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Interaction and integration of observation and models – the EcoFish approach

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Ecosystem approach to fisheries management demand new scientific approaches and tools. The EcoFish project is a recently established project that pursues the challenges set by the new approach. It aims at supporting adequate advice by 1) improving the data basis in general, 2) by creating a model complex that can assist traditional assessment tools, e.g. in developing indicators or analysing ecosystem based trigger points for harvest control rules and 3) develop supplementary tools for spatial management. The EcoFish concept therefore challenges new technologies with respect to producing high quality, relevant data that enable modelling of stock properties of exploited fish stocks with adequate geographical and seasonal resolution for evaluation purposes. Models will for example be used to predict distribution of target stock that can be applied for designing an improved sampling regime of the scientific surveys. In this paper we describe the some of the main principles of the EcoFish concept and illustrate our approach though examples that demonstrate some of the key features of the project.

Key words: ecosystem approach, modelling, observation schemes

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INTRODUCTION

The ecosystem approach to fisheries (EAF) has been recognised by FAO (2001) as "sustainable fisheries management taking into account the impacts of fisheries on the marine ecosystem and the impacts of the marine ecosystem on fisheries". The declarations and agreements on the ecosystem approach reflect a common understanding of the need to extend the traditional fisheries management to sector-crossing management and acknowledging the multiple users of the marine ecosystem (FAO, 2001; UN, 2002). This requires a shift in the information gathered for supporting management decisions (FAO, 2001; UN, 2002; FAO, 2003). An improved understanding and assessments of the ecosystem is called for with emphasis on ecosystem structure, functioning and variability (FAO, 2001; UN, 2002).

Commissions around the world have so far chosen somewhat different ways of interpreting what the main foci are, how to implement the ecosystem approach and what knowledge is necessary to support the EAF. The Joint Russian-Norwegian Fisheries Commission (JRNFC) has focussed on multi-species management and the impacts of the ecosystem on the fisheries rather than a sector-crossing approach or impacts of the fisheries on the non-commercial components of the Barents Sea ecosystem (JRNFC, 2005). In contrast, the Norwegian white paper on integrated management in the Barents Sea (The Royal Ministry of Environment, 2006) has a sector-crossing approach and addresses both aspects of the ecosystem approach to fisheries. Because of the multiple use of the Barents Sea, this paper draws attention to spatial and temporal planning. Similar work with an integrated management plan for the Norwegian Sea started in 2007 and a draft plan is expected in 2008 and a final plan in 2009. This is also a sector-crossing approach where monitoring is one of the central issues.

The EcoFish project intends to develop tools to support the ecosystem approach to fisheries. The idea is to stimulate innovation by bringing together various science disciplines from several research fields to create new insight, enhance models and develop innovative tools. For the EAF this implies that management should broaden its focus to secondary effects of human impacts and that more knowledge, in general, about the marine ecosystems is necessary to understand these impacts. In this sense, all basic research related to the marine ecosystems is valuable for the EAF. Our understanding of how marine ecosystems function, let alone the effects of human impacts,is still very limited. The intention of the EcoFish project is to support the EAF with a better understanding of fish stock dynamics. This covers a range of research fields where there has been, and still is, a large research effort. EcoFish is a strategic institute program, which will point to a direction for research in the future.

How is EcoFish different and what will be its main contribution? We think the most important requirements for management advice where stock dynamics are central are:

a) the implementation of environmental effects on fish stocks in to fisheries management,

b) spatial planning, which requires more knowledge about the distribution of fish in its different life stages,

c) providing sound data underpinning the exploitation of new marine resources, such as plankton, which requires studies on species interactions and ecosystem functions and

d) the provision of knowledge and understanding of the effects of climate change on the distributions and productivity of species and ecosystems.

We believe that answering these questions will benefit from strengthening multidisciplinary basic research. To undertake this will require new ways of making scientific knowledge applicable and they require alternative ways of monitoring the stocks and their environmental impacts.

In this paper we present the EcoFish framework that is being designed to address the above questions. We describe the development on the theoretical foundation of the framework so far and finally we present some examples and preliminary results and discuss these in relation to the framework.

GENERAL FRAMEWORK

The framework is illustrated in Figure 1. Ecosystem dynamics can be described by changes in a given set of state variables. Both external drivers, such as fishing, and ecosystem drivers can cause such changes. The state variables are identified from observations through models of different complexity. Some state variables (indicators) encompass ecosystem condition to an extent that they are of particular value for the ecosystem approach. The definition of indicators and formation of models originates from careful analyses based on observations and/or simulations.

EcoFish will deal with the part above the dotted line (Figure 1) but will use the requirements of management as the basis for our development.
The boxes represent data collection, different levels of analyses, advice and management. The main content of the boxes in the framework is a combination of available information and results from ongoing projects. As any marine research project can be placed in one or more of the framework boxes, the innovative and strategic elements in the EcoFish project are found in the links between them. We have decided that all the research issues within the project must be represented by one of three defined framework loops. The *upper loop* consists of the interactions between observations and dynamics (three upper boxes), the *left loop* between dynamics and advice and the third loops is the entire framework.

In practise this means that developing data collection strategies cannot be done without considering the priority tasks of basic research and management needs (upper and entire loop). We want to focus on three theoretical approaches to improve research on dynamics. Firstly, how we can evaluate model-based hypotheses through observations. Second, how we can establish techniques for recognizing patterns in sets of data. And finally, can we find ecological explanation for the observed patterns. Although all three questions are based on the upper left corner of the framework, they are differently linked to the rest of the framework. The first is represented the upper loop, the second and third are relevant for management and thereby represented by the left loop.

Our last research area is how to implement environmental impacts on fish dynamics in the various forms of advice. This is applied research and therefore demands a totally different theoretical approach, often combined with basic research. Applicability requires careful analyses of the uncertainty related to the purpose of the knowledge production, and we would like to emphasise the importance of sensitivity analyses and how to present advice in accordance with the precautionary approach (see example below).

The links therefore represent a number of crucial research questions:

- How to develop strategies for optimising data collection based on the existing knowledge on ecosystem dynamics,
- How to choose platforms for observations depending on the state variables wanted/needed to be measured,
- What are the measurement uncertainties, and are there measurement variations due to environmental (both physical and biological effects)?
- What state variable or sub-model is the dynamics analysis sensitive to?
- How to transform environmental dynamics or environmental driven dynamics into advice for ecosystem based management, including indicators.
- Validation. For example how can observations validate models? How to validate insights and model output in terms of improvement and relevance?

EXAMPLES

The inaccessibility of the underwater world for man represents challenges for obtaining reliable observations as well as understanding of how the ecosystem functions. Present strategies in stock assessment exploit trends in indices of abundance or other stock characteristics from time series of data. Such trends have proven valuable for single stock assessments but often lacks details on key parameters of importance for stock dynamics. The best way to introduce new ideas to replace established approaches is by presenting convincing examples that demonstrates important principle of the new approach. The EcoFish approach aims at extending the utility of the relationships between physics and biology or biological interactions. The examples highlight various part of the EcoFish framework and will be associated with specific assessment/management problems.

<u>1) Geographic distribution and physical/biological modelling</u>

Interaction between the physical environment and fish stocks can be utilized in several ways. Long term climatic changes affect the productivity of fish stocks. The geographical distribution might be temperature dependent or co-occurring with temperature due to temperature effects on prey production. Thus, such factors may also affect distribution patterns, including feeding and growth conditions. As a result, temperature driven distribution patterns might also affect coverage of scientific surveys and hence the stock estimates from these surveys.

Temperature, distribution and year class development

When stocks are distributed towards the extremes of their environmental boundaries they will be particularly susceptible to climatic changes. Ottersen *et al.* (1998) demonstrate the temperature effects on distribution of various ages of cod in the Barents Sea (Figure 2). Their work also show that the geographical distribution as well as the temperature experienced for various age groups and year classes varies over time. Combined with the knowledge of temperature-growth-recruitment effects for the major stocks in this area, Ottersen and Loeng (2000) demonstrated the importance of taking appropriate consideration of thermal regimes in stock assessment and management.

In the EcoFish concept we focus on taking proper account of dynamics. Distributional and growth effects caused by temperature variation are typical cases. The EcoFish project demands models that bring this type of knowledge into a framework for application in assessment and management. In this particular case, prediction models of the physical environment can support the feed-back loop in Figure 1 between model output and data collection. This might improve efficiency of the survey and quality of the stock properties estimated from such field efforts. Also, such models may improve the prediction of key information, such as growth, for use in management advice.

Coupled ocean and biological modelling

The physical environment is considered an important factor regarding fish dynamics. Recent works connecting ocean dynamics and biology (for example the Barents Sea inflow, primary production and cod recruitment relationship found by Svendsen et al, (2006)) have shown the need to explore coupled ocean-biological dynamics. Starting with lower level productivity, we have set up a model system where currents, hydrography and mixing parameters from an ocean physics model drive both a phytoplankton model and a zooplankton model, and these two models themselves interact: The zooplankton model provides grazing fields for the phytoplankton, and vice versa. We intend to explore established indicators and establish new indicators, thus connecting modeling and field sampling to describe state variables both in past and future. Use of coupled physical and biological models is also crucial in assessing future climate change questions. The research will include past, present and future environmental effects and lower level species interaction. As model results will be compared to field studies, it fits the upper loop of the EcoFish framework. We will explore the several possibilities of including the results in various forms of advice and seek ways to evaluate its contributions to fulfil the left hand loop.

Distribution patterns and survey indices

Due to relationships between densities of fish in different parts of the total distribution area, Johansen (submitted) demonstrates that abundance of the complete stock by age can be modelled from density information in selected subareas and temperature:

$$\log(I_{a,i,age}) = \beta_0 + \beta_1 \log(I_{b,i,age}) + \boldsymbol{\beta_2}(agefactor) + \beta_3(temperature_i) + \boldsymbol{\beta_4}\log(I_{b,i,age}) \times (agefactor) + \beta_5 \log(I_{b,i,age}) \times (temperature_i) + \boldsymbol{\beta_6}(agefactor) \times (temperature_i) + \varepsilon_{a,i,age}$$

where *a* and b denote sub-areas in the total survey area and *i* denotes year. The main objective is to establish a correct stock estimates based on data from incomplete survey coverage and thereby improve the survey time series for the analytical stock assessment (see Figure 3).

The model is useful for harmonising time series of survey data collected with a rigid standardized design where distributions have changed over time in a way that has affected the degree of coverage. In the EcoFish context such models are needed in the upper modules linking observations, state variables and dynamics. The approach enhances understanding of distribution patterns and can also be used in the feedback loop; i.e modelling distribution patterns for ongoing surveys to enhance efficiency and improve output.

The research for improving survey indices aims at improving the indices of the past through corrections based on environmental impact on the distribution. This approach also improves the information base for optimising survey strategies regarding area coverage. This fits very well with the EcoFish framework, but are such factors influential for the results and for the EcoFish concept? An evaluation of the actual contribution of such changes to historic survey indices and stock assessment is necessary and may contribute to improved survey strategies in the future.

2) Indicators

In the EcoFish project we study indicators with two different purposes. One is to detect abrupt changes in the ecosystem. The other is for use in harvest control rules or in stock assessments for particular fish stocks. So far, EcoFish has concentrated on the latter, through studies on variations in condition and studies on environmental impacts on parameters in stock assessment.

Condition
Generally, it is known from the literature that body condition influences subsequent growth performance, reproductive potential and, probably, recruitment. So far, our analyses have targeted only Norwegian spring-spawning herring (NSSH) (Figure 4) and Northeast Arctic cod, with a focus on the condition dynamics per se. However, the fact that condition effects might be linked over years (seasons) and summarise lower level productivity along with density-dependent effects indicate that this type of information might be particular useful as state variables within the present conceptual framework (Figure 4).

In the case of NSSH there is a well established relationship between the NAO index and the mean condition factor of the over wintering herring (ICES, 2006). This relationship is brought about by a similar relationship between the North Atlantic Oscillation (NAO) index and the abundance of *Calanus* in the Norwegian Sea. The abundance of *Calanus* is indicative of the available prey for adult herring. Low summer prey availability results in a low condition and this impacts on individual growth and pre-winter energy reserves. Low energy reserves can lead to reductions in fecundity or even in extreme cases mass atresia and the failure to spawn or produce eggs. Thus changes in ecosystem productivity (in this case *Calanus* production or abundance) results in a change in herring productivity through changes in Stock Reproductive Potential (SRP). Over-wintering energy reserves are also used for spawning migrations (to and from the spawning grounds) since the fish do not feed between the late autumn and post spawning and thus there is a trade-off between migration distance (longer distances resulting is fitter larvae) and fecundity (individual egg production). Mean condition has varied quite considerably over the years (see ICES 2006) with population values of Fulton's Condition Factor (K) close to 0.7, a value thought to a lower bound trigger point for mass atresia (loss of egg production) in herring. Energy reserves post spawning and then in the following winter may be particularly important for first time spawners especially when ecosystem productivity is shifting as the energetic demands on small fish are higher and this may lead to 'skipping' of spawning. The overall effect of shifts in ecosystem productivity is, in the case of a fish stock a shift in SRP but more importantly a shift in productivity and ultimately the level of sustainable exploitation.

Variability in condition is seen in other stocks e.g. cod (both in the Barents Sea and the western Atlantic) and these changes have been shown to affect stock productivity through SRP and Total Egg production (TEP). Whist the condition to productivity correlations are present the relationships between the two are more than likely stock or ecosystem specific. Therefore there is a need to investigate the condition to productivity relationships in detail and for each target population.

The relationship between NAO and herring condition is reasonably good (R^2= 0.51 P=0.004) (ICES 2006), however, this needs to be examined and possibly refined. The advantage of a linking to NAO with a 2 year lag is that there is the possibility of short-term forecasting and with the NAO alone the possibility of limited retrospective analyses (using time periods earlier than the current zooplankton data) to examine historical trends in stock condition factor. The link between ecosystem productivity and condition will be used to estimate SRP and stock resilience and on to the current methods of setting reference or limit points. In addition scenario testing will examine the effects of changes in ecosystem productivity, either long slow monotonic shifts or regime shifts, on SRP and the potential consequences for the target stocks. The ultimate aim is to identify patterns in the dynamics of fish condition which are indicative of shifts in stock productivity.

Recruitment

Predicting the number of individuals in a recruiting yearclass is still a much discussed issue as it is a considerable source of uncertainty in stock assessments. Bogstad et al. (2007) demonstrated by hindcasts that if the predicted recruitment had been equal to the measured recruitment, the quota advice of Northeast Arctic cod would have been altered significantly. They compare several different methods of predicting the recruitment of this stock to see whether environmental factors can improve the predictions. The environmental explanatory factors which are used are temperature (indicating zooplankton availability), capelin abundance and cannibalism. They conclude that on average, they are not able to improve the recruitment predictions by including environmental information. Still, the couple of times when the traditional ICES predictions have been far off, showing quite exceptionally good or low recruitment, the predictions including environmental information have performed much better.

These alternative models could thus be used as quality checks when the traditional one shows extreme events. This could be formulated as a rule based on recruitment prediction values as an indicator, and threshold values triggering switches to another prediction model, or a combination of models. The intention of this rule is thus to reduce the problems in quota advice. If the managers do not consider underestimates a problem, or there is a concern of adjusting quotas upwards, a rule can be designed in accordance with a precautionary approach to avoid only overestimates.

Growth parameters

The growth of Northeast Arctic cod has fluctuated significantly over the decades it has been observed. This has caused problems for the management of this stock as too optimistic growth predictions have contributed to considerable overestimates the stock and vice versa. Bogstad et al. (2007) demonstrate that the quota would have been set significantly lower and higher, respectively, if the growth parameters had been predicted as they are later observed. They further explain the variability by food availability and suggest a growth prediction model that incorporates cod biomass, prey abundance and temperature.

This issue fits well within the EcoFish framework as it addresses a highly relevant problem for fisheries management and has an environmental (broadly speaking) explanation. However, there are still some important aspects that remain to complete the analysis in accordance with the framework. When the alternative growth model is developed, it has to be compared with the simple one used in stock assessment today. We expect, like in the recruitment example that results will show that the alternative model will solve some problems but may in some cases perform worse than the traditional one. It is then important to keep in mind what kind of problem this alternative is to solve: is it to perform better on average or is it to avoid severe overestimates (also, see the recruitment example above).

3) Migration

Migration is one of the most difficult factors to control in relation to modelling of ecosystems and their productivity and harvest potential. Efficient observation systems are lacking and movement and overlap of predators and prey are often assumed or evaluated based on crude distribution information from surveys or commercial fishing. We have two cases under evaluation in relation to the EcoFish requirements

Modelling recruitment at age 0 (distribution and abundance of juveniles)
Drift and distribution of young of the year larvae of gadoids are crucial for feeding condition, growth and survival. In 2006 a larva drift model was used to predict distribution of age 0 cod in the autumn (Johansen et al. 2007). The model indicated distribution of fish in the Eastern Barents Sea and none in the Bear Island region. In October this year new acoustic instrumentation was used to study vertical distribution and migration of 0-group gadoids in this region (Johansen et al. 2007). Large concentrations of age 0 cod were found contrasting the distribution predicted by the model. Further, the fish were distributed deeper and with a diurnal dynamics that were not taken into account in the model. Based on this they designed a concept of the vertical distribution of cod in the recruitment phase (Figure 5). The concept is based on the observations undertaken in October specifically and knowledge gained during field work done on 0-group at other times of the year. The October field work demonstrates a methodology for validation and calibration of the drift/migration models of young of the year cod.

This example demonstrates implementation of new technology to give improved information and insight appropriate for modelling of dynamics that is presently assumed modelling of recruitment. The approach gives potentially better prediction of recruitment and will certainly be used in the feed back loop to support the survey strategy during field assessment of recruitment at the 0-group stage.

Migration of capelin
Migration of fish affects stock assessment from surveys when systematic displacement take place during the period of the survey (see e.g. Simmonds and MacLennan (2005)). Migration and distribution is also essential in an ecosystem context because overlap and interaction between predator and prey is depending of their dynamics. In most cases we find limited detailed quantitative information about migration speed and direction. Some preliminary studies were done in 2007 to study migration of capelin during their spawning migration towards the coast. During an acoustic abundance survey, systematic observations of migration speed and direction on school level as recorded by fisheries sonar was used to study migration behaviour (Iida *et al*. in prep). Later this information has been analysed with respect to assessing dominant migration direction and speed on stock level (Sigurd Tjelmeland, IMR, Bergen, personal communication).

This work demonstrates that available technology offers tools for better assessment of migration speed and direction that can be used in modelling of fish migration. The approach may improve survey stock assessment (state variables) by removing a potential bias caused by a dominant migration direction. Later at a greater scale, such detailed information of migration of predator and prey species may support adequate modelling of overlap, predation pressure and predator growth potential.

In this section we have demonstrated that new technology may feed new information to the modelling framework that enhances the possibilities for understanding and quantification of ecosystem dynamics. Such approaches are needed in several parts of the framework including the *modelling – observation feedback loop* and linking *observation, state variables* and *dynamics*.

SUMMARY

The EcoFish framework is under development to support management in the following areas: a) to implement environmental effects on fish stocks in stock management, b) spatial planning c) exploiting new marine resources, d) distribution effects of a climate change. We have argued that the theoretical foundation across the relevant research fields needs to be strengthened. Burning issues are:

- How can we evaluate model-based hypotheses through observations?
- How can we develop techniques for recognizing patterns in sets of data?
- And finally, how can we search for ecological explanation for such patterns?

The theoretical approaches are to be combined with the following main research issues:

1) Evaluating the feasibility for new approaches that include environmental impact on stock dynamics in management advice for different purposes.
2) Improving research strategies to uncover and understand fish stock dynamics
3) Prioritising research and monitoring effort to enhance the ecosystem approach to assessment and management.

Traditional approaches are susceptible to dynamics caused by environmental and/or ecological changes that either corrupts the involved time series or causes changes in the dynamics of the ecosystem. Therefore the EcoFish approach focuses on dynamics and the argumentation is twofold: Firstly, we want to evaluate what key environmental factors affect the stock dynamics and how. Secondly, we will evaluate whether the recently developed tools and knowledge can be used to augment advice under the EAF. The latter has a strong focus on how to apply existing knowledge, which requires an evaluation of its contribution when it is applied, including a comparison with the impact of other relevant factors. The former requires basic research that may become applicable in the future. In this case we will keep a strong focus on trans-disciplinary research and on validating model and research results.

The EcoFish approach is still in its infancy. In this paper we focus mainly on demonstrating the approach through examples than giving it a theoretical fundament. Some of the examples show clearly how they fit into the framework while others indicate that suitable methods for validation and evaluation must be sought or remain to be developed.

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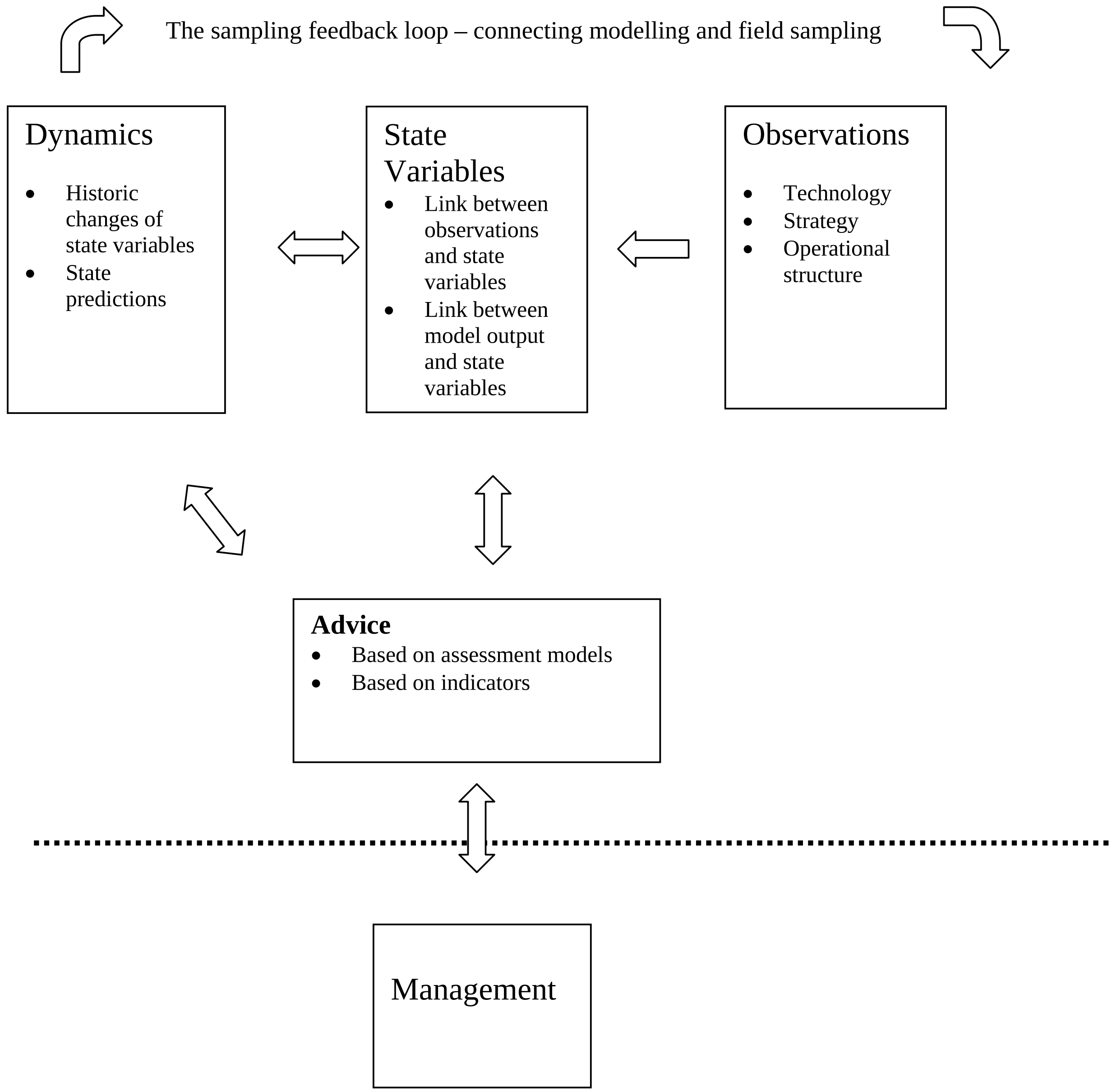

Figure 1. The EcoFish framework.

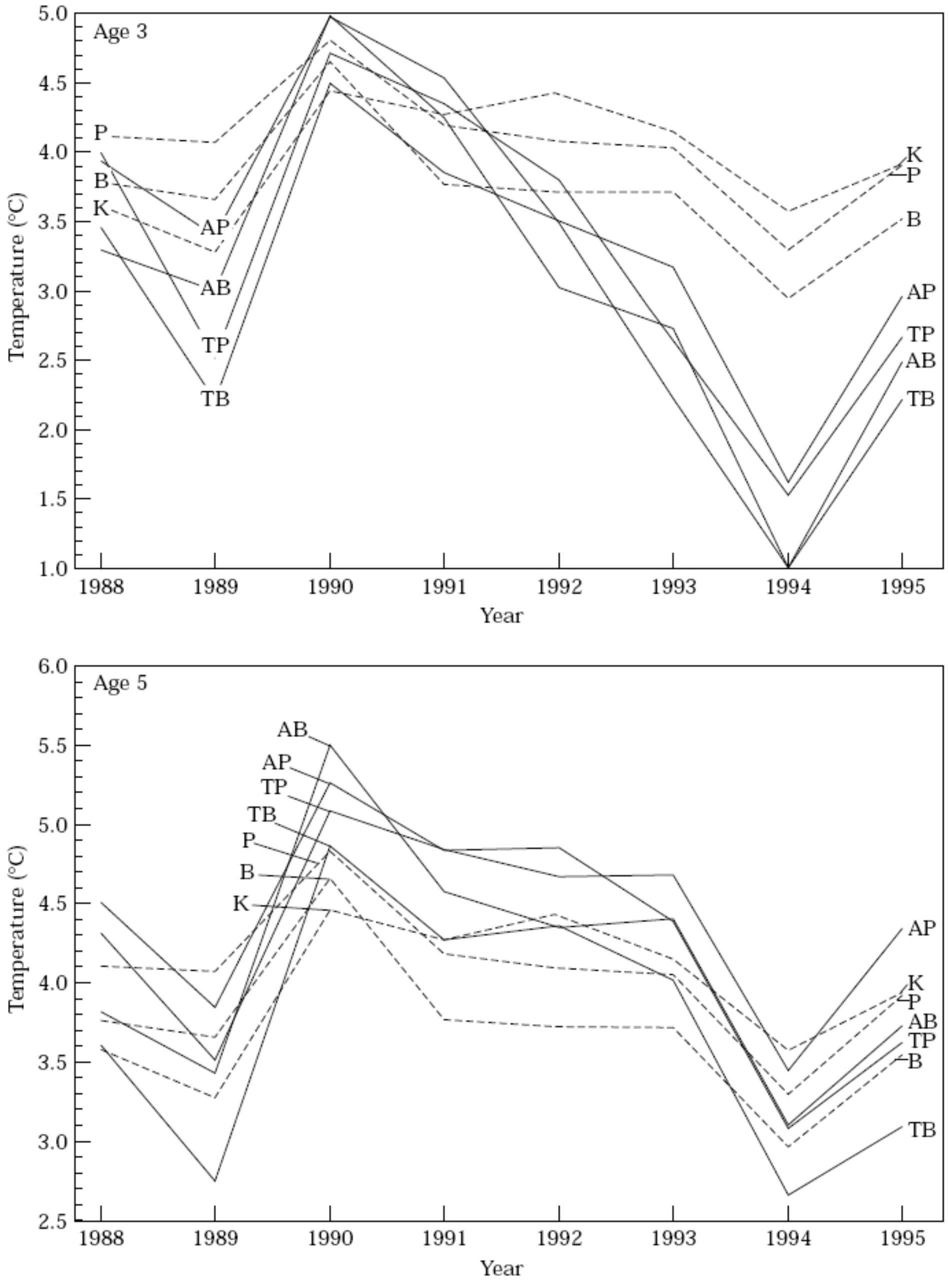

Figure 2. Mean ambient temperatures of 3-year-old cod (upper graph) and 5-year-old cod (lower graph) in February 1988–1995 based on acoustic estimates and temperatures 100 m - bottom (AP), trawl estimates and temperatures 100 m - bottom (TP), acoustic estimates and bottom temperatures (AB) and trawl estimates and bottom temperatures (TB). Mean temperatures at 0–200 m in the Kola section (K), in the main survey area at the bottom (B) and 100 m to bottom (P) are also shown (stippled lines) (from (Ottersen et al. 1998)).

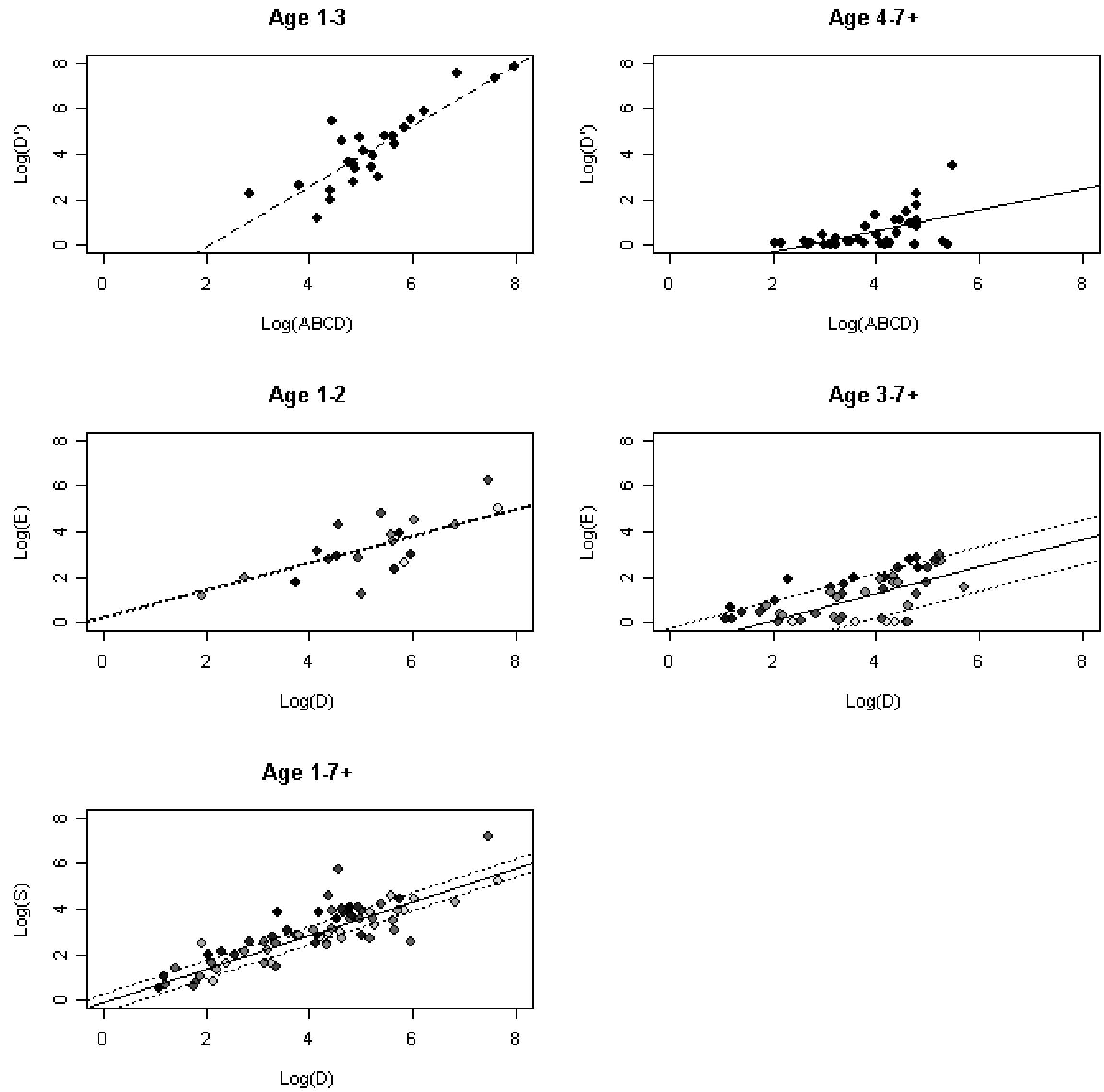

Figure 3. Relationship between the abundance indices in different sub areas (in this case A,B, C, D, D’, E, S and combination of them). Grey-shading of the points in the indicate variation in temperature where white is coldest and black is warmest. The solid lines in the plots for main areas E and S indicates the linear relationship at the average temperature in the respective temperature data. The doted lines indicate the linear relationships at minimum (lowest line) and maximum (highest line) temperature (from Johnsen (subm.)).

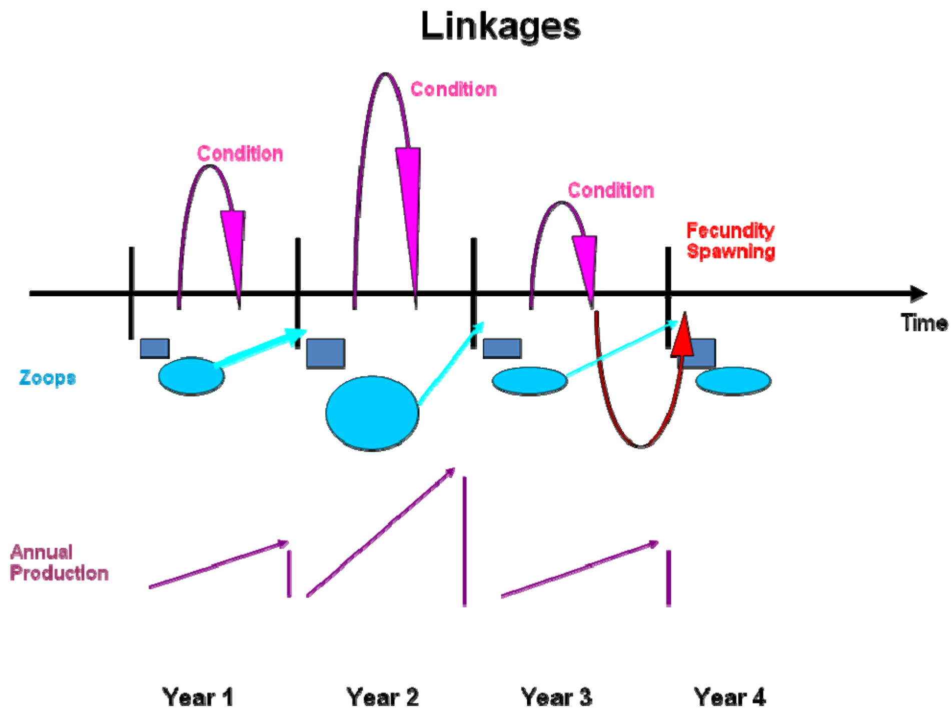

Figure 4. This illustrates that observed condition of adult Norwegian spring-spawning herring in a year (Year 4) is a consequence of earlier linkages between phytoplankton, zooplankton and herring abundance. Thus, condition in Year 4 is to a large extent determined in the summer feeding season in Year 3 by the amount and type of available zooplankton. The latter is a consequence of the zooplankton overwintering population between Year 2 and 3. This again is influenced by zooplankton abundance in Year 1. Thus, this type of hindcast methodology/relationships can in principle be reversed to be used in forecast exercises provided the necessary monitoring programmes are up and running.

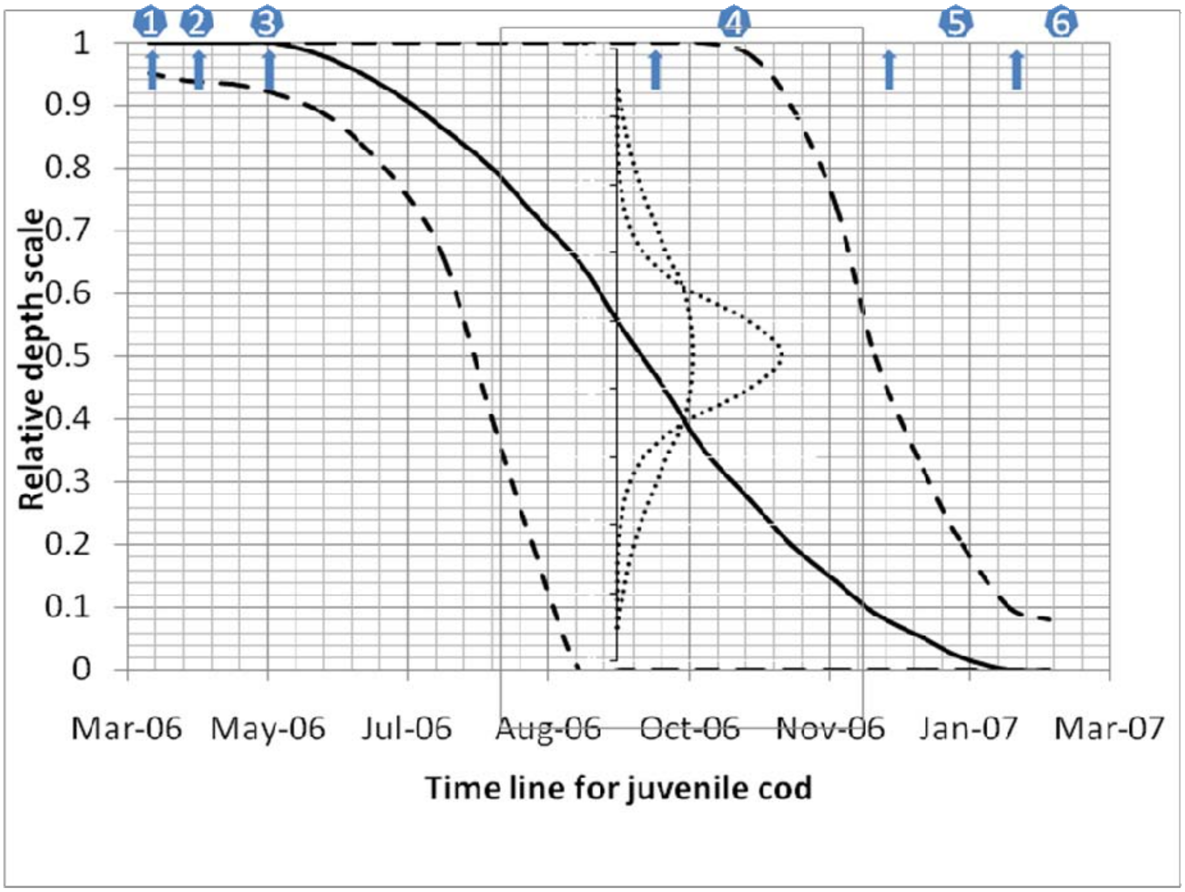

Figure 5. Average relative depth of 0-group cod during the first year of life illustrated by solid line moving from surface (relative depth=1) in April to bottom in January next year. Parallel dashed lines illustrate distribution range. Arrows and numbers at top indicate events in the development: 1-spawning, 2-hatching, 3 development of functional swimbladder, 4 changes from surface to mid water association, 5- changes to bottom association, 6- settled. Day and night vertical distributions in the autumn are illustrated by the two hatched normal distribution curves (from Johansen *et al.* 2007).