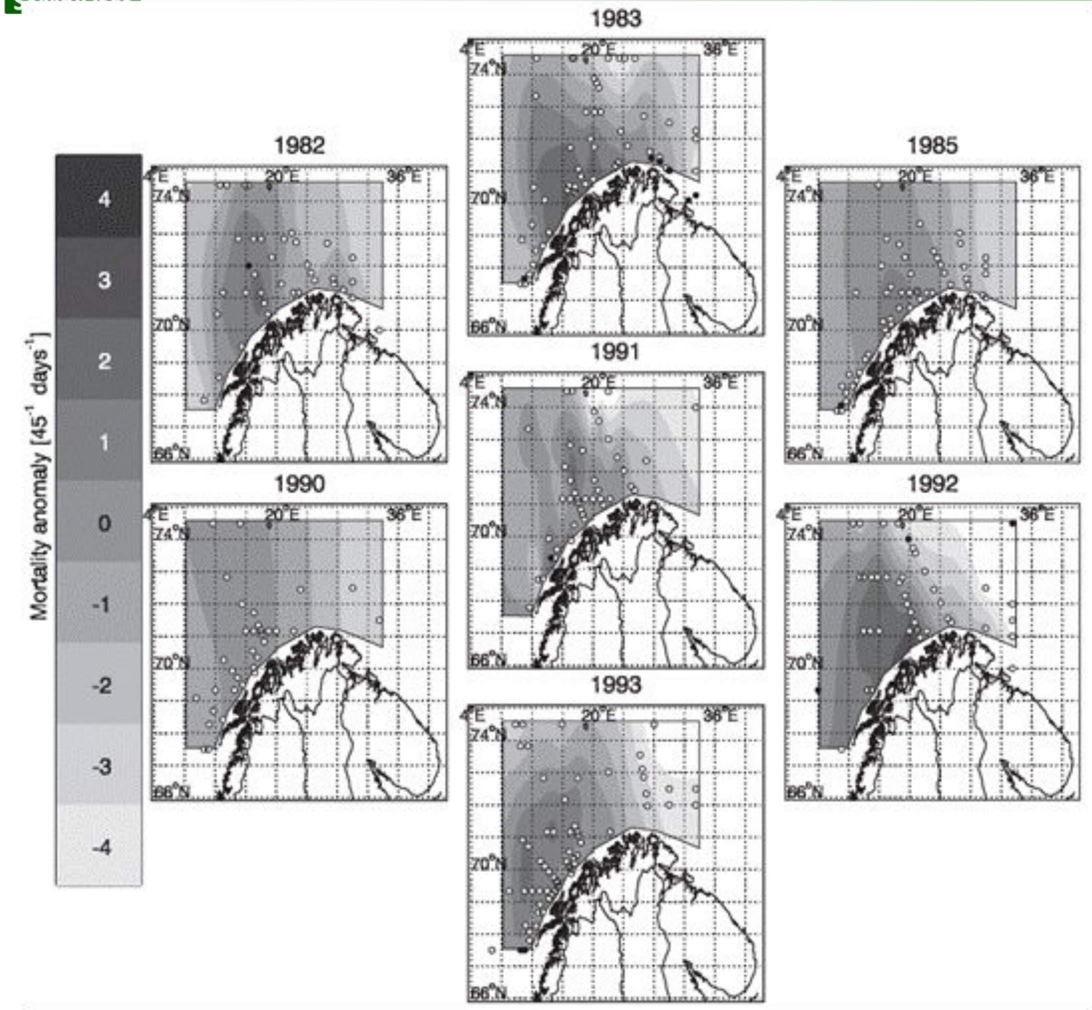
Fish larvae feeding

- **Dynamic state variables:** environmental signals (e.g. temperature, turbulens, light, advection, prey, toxins) affect the dynamic state variables (position, weight, stomach content, survival probability) in LARMOD.
- **Behavior:** Vertical gradients stronger than horizontal gradients. Vertical distribution of eggs and larvae important to predict environmental exposure. LARMOD allow larvae to migrate vertically. Horizontal migration considered irrelevant.
- **Imposed vs emergent behavoir:** Behavior is a function of environmental exposure and dynamic state.



(Kristiansen et al. 2007)

Natural mortality in fish eggs and larvae

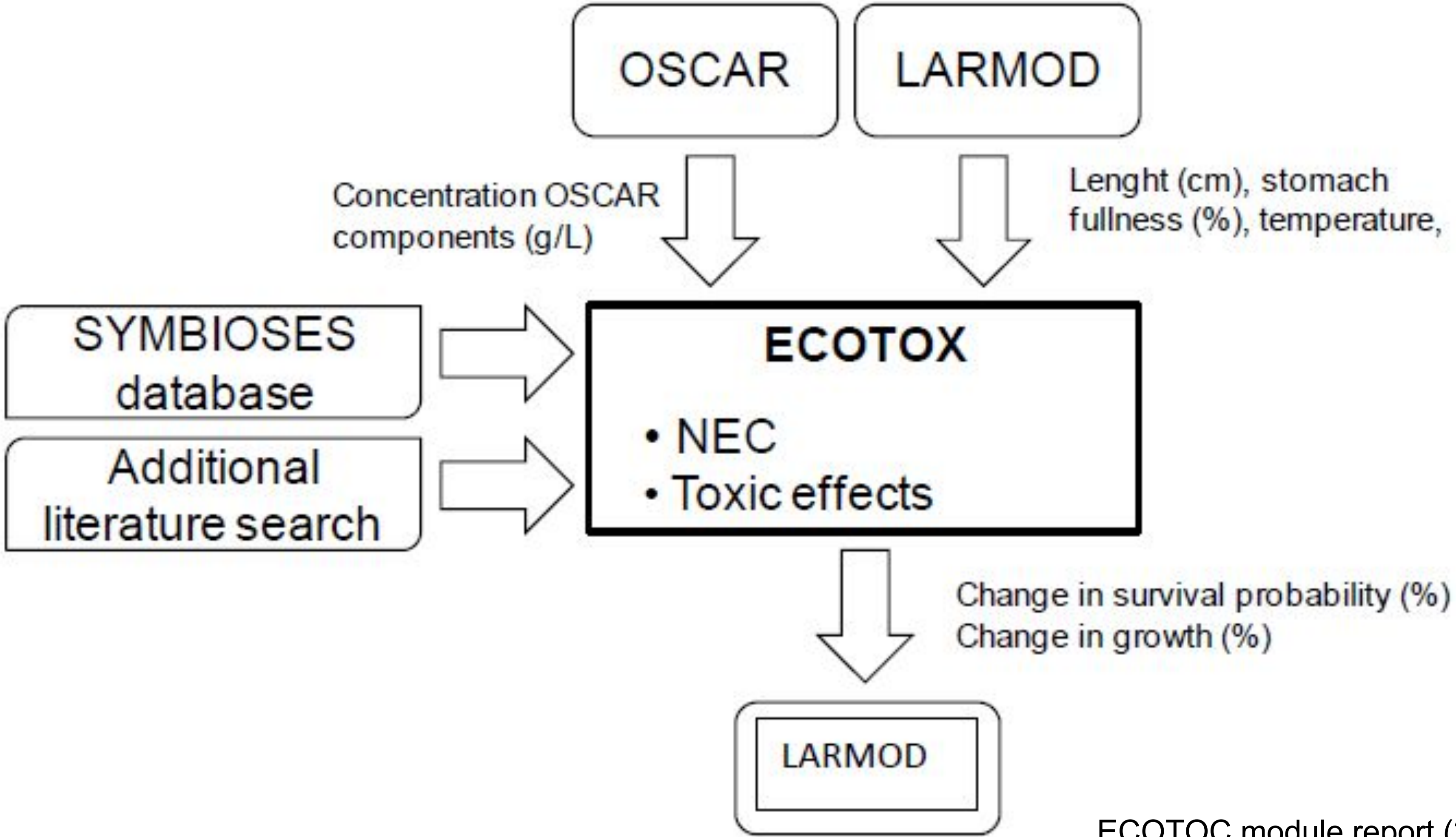


Langangen et al. 2014

- Egg mortality are based on fixed rates (Langangen et al. 2013).
- Larvae mortality can either be fixed rates (Langangen et al. 2013) or a combination of size and light dependence (Vikebø et al. 2007).
- A future possibility is to utilize estimates of spatial anomalies in mortality based on spring and summer observations of ELS of NEA cod in combination with a biophysical model (Langangen et al. 2014).

A key knowledge gap

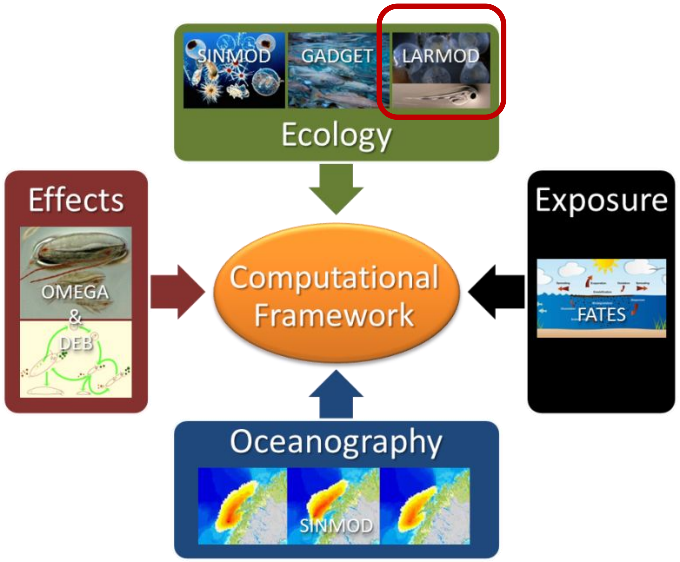
LARMOD and the DEB model



ECOTOC module report (2013)

Model inputs & outputs

LARMOD interaction with SYMBIOSES summarized



Fish larvae & egg Model

Input

- 3D oceanographic time series
- Light
- Stage-dependent prey concentrations
- Predator effects/ concentrations
- Data sets of egg distributions and abundance
- Ambient chemical concentrations
- Rate reductions from Ecotox module:
  - Mortality
  - Growth
  - Reproduction

Survival fraction as a function of age

Larval stomach content

Lipid content, energy reserves in fish larvae

Age structure

Behavior

Output

- 3D distribution time series
- Species and life stages (eggs to juveniles)
- Effects
  - Body burden
  - Survival probability
  - Growth effects
  - Survival fraction as a function of age

Model inputs & outputs

Larvae to fish: LARMOD to Gadget

It is known to be difficult to go directly from the number of eggs to the number of fish the following year

Typically over 99% mortality on larvae

=>cannot be precise enough in modelling the mortality to get the fish numbers right

Use recruitment estimates from a purely fish model

Larvae to fish: LARMOD to Gadget

”Gadget” models recruitment as the number of ”baby fish” needed to fit the data we have on the fish population.

We then just need to transfer the ”extra mortality” from LARMOD to Gadget
Reduce the number of recruiting fish according to what fraction were killed by the oil

BUT…

0-group

LARMOD is a IBM model of the drifting larvae

Gadget is a fisheries model working from age 1+

There is a gap in the middle, swimming ”0-group”

0-group

Cannot model 0-group as drifting particles

Difficult to directly model the processes affecting the 0-group (limited data)

We do know that there is ”density dependent mortality”
(probably ”food dependent” in reality but we don’t have enough data to model this)

0-group

Why does density dependent mortality matter?

More 0-group=more natural mortality
Less 0-group=less mortality

Killing larvae reduces the number of 0-group
=>which reduces natural mortality

Compensatory mechanism, reduces the impact of the oil spill

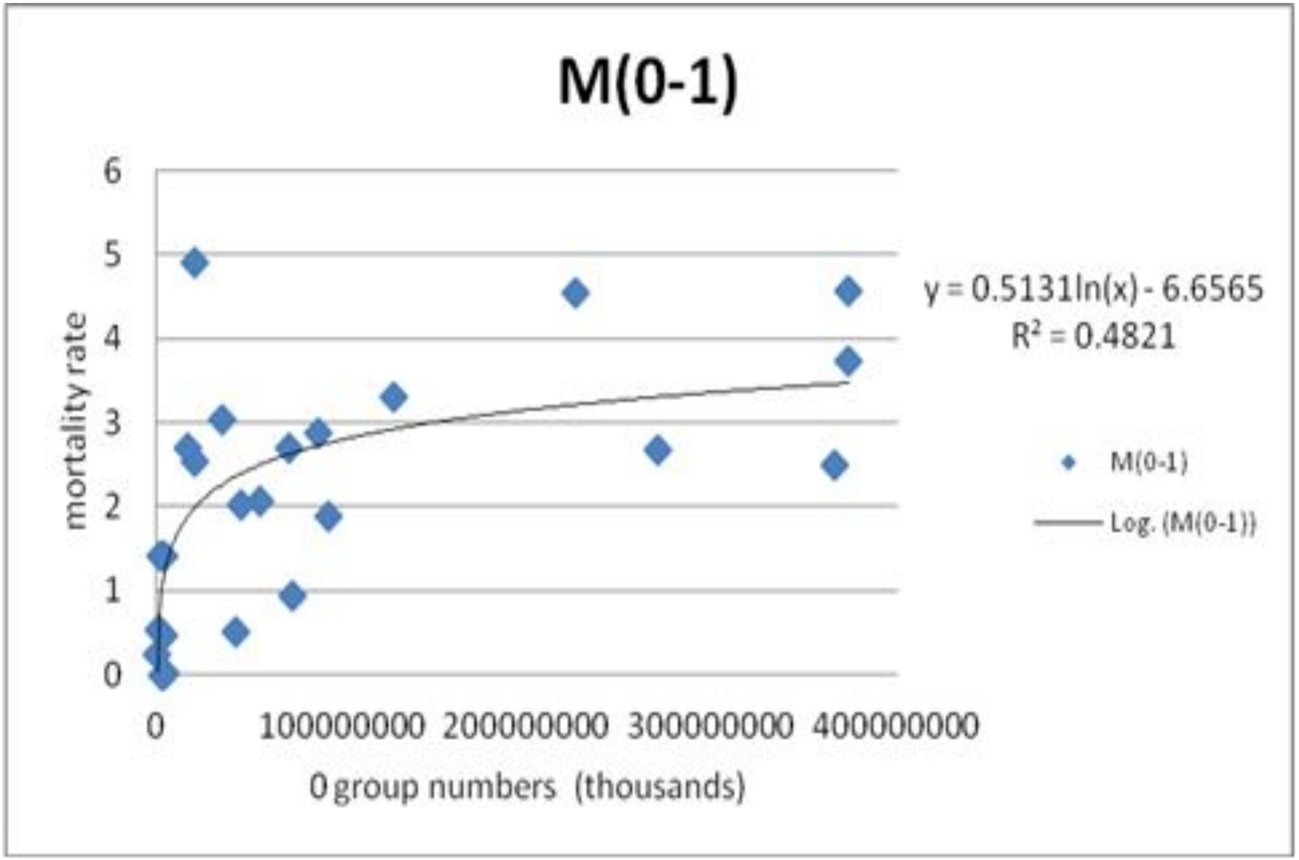
There is considerable year-to-year variation in

- The number of 0-group recruited
- The mortality on the 0-group

- Noisy data
- Real variability in mortality

But there is also a strong signal that comes through

0-group


M(0-1)
6
5
4
3
2
1
0
mortality rate
0
100000000
200000000
300000000
400000000
0 group numbers (thousands)
y = 0.5131ln(x) - 6.6565
R² = 0.4821
M(0-1)
Log. (M(0-1))

0-group

We impliment this density dependent mortality
And add year effects to account for the variability

Reduces number of 0-group to get the number of fish the following year

Accounts for the reduction in the effect of oil-induced mortality

GADGET: fish population model

Minimum likelihood, multi-species, multi-area, age-length structured, process-based, forward-simulation Markovian fish population model

OR (in english)

Sets up a model for the main species, follows them through their lives (born, grow, breed and die), optimises the model to fit the available data

GADGET: fish population model

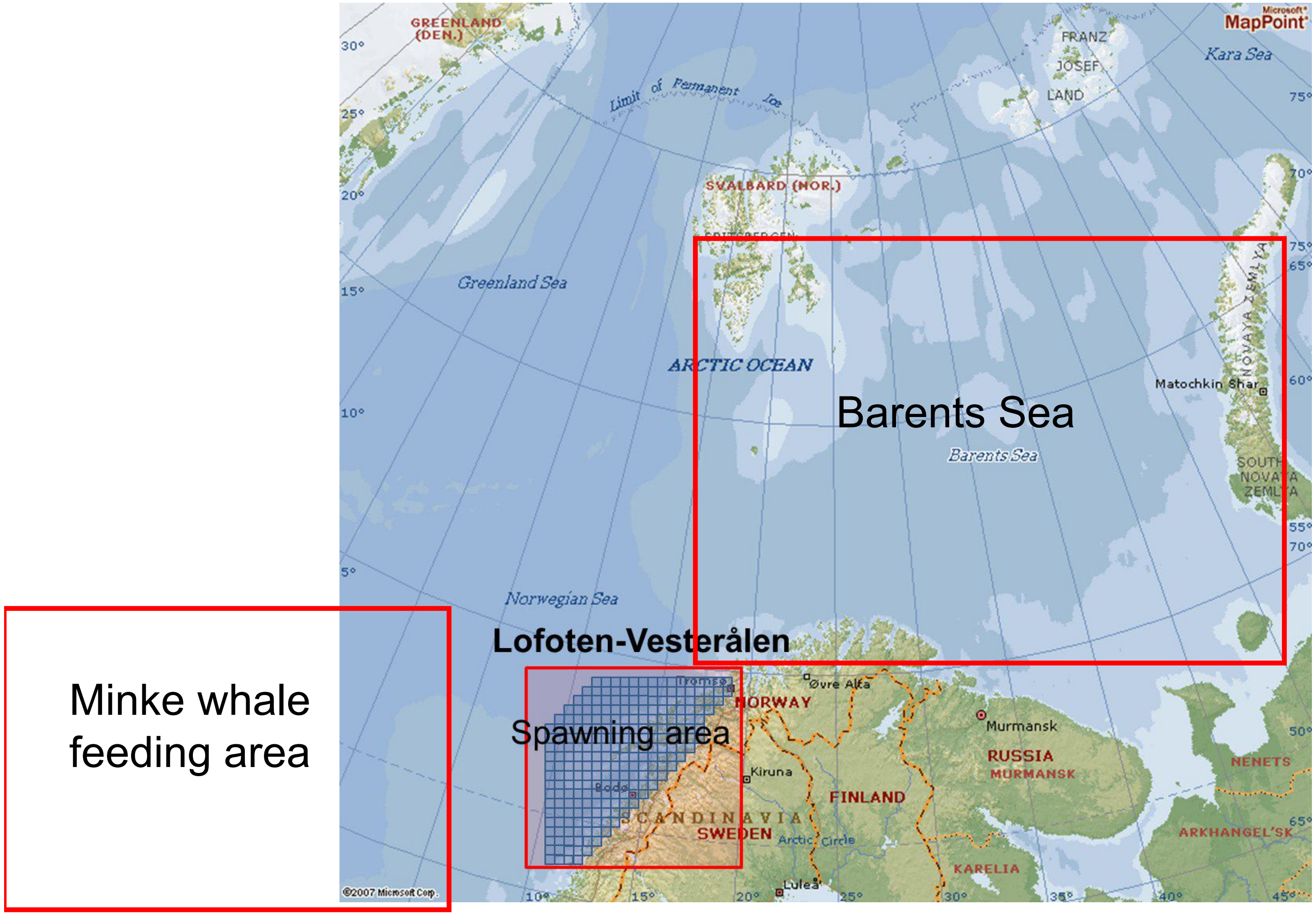
Create a model without oil influence

Tune this to best fit the historical data

Add in the extra mortality for the simulated oil spill

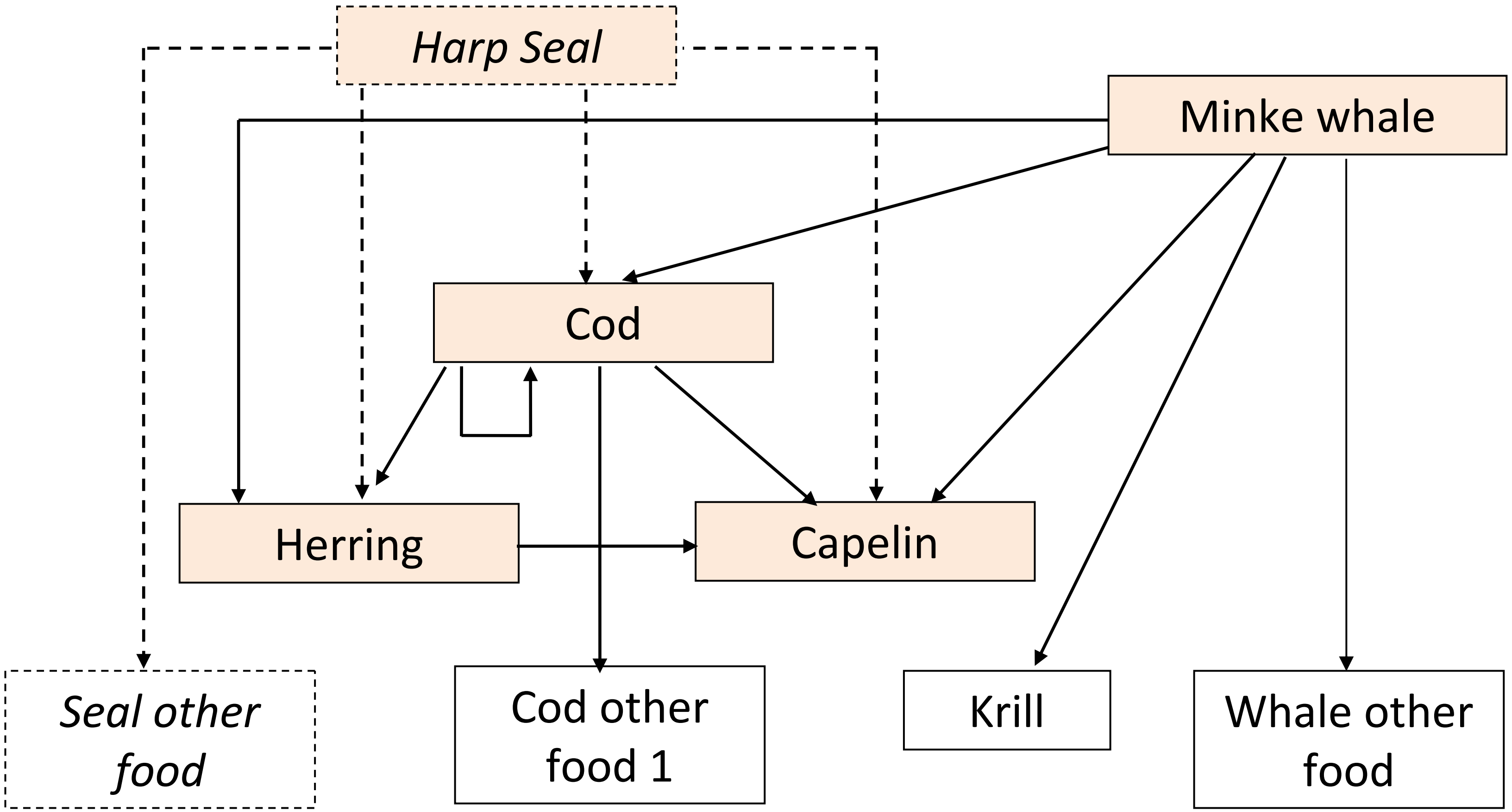
Model the effects on the cod population

Gadget: model area



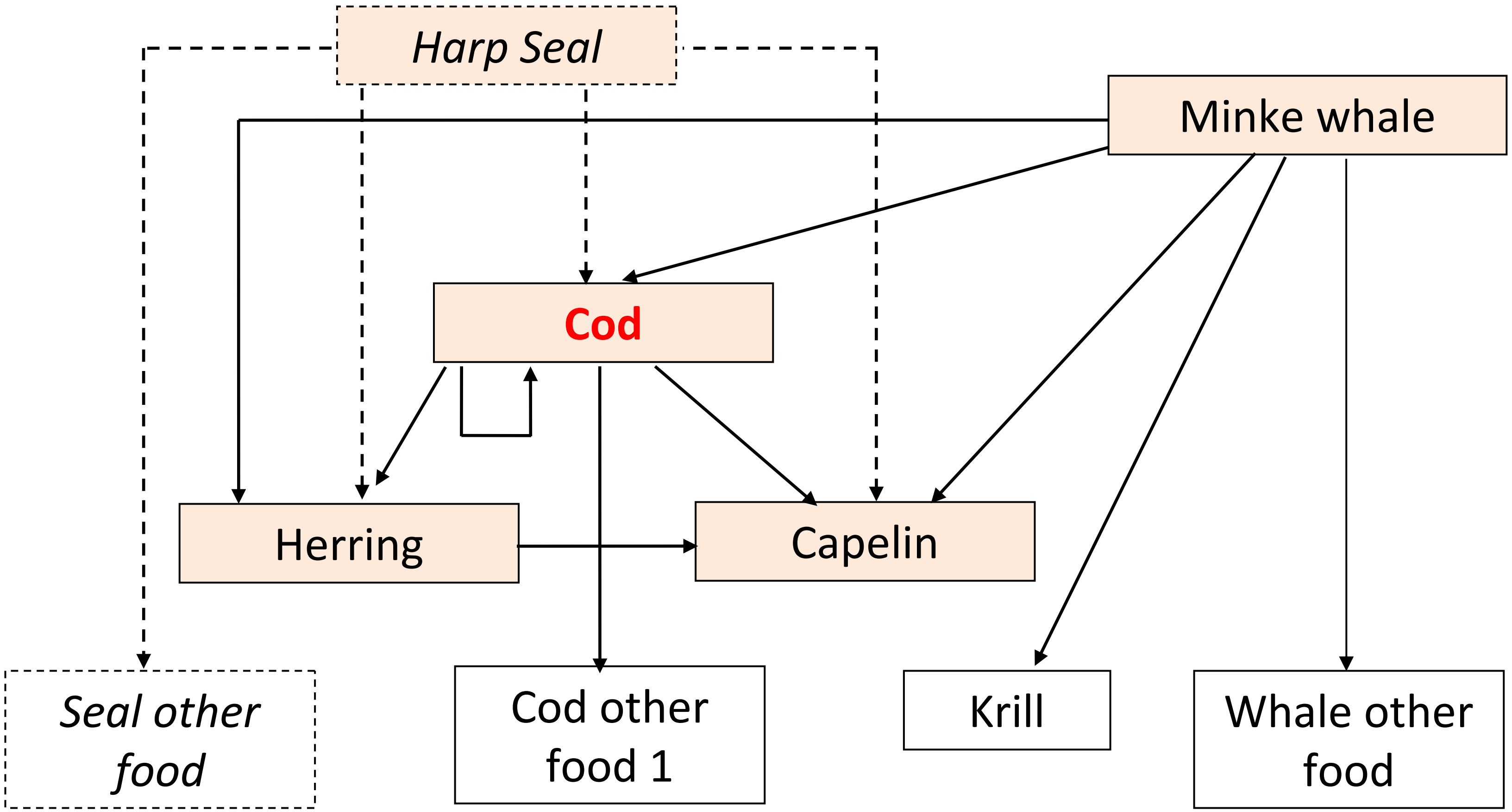
Fish populations

Gadget: fish population model



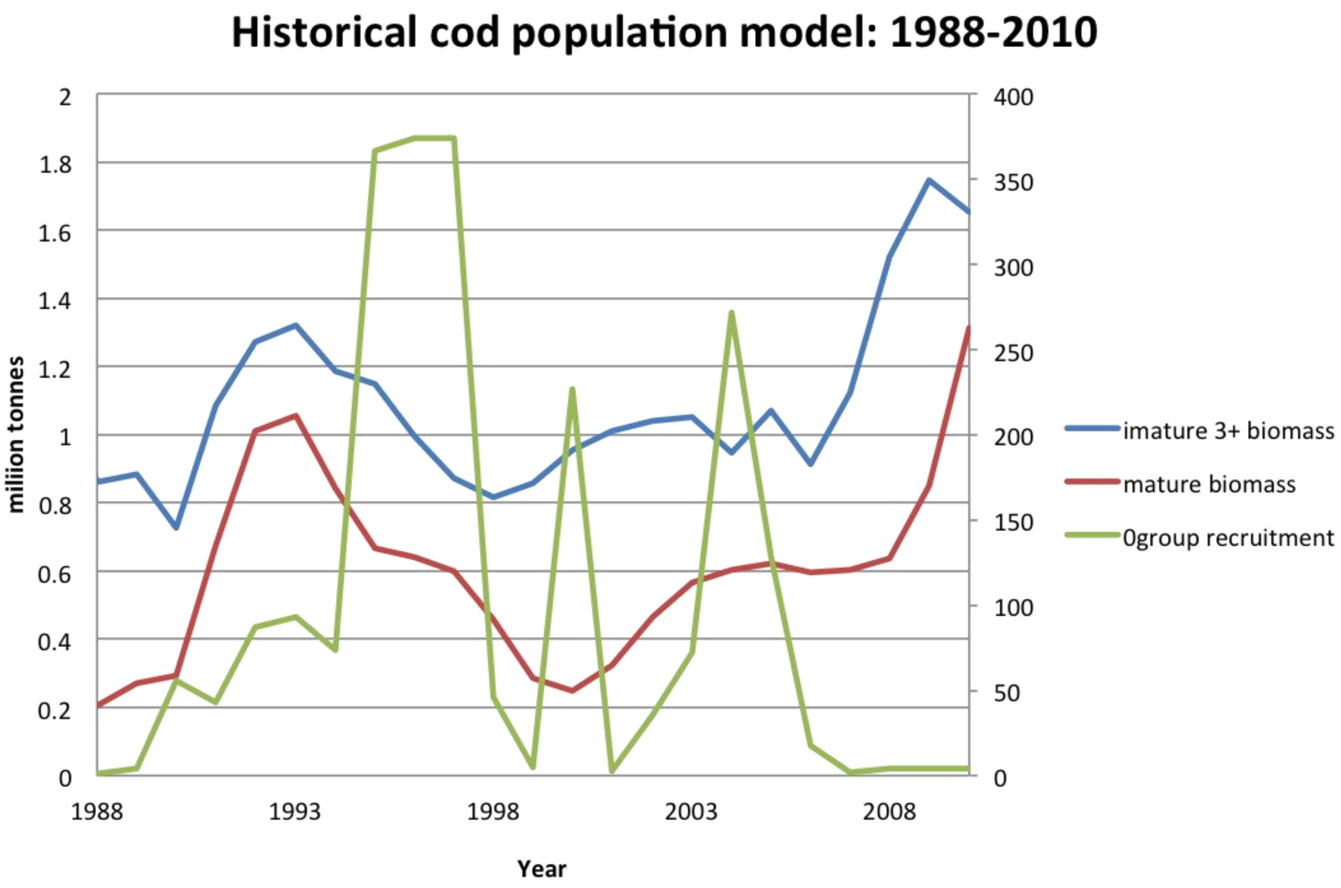
Fish populations

Gadget: fish population model



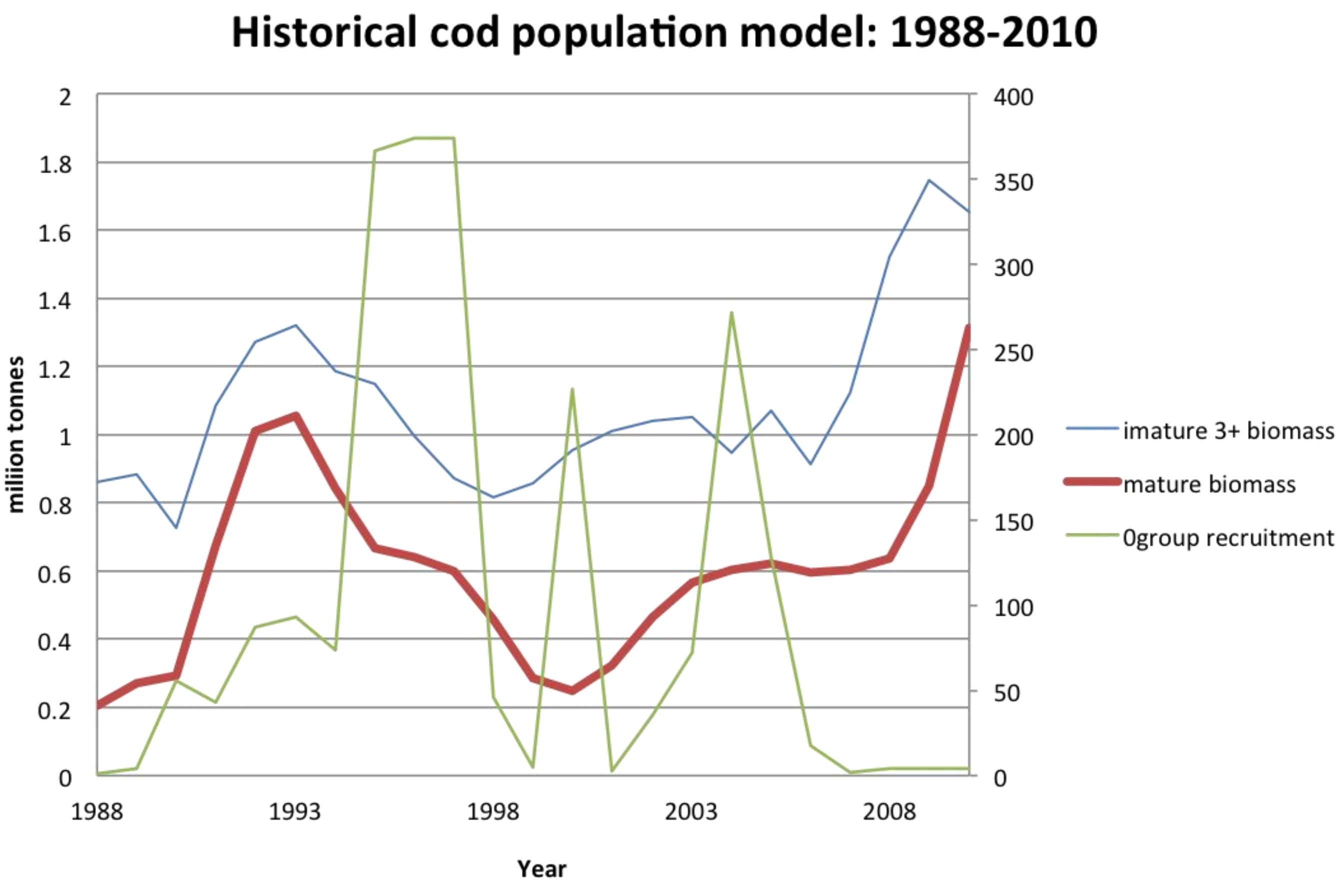
Fish populations

Gadget: fish populations



No oil discharge

Gadget: fish populations



No oil discharge

Purposes

OR: what is this good for?

Obvious answer: improving the current risk assessments around oil spills

=> replacing some of the ”rule of thumb” safety factors with more realistic modelling

Spatial analysis of different oil spill sites

Examination of possible mitigation measure

Puts oil and fishing impacts into a common framework

=> integrated ecosystem management

Purposes: Spatial management

The model is spatially detailed

Can evaluate the likely outcomes of oil spills in different location

Oil drilling has flexibility where a rig should be located (at a cost)

Can go beyond saying ”how bad are oil spills in the Lofotens”

Can ask ”is an oil spill worse *here* or *there?*”

Purposes: Spatial management

Combines

where the oil goes from a particular place
how toxic it is
how it affects plankton
how it affects larvae

=>overall effect on fish stock

Allows comparisons between different possible spill sites

Purposes: Mitigating action

Hypothetical scenario: kill c.60% of ”0group” recruits in 1995

This will lead to a reduction in recruitment, then reduction in young fish, and eventually to a reduction in adult fish

Several years between an oil spill and reduction in adult biomass

3-4 years before the affected yearclass is fished

6-8 years before they become mature

Can we reduce other sources of mortality (i.e. fishing) to build up a buffer in the adult stock to prevent negative effects?

Oil influence: no change in fishing

year	0group recruitment	Immature 3+ biomass	Mature biomass	Catches
1994	1.00	1.00	1.00	1.00
1995	**0.41**	**1.00**	**1.00**	**1.00**
1996	1.00	1.00	1.00	1.00
1997	1.00	1.00	1.00	1.00
1998	1.00	0.92	1.00	0.99
1999	1.00	0.85	1.00	0.94
2000	1.00	0.84	0.93	0.86
2001	0.99	0.89	0.84	0.84
2002	1.00	0.96	0.83	0.89
2003	1.00	1.00	0.89	0.94
2004	1.00	1.02	0.94	0.98
2005	1.00	1.01	0.99	1.00

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2002	1.00	0.96	0.83	0.89
2003	1.00	1.00	0.89	0.94
2004	1.00	1.02	0.94	0.98
2005	1.00	1.01	0.99	1.00

Fishing less to mitigate oil influence

Maximum 17% reduction in SSB

10 year loss of catch is around 300,000 tonnes

But we could further curtail fishing in order to avoid stock depletion

Build up a buffer in the SSB before the depletion occurs

Fishing less to mitigate oil influence

Response scenario:

Reduce fishing effort by 15% for 7 years

Starting the year after the oil spill

- The earlier this starts the less severe the reduction needs to be

Fishing less to mitigate oil influence

year	0group recruitment	Immature 3+ biomass	Mature biomass	Catches
1994	1.00	1.00	1.00	1.00
1995	**0.41**	**1.00**	**1.00**	**1.00**
1996	1.00	1.00	1.00	0.88
1997	1.00	1.03	1.12	0.97
1998	1.00	0.96	1.25	1.04
1999	1.01	0.88	1.35	1.01
2000	1.01	0.86	1.27	0.90
2001	1.00	0.91	1.08	0.85
2002	1.00	0.98	1.02	0.88
2003	1.00	1.03	1.08	1.06
2004	1.00	1.02	1.06	1.04
2005	1.00	1.01	1.04	1.03

Fishing less to mitigate oil influence

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1998	1.00	0.96	1.25	1.04
1999	1.01	0.88	1.35	1.01
2000	1.01	0.86	1.27	0.90
2001	1.00	0.91	1.08	0.85
2002	1.00	0.98	1.02	0.88
2003	1.00	1.03	1.08	1.06
2004	1.00	1.02	1.06	1.04
2005	1.00	1.01	1.04	1.03

For this scenario, 15% reduction in fishing effort for 7 years:

- Eliminates reduction in adult biomass (SSB)
- 10 year loss of catch is reduced to 190,000 tonnes
  - (down from 300,000 tonnes)

- Early intervention means that the annual reduction is less severe

Limitations

Important to state what we are not modelling

- Any model is only as good as its assumptions
  - Here we assume that **all larvae have equal impact** on recruitment, oil **only effects larvae** not adult fish, that any **larvae that survive recover** fully, and that there are **no lasting multi-year effects** on the spawning grounds

- So far only developed for cod, best for ages 3+
- Only models the large ”Skrei” Barents Sea stock, not the local coastal cod stock

- Nothing about the impact on the local enviroment

- Structure of the tool is to include the *least* amount of complexity required to answer our question
- => greater complexity brings with greater uncertainties

Take home messages

- First time anyone has combined oil mortalities on larvae into a general fisheries model
- Lower uncertainties than a "whole ecosystem model" (e.g. Atlantis)
- Have built a (preliminary) tool that allows not only risk assessments, but can place the risks in the broader context of marine ecosystem management and **integrated ecosystem assessments**