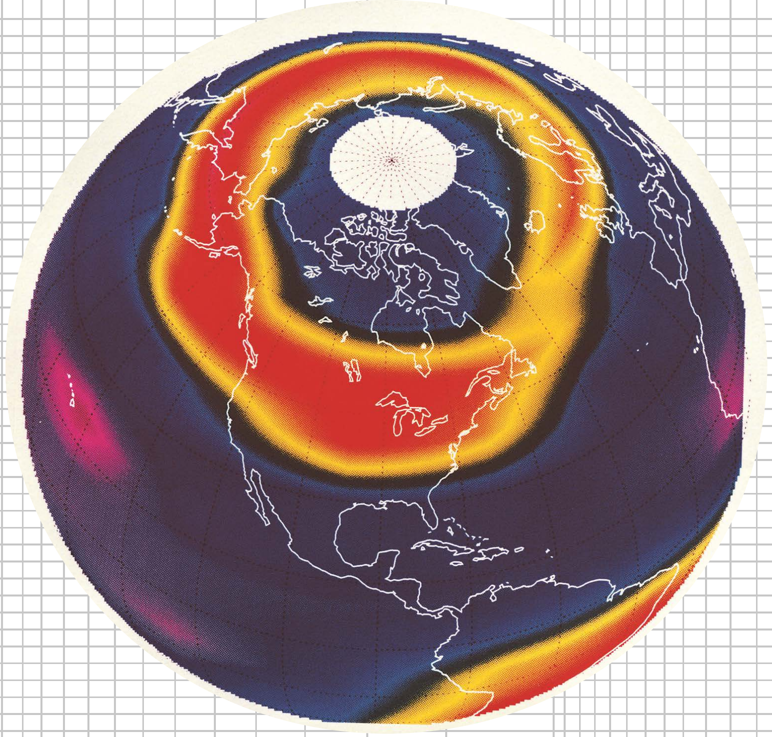

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NorMER Workshop on Climate Change

Copenhagen 28 September 2014

Helén Andersson, Christian Dieterich, Markus Meier & Kari Eilola

Bioclimate envelope model, include preferences to T, S, habitat types etc. and changes in T, S, currents, sea-ice extent

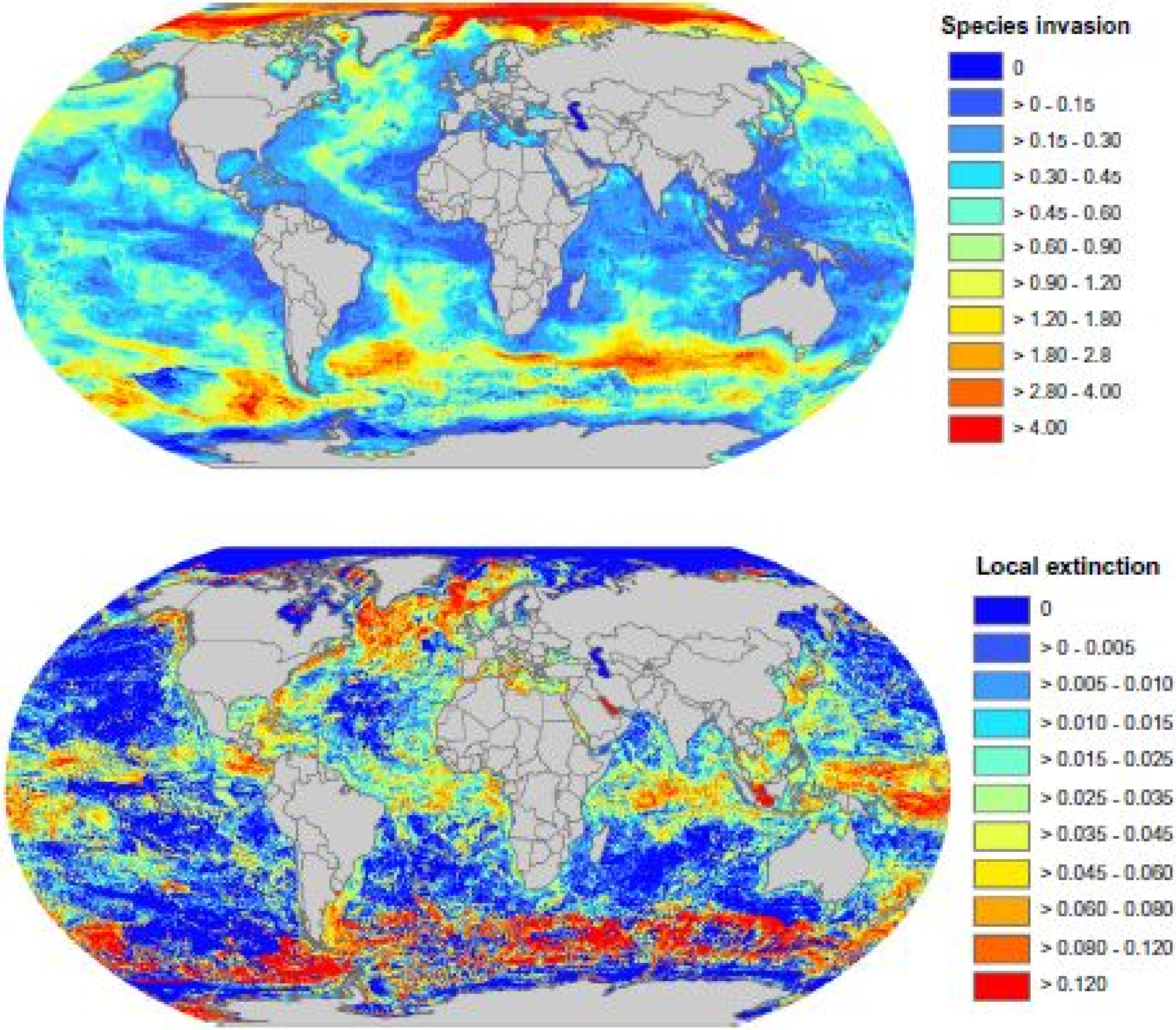

Fig. 7. Predicted global pattern of species invasion (a) and local extinction (b) in 2050 relative to 2000 due to range shifts in marine metazoans SRES A1B scenario. The values are expressed as proportion relative to the initial species richness in each 30′ × 30′ cell. This is based on an analysis of 1066 species of marine fish and invertebrates (redrawn from Cheung et al. (2009)).

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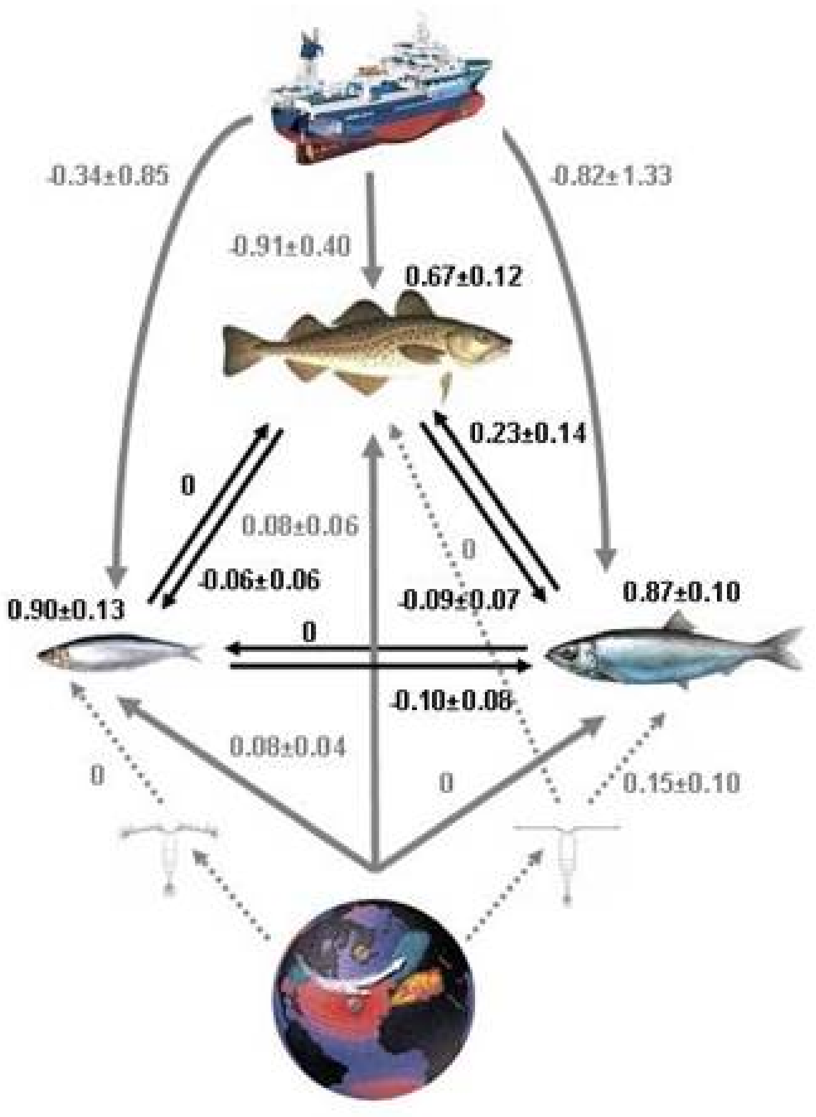

ICES Report 2010: Cod and future climate change:

Impacts of climate change will effect both structure and function of marine ecosystems

Most studies have been focused on individual species response to increased warming

”The methodology for projecting future states of the marine ecosystems and particular species, such as cod, is in its infancy”

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What needs to be considered to understand future changes?

1. Projections of future climate related ocean changes as well as changes in extreme events as a basis for projections of fish population dynamics and distribution

2. Projections of likely changes in phytoplankton and zooplankton production and distribution

3. Projections of likely changes in prey and predators of cod

4. Projections of likely changes in cod production (growth, reproduction, mortality, recruitment) and distribution

5. Combination of stressors, such as climate change and fishing, climate change and eutrophication, etc.

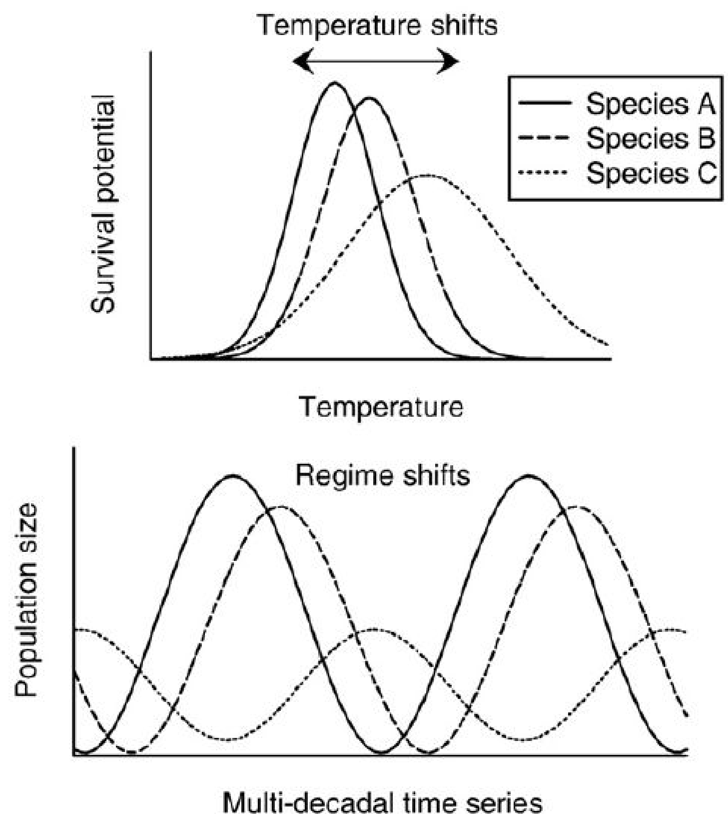
Climate-change related parameters that might impact the ecosystem at different levels:

- Sea temperature
- Wind patterns
- Ocean currents
- Loss of sea ice
- Rise in sea level
- Ocean acidification, pH
- Sea salinity
- Nutrient supply
- Mixing
- Light availability
- Oxygen concentrations
- Mixed layer depth
- ……

Temperature

- Shifts in geographical distribution – often associated with changes in thermal extremes in minima or maxima rather than mean temperature
- Population structure and community composition has been related to recent decreasing frequency of colder winters and increased occurrence of warmer summers

Observed patterns – but difficult to use in predictions if we do not understand the underlying processes…may be the result of either active migration or from differential productivity of local populations in lower and higher latitudes…



Drinkwater et al, JMS, 2010

<u>Growth</u>

- Preferred thermal range ”latitudinal compensation hypothesis” – local evolution should maximize metabolic efficiency and thus favor maximum growth under local thermal conditions

- Faster growing individuals or populations will usually gain survival advantages (due to min predation)

- Growth variations has showed hundred-fold difference in survival probabilities during larval stages

- Reduced feeding abilities in too warm/cold waters

Temperature

Swimming speed and activity rates

- Viscosity of water (low T increase drag on the organism)
- Oxygen-consumption rate temperature dependent

Reproduction

- Egg-production rate T dependent
- Spawning times occur earlier in warm water
- Age-of-maturity T dependent
- Egg size vary with T

Temperature

Phenology (periodic biological phenomena)

- T increase trigger earlier phytoplankton blooms
- Spawning time earlier in warmer T
- Warmer seasons give earlier migratory movements

Distribution

- Distributional shifts esp. near northern and southern boundaries of the geographical range
- Warming gives poleward movement
- Cooling gives equatorial movement

Temperature

Recruitment

- Both positive and negative correlations

Mortality

- Usually indirect effect through influence on growth rate and larval stage duration
- Direct during extremes or e.g. coral reef bleaching

Vertical stratification and MLD

- Through e.g. implication on primary production (light level) and nutrient availability

Sea ice
- Ice retreat effects the timing of the spring bloom due to impact on stratification
- Sea ice provides necessary habitat for many species

Turbulence
- Increase of contact rate between plankton predators and prey
- Rate of egg production

Advection

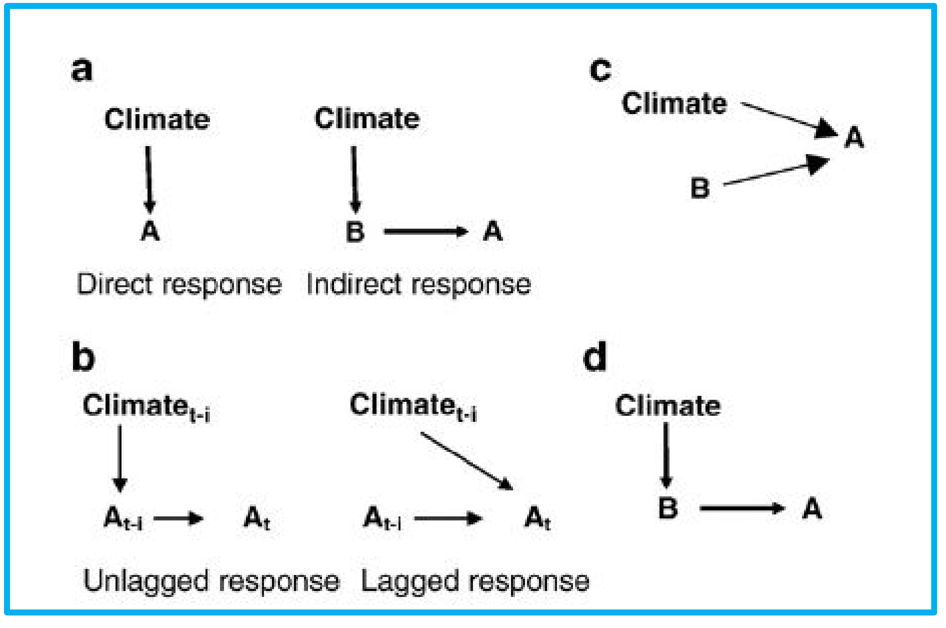
- Dispersion of fish eggs, larvae and zooplankton from spawning ground
- Changes in circulation patterns and water mass distribution

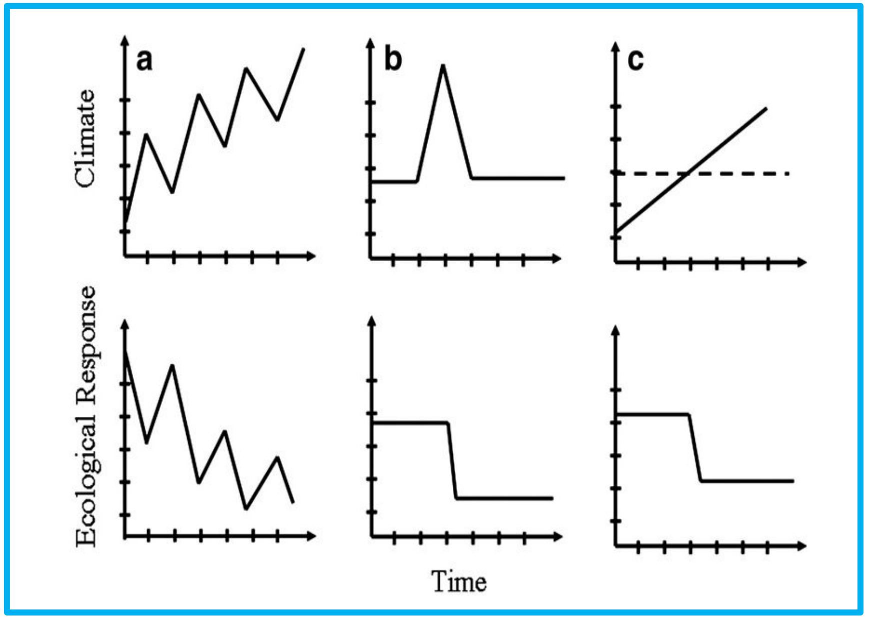
Sea level

- Water-column depth
- Wave regime
- Flooding

Climate-change impacts – a multitude of forcing and pathways

- Direct effects
- Indirect effects due to changes in the prey, predators and competitors
- Response of the population can be unlagged or lagged
- Climate in combination independent stressor (e.g. fishery) impact the population
- Climate impacts e.g. availability of prey that impacts population
- Linear, non-linear responses, regime shifts
- Integrated effects (biological or physical inertia)
- Translations (movements of organisms)
- Response can be controlled “bottom-up”, “top-down” or through trophic cascades





Ottersen et al, JMS, 2010

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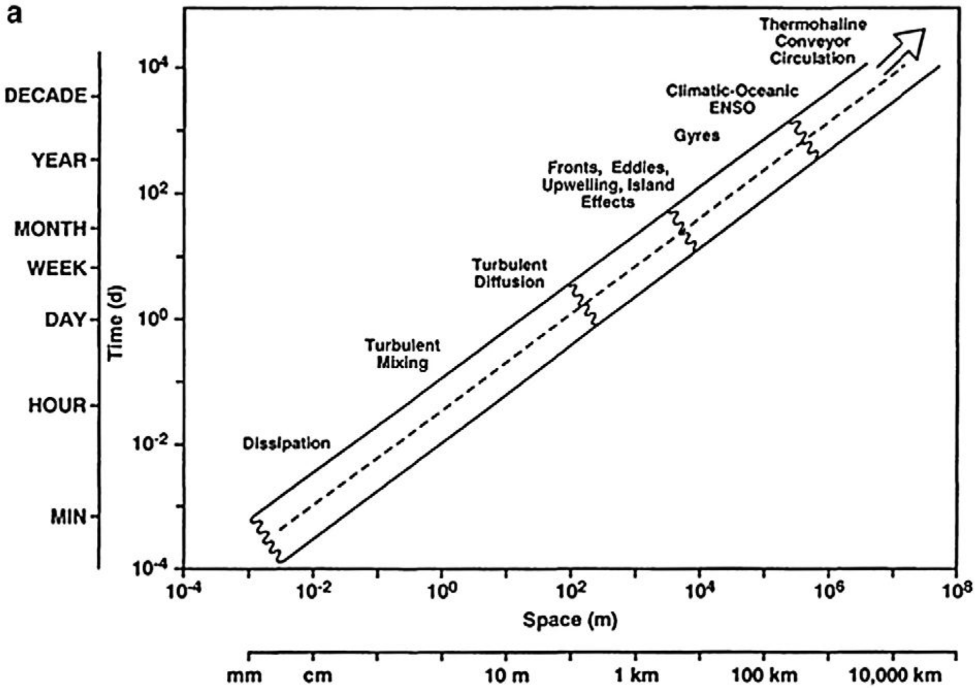

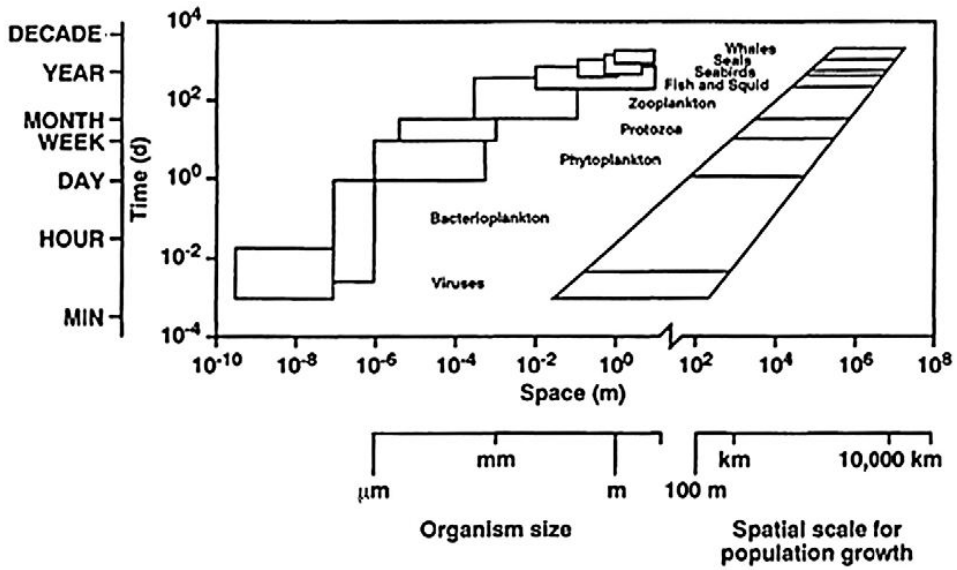

Ottersen et al, JMS, 2010

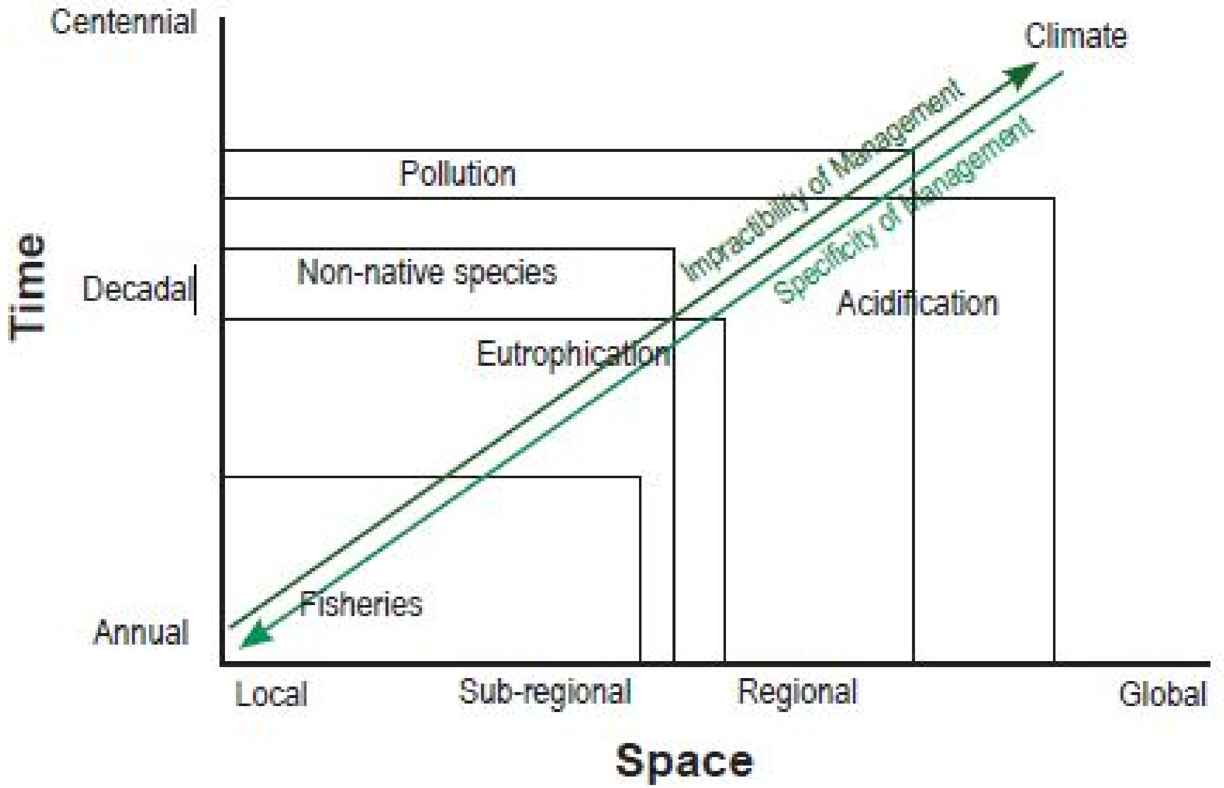

Figure 12. Schematic illustration on differences in temporal and spatial scales involved in the impact and management of drivers

From MEECE project

Study of past climate – ecosystem relations:

”There is no doubt that interannual and interdecadal variations in atmosphere – ocean climate strongly affect the structure and function of marine ecosystems. However, a number of different mechanisms are at play and their relative importance varies between different regions and with time”

(Ottersen et al., 2010)

Some ways to approach the subject

- Comparative approach
- Process approach
- Study past climate variability effects
- Future projections: modelling of ”what if” scenarios, or use of climate indices (aggregates complex patterns)
- Future projections: modelling of transient scenarios

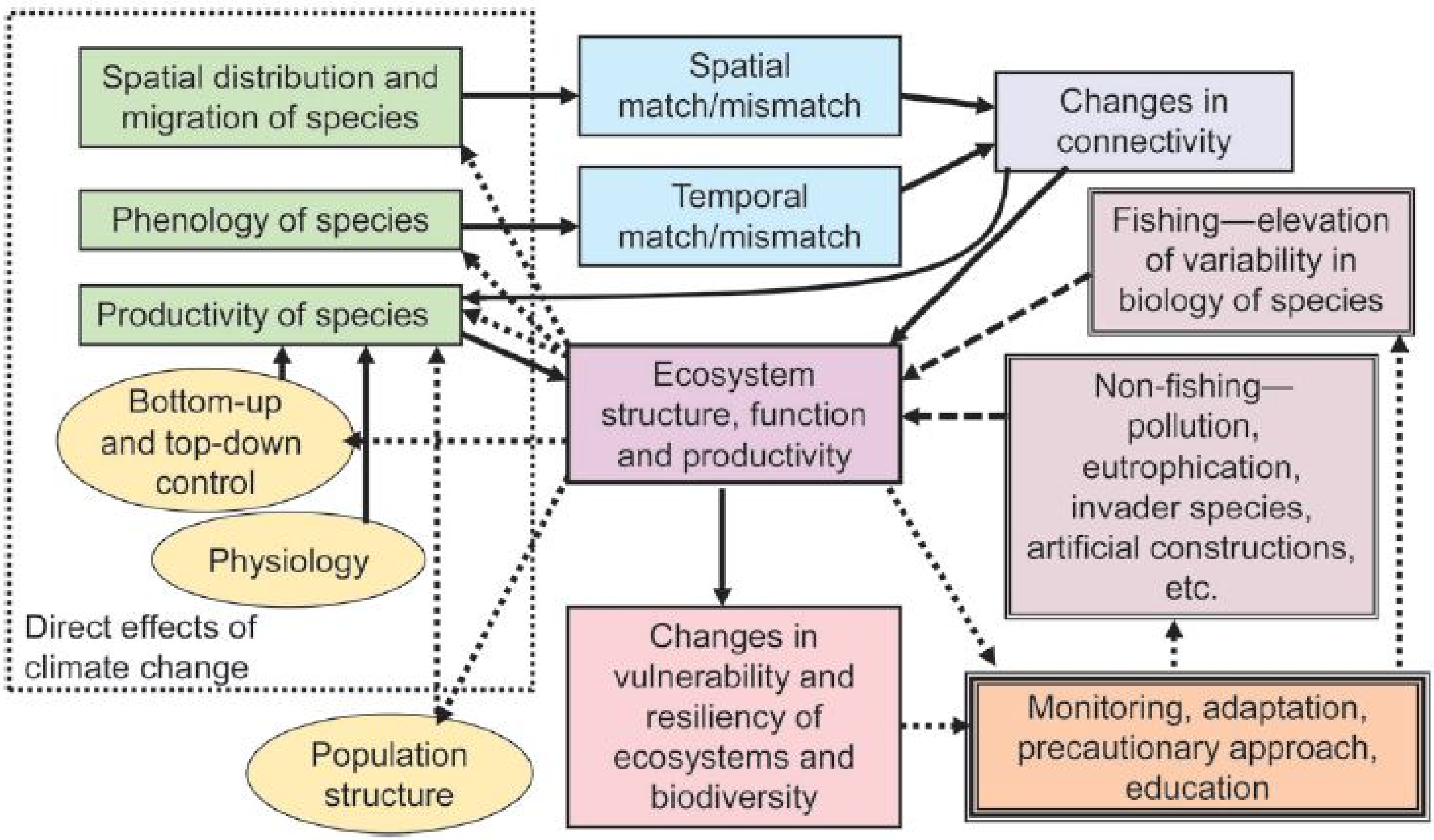

Figure 2. Conceptual pathways of direct and indirect effects of climate change and other anthropogenic factors on marine ecosystems, with their implications to adaptation and management. Solid arrows, consequences of climate change; dotted arrows, feedback routes.

Responses

Distribution changes in space and time

Productivity changes

Adaptation: the extent of population changes depends on the capacity to adapt

”Adaptation of a species to new environmental conditions is one of the most difficult issues to evaluate – especially when attempting to project connectivity among ecosystem components” (Planque et al, 2011)

Kingsolver, 2009

An analysis of changes in distribution of **North Sea cod** over past century explored the effects of **fishing, temperature, winds and other environmental variables.**

Distribution changes have been large.

Despite good information it is not possible to choose among a number of plausible explanations – climate, fishing pressure, meta-population dynamics, biological interactions with prey fields.

→ More research needed to entangle cause and effect

→ Caution needed when predicting future changes

Stock et al, Progress in Oceanography, 2011

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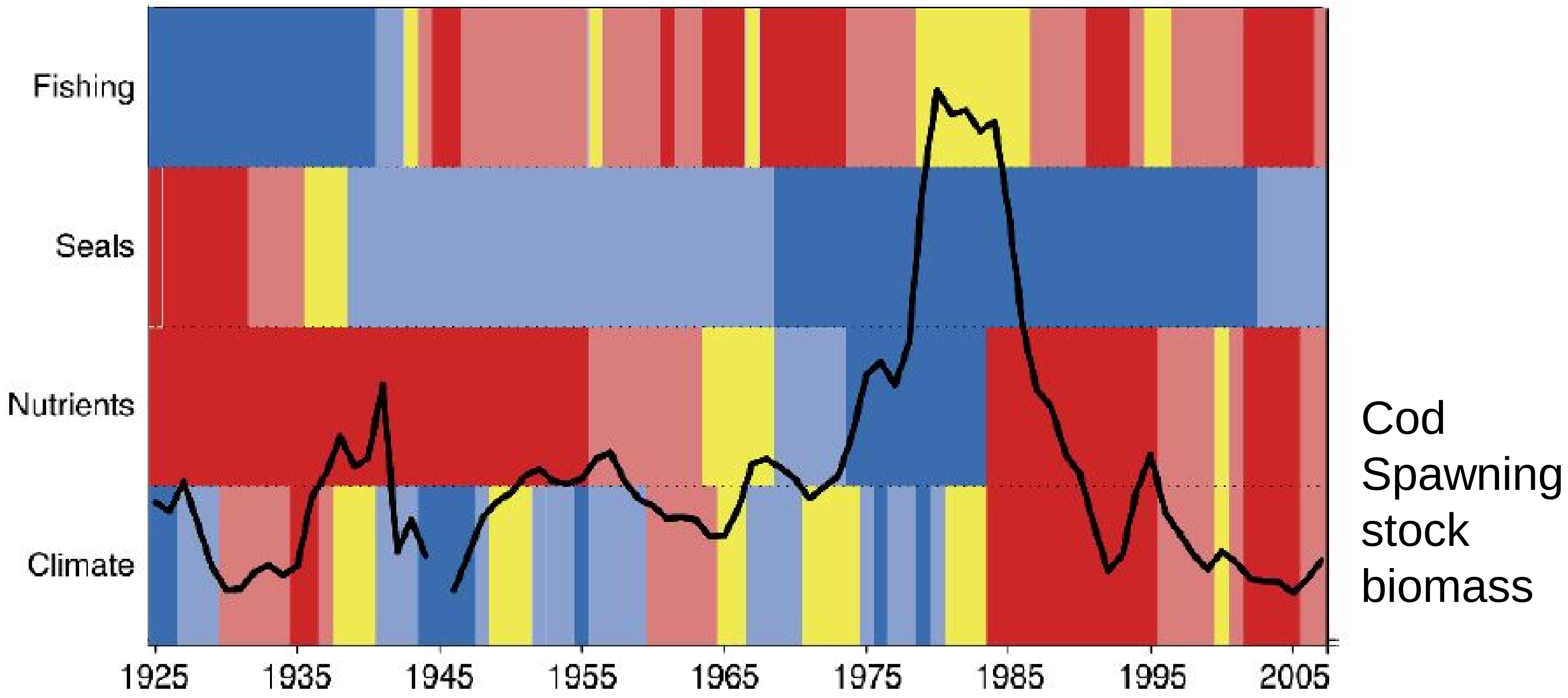

FIG. 4. Changes in climate-driven hydrographic conditions, nutrient concentration, seal abundance, and fishing mortality compared to trends in SSB of the eastern Baltic cod (shown as a line) during 1925–2007. The data for climate and fishing variables are lagged in relation to SSB to represent their potential impacts on age groups 3–7 in SSB in a given year. The values of the parameters shown by the five color categories represent 20th percentiles of the range of observed values (from minimum to maximum) for each variable during the analyzed period. The colors represent beneficial and detrimental effects on cod, coded from red (detrimental) to yellow (neutral or moderate) to blue (beneficial).

Eeero et al., 2011.

Region	Climate drivers						Human induced drivers			
	Air temp	Wind stress	High CO2	Light	Ocean Nutrient Supply	Sea Ice Loss	Eutroph-ication	Pollu-tion	Fish-ing	Invasive species
Global (1)	2.0	2.0	1.0	3.0	NA	2.0	0.0	1.0	2.0	1.0
Barents Sea (3)	2.7	2.7	3.0	2.0	2.3	3.0	1.0	1.3	1.5	1.0
Ne Atlantic (2)	2.0	1.5	1.5	1.0	3.0	NA	1.0	2.0	2.0	1.0
North Sea (4)	1.5	1.5	1.8	1.7	2.5	NA	1.8	2.0	2.0	1.5
Baltic Sea (3)	1.7	2.7	2.3	1.3	0.3	1.7	3.0	3.0	2.0	1.5
Bay of Bis-cay (1)	3.0	2.0	NA	1.0	3.0	NA	2.0	NA	1.0	NA
Black Sea (2)	2.0	3.0	NA	2.5	NA	NA	3.0	NA	3.0	2.5
North Ae-gean (1)	3.0	2.0	2.0	3.0	3.0	NA	3.0	2.0	3.0	NA
Adriatic Sea (2)	2.0	2.5	2.0	2.5	0.0	NA	3.0	2.0	2.5	2.5
Benguela (3)	3.0	3.0	2.7	2.5	3.0	NA	NA	NA	3.0	NA

From MEECE project

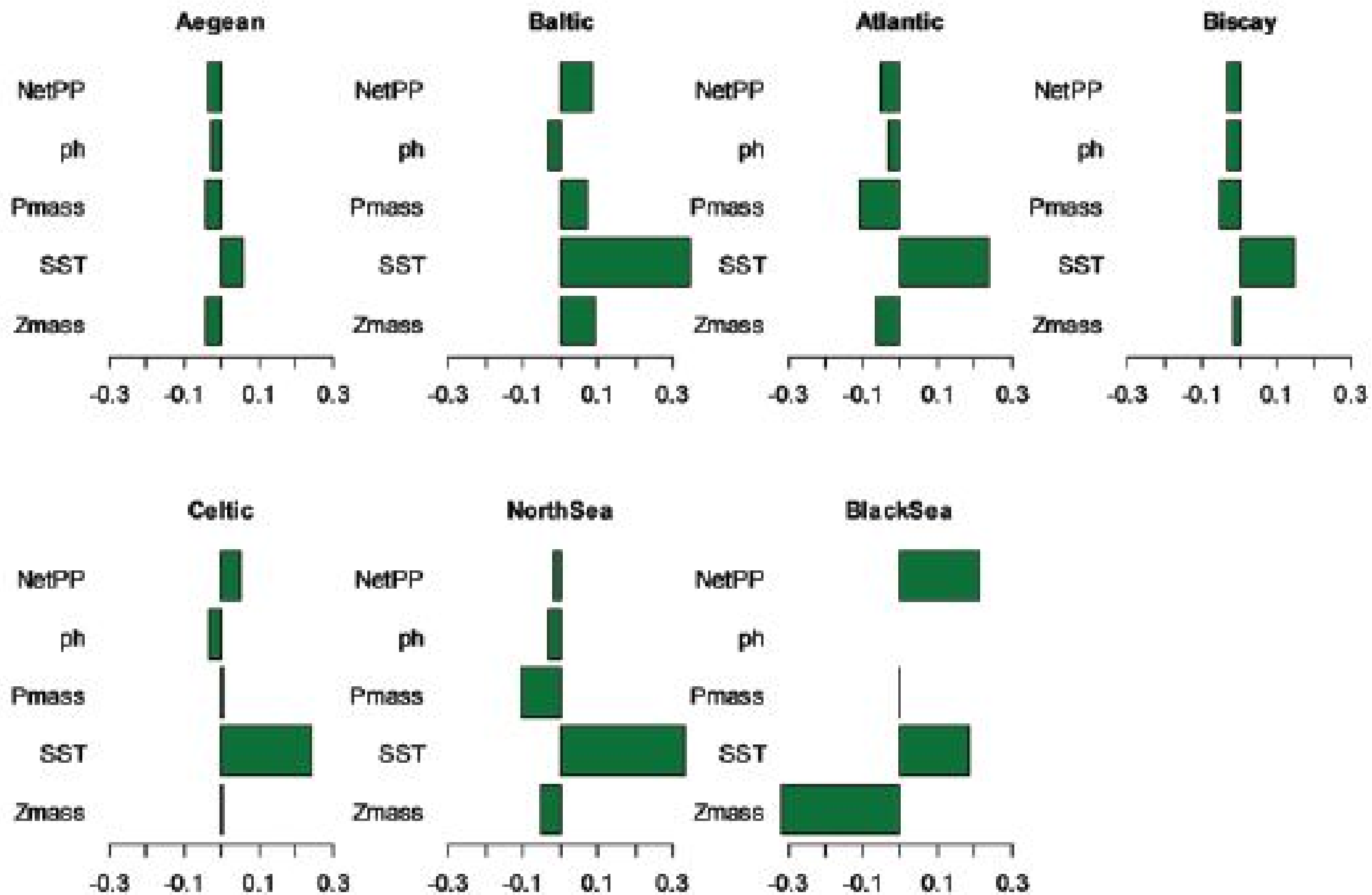

Figure 10. Simulated changes in selected indicators in different regions, presented as a proportional change in variables when applying a scenario with predicted climate change (A1B) compared to the scenario with present day climate. The scale on x-axis indicate proportional change, positive values corresponding to an increase and negative values to a decline (Data from Model Atlas, www.meeceatlas.eu).

Lower Trophic Response:

Overall globally and in temperate and southern European seas primary production is expected to decrease, due to enhanced stratification, reduced mixed-layer depths and slowed circulation

In Northern European seas primary production is expected to increase due to increased light levels (ice reduction) longer period of production and changes in the ice-edge bloom

Reconstructions of food web pyramids

Higher trophic level response:

Globally an 18% decrease in fish biomass is projected by 2100 due to decreased primary and secondary production.

Projections also show reduced fish size and production

Cod can be favored in the Barents Sea – 8% increase

Baltic Sea production decrease due to reduction of suitable spawning habitats

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Higher trophic level response :

Zooplankton maximum peaks earlier in the season and could give a mismatch between larval growth and zooplankton bloom.

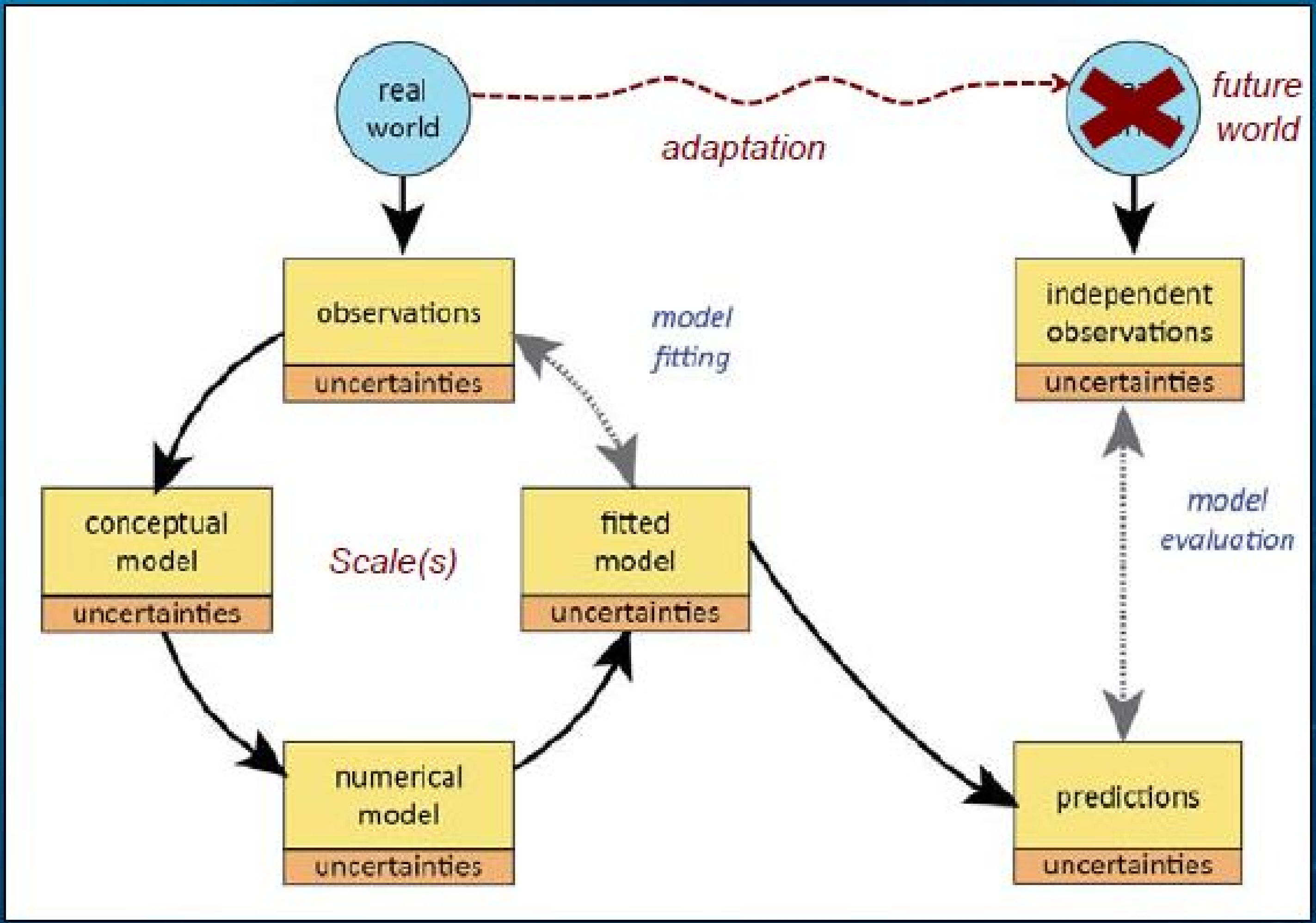
Cod larvae took higher risk to subdue themselves to predators in order to get food by positioning higher up in the surface layer

Ecosystems not equally sensitive: critical thermal boundary where small increase in T triggers abrupt ecosystem shifts seen across multiple trophic levels

Drinkwater et al, 2010: ”As we move to higher trophic levels our understanding tends to be much more limited”

Robust prediction: under warming conditions there will be a general tendancy for species to move polewards

Evaluating uncertainties



Now you see me, now you don't: uncertainties in projecting future spatial distribution of marine populations.

Review summary

Review found that little attention is given to most sources of uncertainty, except for uncertainty in parameter estimates. As a result, most current projections are expected to be far less reliable than usually assumed. The conclusion is that, unless uncertainty can be better accounted for, such projections may be of limited use, or even risky to use for management purposes.
(Planque et al, 2011)

…but different attempts have of course been made through e.g.

- Hierarchical models (Bayesian approaches)
- Analyzing different models and comparing and contrasting resulting patterns across models
- Ensemble modeling
- Monte-Carlo approaches
- Model-parameter sensitivity experiments

Climate impact on fishing practices:

Example: Direct climate effects on fish caused slow growth and poor condition with the indirect consequences on fishing practices – ”high-grading” – associated with truncated age structure resulted in additional stress on an already stressed stock and thereby contributing to the collapse of Northern Cod (Drinkwater, 2002).

Exploitation can alter the response of exploited marine populations and ecosystems to climate.

Planque et al, 2010

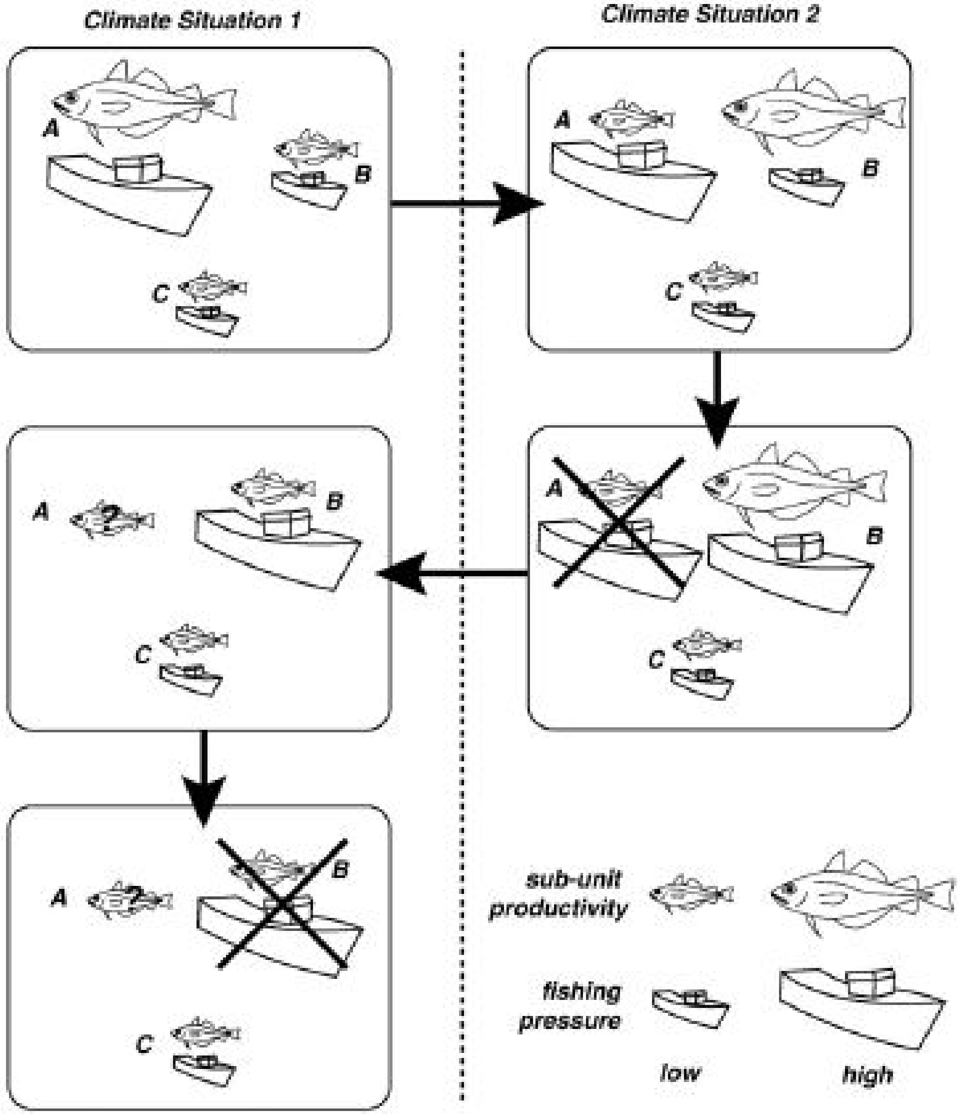


Fig. 4. A schematic representation of the possible combined effects of fishing and decadal climate oscillations on fish populations with multiple sub-units. The population is composed of three sub-units *A*, *B* and *C*. Sub-unit *A* is favoured under climate situation 1 (left) and unfavoured under climate situation 2 (right). The reverse is true for sub-unit *B* and sub-unit *C* is unaffected. Transition from climate situation 1 to 2 induces changes in the respective contributions of *A* and *B* to the productivity of the whole population. Time-lagged reaction of exploitation level leads to overexploitation of sub-unit *A* (and underexploitation of sub-unit *B*), which can ultimately result in the collapse of sub-unit *A*. The increase in productivity of sub-unit *B* is gradually matched by an increase of fishing pressure on this sub-unit. The return to climate situation 1 provokes a decline in the productivity of sub-unit *B* which is not compensated by sub-unit *A* which has collapsed (and may be in a recovery phase). Maintenance of high fishing pressure on sub-unit *B* can ultimately lead to collapse, leaving the population with only subunit *C* which displays low productivity.

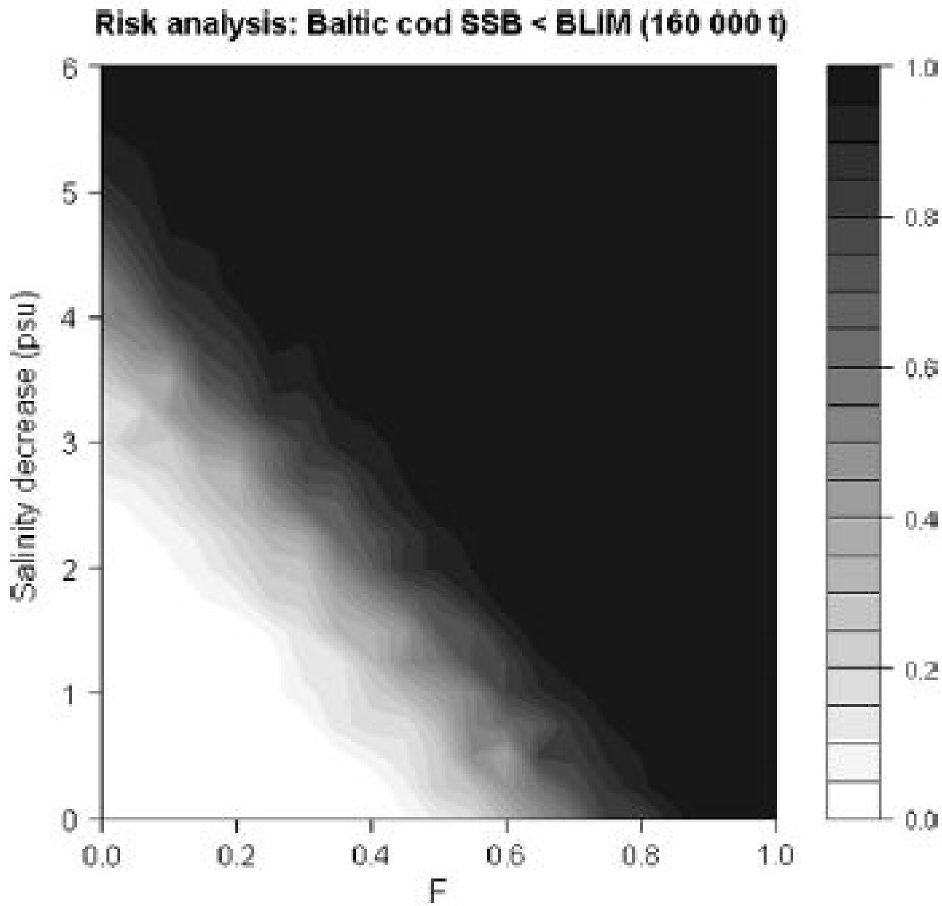
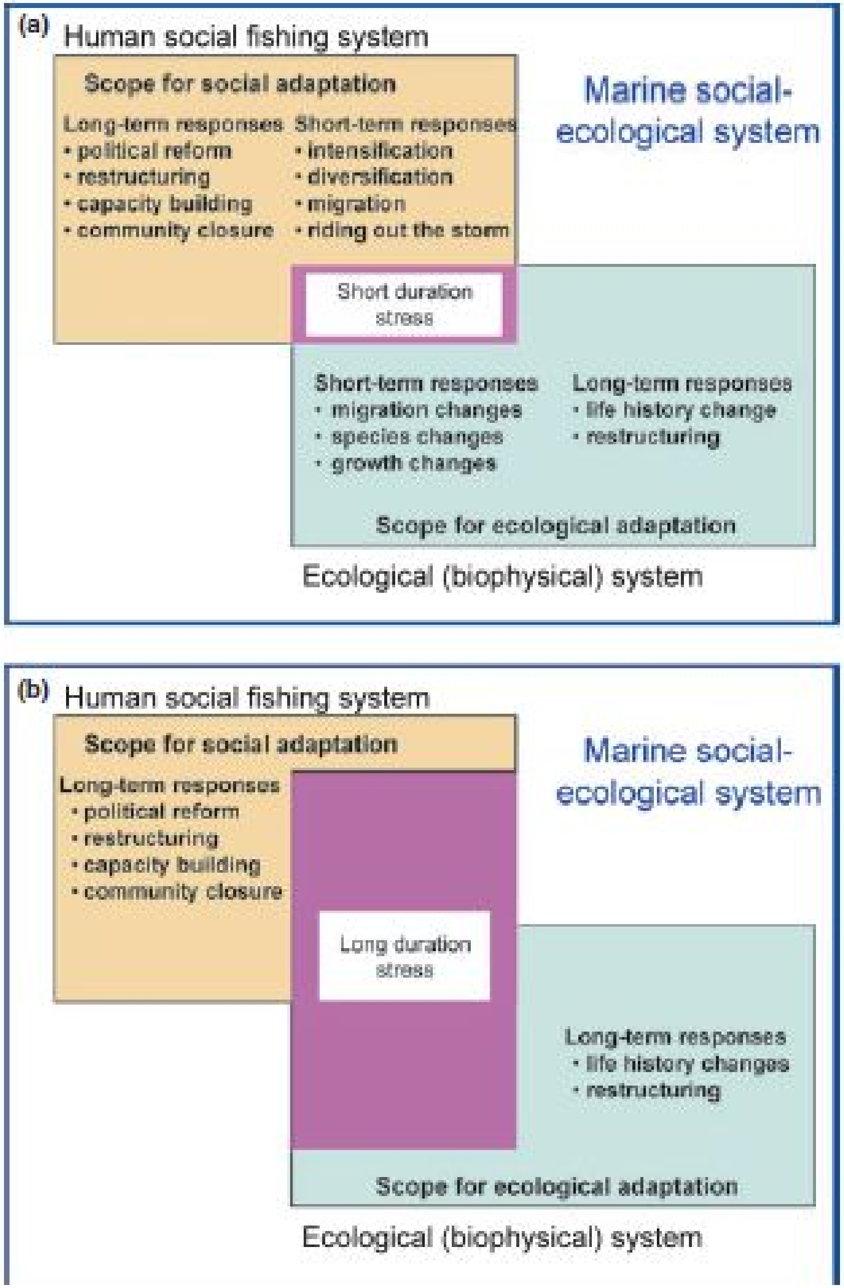


Fig. 11. The probability of Baltic cod spawning stock biomass (SSB) falling below the limiting stock size (Blim). Decrease in salinity is relative to the mean salinity from 1974 to 2004. The risk of falling below Blim increases rapidly and non-linearly as salinities decrease with increasing fishing mortalities (Redrawn from Lindegren et al. (2010)).



”Projecting climate change effects on fish and fisheries is challenging due to the cumulative effects of climate change, other anthropogenic activities and feedback mechanisms” (Fulton et al, 2011, Perry et al., 2011)

Figure 6 Schematic of marine ecological and human social fishing system responses to short- and long-duration stresses. (a) With a short-duration stress, ecological and human fishing systems are able to respond with both short-term coping and longer-term adaptive responses to compensate for the changes caused by the stress. (b) With a longer-duration stress, the short-term coping responses of both systems are exhausted, leaving only the longer-term adaptive responses. The result is decreasing flexibility in the human fishing system and increasing variability in the ecological system.

It is unrealistic to separate climate induced from fishing induced effects, but calls for studies oriented towards understanding the interactions between climate and fishing

Marine species may have evolved to cope with climate variability over long time-scales, but the increase in fishing pressure has been rapid and resulted in

- reduction in age/size
- removal of metapopulation units
- alteration of life-history traits
- increase in population/ecosystem turnover rates
- reduction in ecosystem complexity.

All these converge towards a reduction in diversity at the individual, population and ecosystem levels.

Despite the specificities of local situations, the reduction in marine diversity will likely lead to a reduction in the capacity of populations and ecosystems to adapt and take advantage of climate variability and change. (Planque et al., 2010).