ICES Annual Science Conference
September 19-24, 2005
Report on Theme Session O

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Objectives. We convened the Theme Session on "Connecting Physical-Biological Interactions to Recruitment Variability, Ecosystem Dynamics, and the Management of Exploited Stocks" (O) to bring to the ICES community recent findings from laboratory, field and modelling approaches aimed at identifying and advancing our understanding of the interactions between physical and biological processes in marine ecosystems. These interactions occur at many scales, from fish egg sinking, to zooplankton aggregations at hydrographic fronts, to basin scale changes in temperature that influence ecosystem production. Advances in this field will improve our ability to predict fish recruitment, help us understand and mitigate the impacts of climate change, and support ecosystem-based fisheries management. Our goal was to survey recent findings, assess the state-of-the art, and discuss knowledge gaps that must be filled to advance toward a better understanding of ecosystem processes and enhanced predictive ability in support of ecosystem-based fisheries management.

Participation. Participation in Theme Session O was outstanding. A total of 37 papers and 6 posters was presented. Audience attendance was greater than expected at all 6 sections of the 2.5 day Theme Session, including the open discussion on Thursday afternoon. In addition, both presentations that received ICES ASC awards were given in Theme Session O. Best Paper was awarded to Beth Scott of University of Aberdeen (UK) for "Hotspots: Marine top predator foraging habitat predicted from a detailed understanding of temporal and spatial oceanographic processes" (O:39). Best Newcomer was awarded to Ute Hochbaum of University of Hamburg (Germany) for "Simulating the influence of climate variability on larval fish survival: An example using sprat (*Sprattus sprattus*) in the southern North Sea" (O:18).

Research Overview and Highlights. Contributions to Theme Session O included laboratory, field and modelling approaches, often in combination. They spanned small to large scales, and focused on a suite of species and their prey ranging from finfish (e.g., anchovy, herring, cod, mackerel, swordfish, tuna), to crustaceans (e.g., copepods, lobsters, snow crab), to molluscs (e.g., squid, oysters, scallop).

Small-scale studies related to turbulence and larval fish feeding were presented. Laboratory experiments with bluefin tuna larvae showed a dome-shaped relationship between their survival and turbulence (O:15). In addition, field observations in low stratification, low wind, and low tidal current conditions indicated that swells may be an additional source of turbulence that may affect larval fish feeding success (O:26). Finally, a coupled field and modelling study of cod on Georges Bank indicated that prey preference is an important component of larval fish feeding that depends on the copepod species characteristics such as visibility and catchability, not just on prey length (O:19).

Several presentations demonstrated that distributional patterns of a suite of zooplankton and larval fish were clearly related to meso-scale features such as the hydrographic properties of fronts in the North Sea (O:30), the seasonal thermocline and permanent halocline in the Baltic Sea (O:22), and coastal upwelling, eddies and hydrographic fronts off the Northwest African coast (O:35). Two promising approaches were presented for reconstructing time series of the location and strength of meso-scale features; one based on satellite altimetry data (O:36) and one with output from 3D numerical models (O:17). Although it was noted that computational artefacts may create artificial patterns in results, further developments of these techniques will be important for identifying time series of environmental conditions at the meso-scale that influence fish recruitment.

Scott et al. (O:39) identified another type of physical feature that can structure ecosystem dynamics: the persistent mixing zones created by interaction of tides and bathymetry. These zones, or 'hotspots of production', were associated with localized peaks in chlorophyll as well as increases in the number of seabirds and marine mammals engaging in active foraging behaviour (Fig. 1).

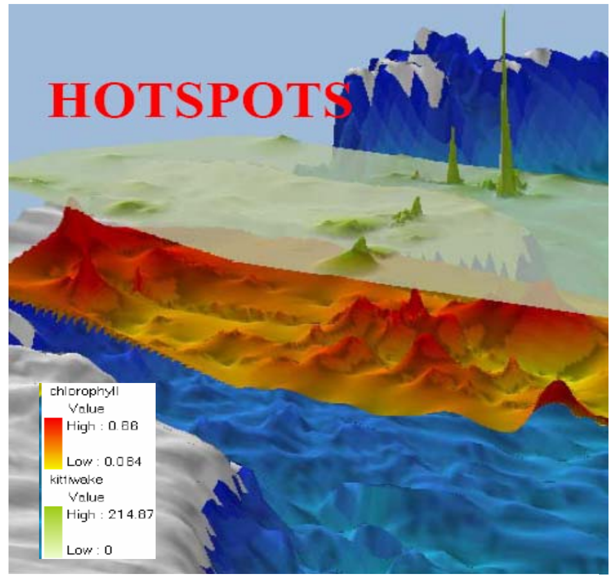

Fig. 1. Bottom topography of the Firth of Forth, Scotland (blue contors), the maximum level of chlorophyll (flouresence voltage) found within the water column (red/orange contours) and the number of kittiwake seabirds (*Rissa tridactyla*) seen foraging (green contours). (Scott el al. O:39)

Numerical modelling studies, coupled with field observations, also provided information on factors that influence zooplankton production and distribution. Physical parameters such as the depth of the thermocline, turbulence and nutrient transports were found to be hydrodynamic indicators for ecosystem variability and zooplankton production in the North Sea (O:28). The different vertical migratory behaviours of two copepod species lead to good agreement between modelled and observed distributions in the Baltic Sea. This result was obtained by explicitly modelling migratory behaviour in an Eulerian framework using a computationally efficient evaluation function (O:10).

One of the strengths of the session was the large number of papers on numerical modelling approaches applied to the early-life history of fish. Several papers were aimed at identifying and linking spawning and nursery grounds and understanding important processes that affect larval transport and survival. For example, it was demonstrated that jack mackerel larvae found in one nursery area were likely spawned at different locations at different times due to changes in transport patterns of the Kuroshio current as well as temperature-dependent effects on survival (O:14). In another study in Chesapeake Bay, settlement success and spatial patterns in settlement of oyster larvae was influenced by physical conditions (wind and freshwater input) and the vertical behaviour of larvae (O:01). Similarly, Arcto-Norwegian larval cod transport and growth was found to be very sensitive to vertical migration behaviour as well as the spawning behaviour of the adults (i.e., choice of location) (O:27). An important consideration in this study was the difference in transport results from using on-line and off-line tracking. Resolution of this issue will benefit the particle trajectory modelling community.

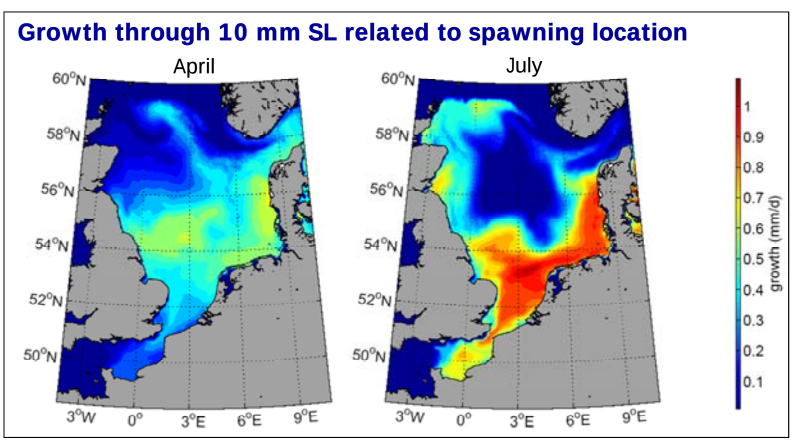

Fig. 2. Growth rates of simulated larval sprat (*Sprattus sprattus*) in the North Sea in 1993 based on predictions of an individually-based model linked to circulation, particle trajectory, and ecosystem models (Hochbaum et al. O:18).

Another set of modelling studies focused on simulating the direct and indirect effects of environmental variability on larval fish growth and survival. A notable example was presented by U. Hochbaum. Growth rates of simulated larval sprat in the North Sea, based on a larval IBM coupled to circulation, particle trajectory and ecosystem models, were found to vary in time and space (Fig. 2) within the range of observations derived from field data. Results indicated that growth rates in spring were controlled by both temperature and prey concentrations whereas growth rates during summer were controlled by prey limitation. Large differences in survival between years were related to the timing of peak prey abundances (O:18).

Another study indicated that simulating prey concentrations may not be necessary to accurately predict growth for larval sandeel in the North Sea. Analysis of modelled temperature and observed prey fields that larvae experience using a larval trajectory model indicated that there was a strong correlation between temperature and zooplankton concentrations. GAM models with explicit temperature and food terms explained only slightly more variability in the data than simpler models with single food or temperature terms (O:04).

Several studies combined particle trajectory modelling with intensive field observations of otolith-based estimates of larval growth. Using this approach, anchovy growth was found to be a function of age, temperature, stratification index and mixing depth (O:34), and identified regional differences in growth rates between northern and southern regions of the Bay of Biscay (O:21). In the Baltic Sea, abrupt environmental changes simulated by a numerical model forced with high-resolution wind data were detected in otolith increment widths (Fig. 3). Model results indicated that higher temperatures led to significantly faster growth throughout the entire age-range of YoY sprat (O:05). In other studies, wind events were also associated with high mortality rates of sprat eggs (O:29) as well as the distribution/aggregation of cod larvae (O:44).

Another strength of the session was the suite of papers that used statistical approaches to investigate the link between climate variability and fisheries production, catch and habitat. For example, regression models for Northeast Arctic cod, Norwegian spring spawning herring and Barents Sea capelin were able to describe 65-85% of the variance in the recruitment data with the incorporation of environmental factors (O:25). Variations in the extent and direction of Norwegian spring-spawning herring migrations were connected with both environment temperature conditions and the structure of herring population (O:32). Sea surface temperature was found to influence both squid and Icelandic scallop abundance (O:16, O:24). In addition, regression equations predicting catch rates were improved by incorporation of environmental variables like sea surface temperature and wind speed (O:33, O:02, O:12). Environmental parameters (temperature, salinity, bottom type) were applied to predict potential habitat of a suite of fish species in the English Channel (O:23, O:46). Finally, the regime shift in the North Sea around 1987/88 may have influenced the diets of a suite of species with important implications for MSVPA predictions (O:41). Although results of these studies help move us toward identifying mechanisms that control fish populations and catch variability,

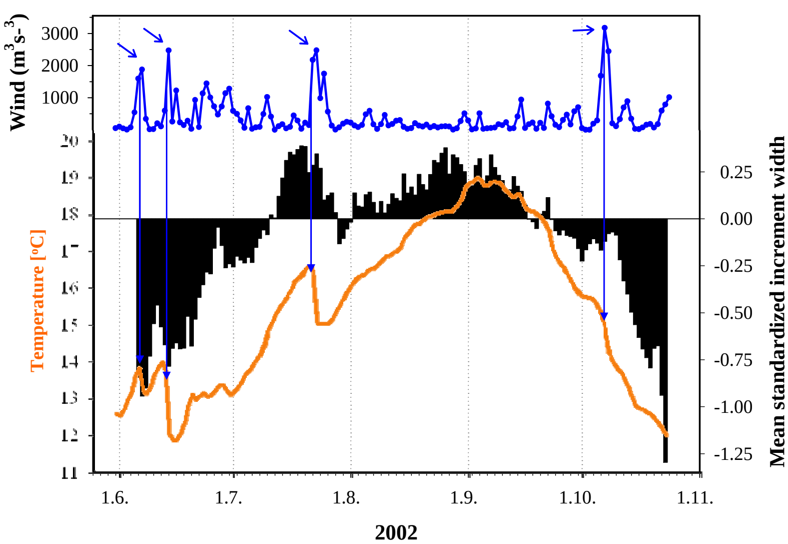

Fig. 3. Mean standardized otolith increment width (black bars) of sprat YOY, modeled Baltic Sea temperature (orange line), and wind energy (blue line). Arrows indicate wind events that corresponde to changes in temperature and YOY growth. (Hinrichsen & Baumann O: 05).

several researchers made a cautionary note about using statistical relationships because they can break down and no longer be predictive if regime shifts occur.

Although most papers noted the important influence of environmental conditions, other processes were found to be significant as well. For example, interactions between size-selective mortality and timing of spawning were also important for Norwegian herring larvae (O:08). In addition, the abundance of year classes largely depends on the size and structure of the Northeast Artic haddock spawning stock (O:03). Finally, eutrophication was found to be an important factor influencing a suite of fish stocks in the Baltic Sea (O:13).

New quantitative approaches were put forward. The empirical traffic light procedure appears to be a good way to communicate to managers and stakeholders, although work will need to done to incorporate the non-linear aspects of population dynamics (O:38). A birth-death model for estimating stage-dependent mortality of mackerel eggs was presented (O:09). Although promising, the effects of advection on mortality rates should be incorporated into the approach.

Of the 47 contributions to this session, only one linked transport processes that occur during early life to a population dynamics model capable of providing population estimates at a scale useful for fisheries and fisheries management. This was achieved by linking two models with different grid resolution; a spatially-explicit circulation/particle tracking for egg production, larval drift, mortality and dispersion and a coarser-grid model for settlement and post-settlement population dynamics of American lobster (*Homarus americanus*) (Fig. 4). The linked models were able to identify management zones in which a high proportion of postlarval production was produced from local spawning populations (O:20).

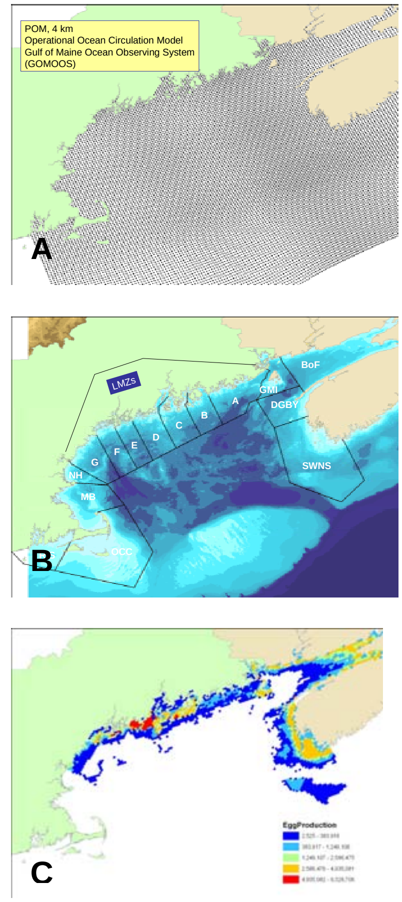

Fig. 4. Multiple-grid scale model for lobster (*Homarus americanus*) in Gulf of Maine. A) Egg production and larval transport grid. B) Juvenile and adult population dynamics grid. C) Example of egg production results. (Incze et al., O:20).

Summary of Open Discussion. A lively and wide-ranging discussion was held. It began with a treatment of the merits of Individual-Based Models (IBM). It was noted that these models do not yet incorporate density-dependent population processes that are critical components of population dynamics, especially the nonlinear processes that compensate for growth. Also, at the outset, IBMs often appear to be academic exercises. Yet, it was recognized that IBMs are useful tools for advancing a mechanistic understanding of processes that affect population variability, and that this understanding is important for making predictions necessary for ecosystem-based fisheries management. After some discussion, participants concluded that the complexity and structure of IBMs must depend upon the species, system and research objectives in question.

The problem of predation mortality was also a subject of discussion. Participants agreed that predation mortality is challenging to measure and difficult to parameterize in models, yet has a huge influence on ecosystem and population dynamics, and on model predictions. Although critical, there have not been recent advances in theoretical descriptions of predation mortality, or even in the ability to distinguish between Type II and Type III functional responses. It was noted that advances in our understanding of predation may result from improvements in the individual-based modelling approach for handling predation mortality. In the field, identifying the characteristics of the surviving cohorts may also advance our understanding.

The effect of infrequent yet reoccurring episodic events (e.g., typhoons, hurricanes, peaks in freshwater flow and saltwater intrusion events) present another challenge for understanding and predicting ecosystem and population dynamics. Often, event-scale forcing is not included in ecosystem, population, or individual-based models. Advances may lie in further explorations of extreme events, extreme year classes, and on better descriptions of the 'tails' of probability density distributions.

The discussion closed with the assertion that we need to understand recruitment processes on the space and time scale of the individual larvae. Although comprehensive data bases exist (i.e., GLOBEC programs), further advances in technology will be needed to make observations at the scale of fish larvae, the scale critical for understanding predation processes as well as for validating IBMs.

Conclusions. Theme Session O provided a forum to share research findings on physical-biological interactions that occur at multiple scales using diverse scientific approaches for a suite of exploited species and their prey. The novel research findings and techniques that were presented, coupled with the outstanding participation in Theme Session O, are a testament to the importance of biological-physical interactions in understanding the dynamics of ecosystems and exploited populations. The success of the research and the interest of the community is likely an outcome of GLOBEC and ICES Cod and Climate programs that highlight the inter-relationships between cod population variability and the physical environment. Research presented in Theme Session O demonstrated that knowledge of the physical environment is emerging as a critical factor for understanding marine ecosystem dynamics and population variability of diverse species. We recommend that the ASC program committee ensure that future Theme Sessions provide forums for researchers to present findings on physical-biological interactions for multiple species (in addition to cod) and on physical oceanographic processes that are important for biology (e.g., turbulence, climate-related changes in current systems, etc.). Although few presenters were able to link research findings directly to fisheries management recommendations, we are encouraged by the intent and progress that the research community is making toward this end.