Theme Session L
Coupled physical and biological models: parameterization, validation, and applications

ICES CM 2008/L:01

The Barents Sea ecosystem dynamics as coupled oscillators to long tides

Harald Yndestad

The Barents Sea ecosystem is associated with large biomass fluctuations. In order to predict these we need to find out whether there is a hidden deterministic process behind the Barents Sea ecosystem. In this study we used wavelet spectrum analysis of a long dataseries from North Atlantic water and the Barents Sea ecosystem. The analysis investigated the annual mean sea level, sea temperature, salinity, the North Atlantic oscillation winter index, and the biomass of plankton, shrimps, capelin, herring, haddock, and northeast Arctic cod in order to study the relation between fluctuation periods and phase in the dataseries. Wavelet analysis shows that the temperature and salinity in the Barents Sea Kola section are correlated with the 18.6 year lunar nodal amplitude tide and the 9.3 year lunar nodal phase tide. Analysis of the Barents Sea ecosystem shows that the biomass of shrimp, herring, haddock, and cod has an optimum life cycle of about 6–7 years, or a third harmonic from the 18.6 year lunar nodal amplitude tide. The capelin biomass has an optimum life cycle of about 3 years, or a third harmonic from the 9.3 year lunar nodal phase tide. The 6- to 7-year biomass life cycles of herring and accumulates in periods of about 3*6=18 years and about 3*18=55 years **[?Q1]**. This result suggests that the Barents Sea ecosystem dynamic can be seen as an oscillating system free-coupled to the forced lunar nodal tide inflow to the Barents Sea. This free-coupled biomass oscillating system has resonance related to the oscillating long tides and the third harmonic periods.

Keywords: lunar nodal tide; eco-oscillation; coupled systems; wavelet analysis.

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ICES CM 2008/L:02

Predictive modelling of sediment response to hypoxia in the Gulf of St Lawrence

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We use a reaction–transport sediment model to examine the effects of progressive oxygen depletion on sediment geochemistry and fluxes. The model includes physical, geochemical, and biological processes and was calibrated using the geochemical data acquired over the last 30 years in the lower St Lawrence River Estuary (Canada). Due to increased nutrient input, as well as changes in the composition of water masses entering the Gulf of St Lawrence, the concentration of oxygen in the bottom water at that location has been decreasing at an average rate of 1 mmol L^{-1} y^{-1} over the past 70 years. Modelled benthic fluxes match those obtained in shipboard sediment incubations. For an assumed scenario of further oxygen depletion, we project the fluxes and sediment distributions of iron, manganese, phosphorus, nitrogen, and sulfur for the next 60 years: the fluxes of reduced substances out of the sediment will increase, reactive iron and manganese oxides will become depleted, and the sediment will become progressively enriched in iron sulfides. The projections are sensitive to the effects of oxygen deficiency on benthic organisms. We compare a gradual response of benthic bioturbation/bioirrigation with a threshold-type response and discuss how biological processes in the benthic layer can be parameterized for modelling purposes. As a next step, the sediment model is being coupled to a large-scale hydrodynamic model for the Gulf of St Lawrence. Accordingly, we discuss the strategies for model adjustments that optimize computer time without sacrificing the accuracy of benthic flux calculations.

Keywords: reaction-transport modelling, coastal hypoxia, sediment diagenesis, model coupling, bioturbation.

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ICEX CM 2008/L:03

Ecosystem model for sea ice influenced seas

Meibing Jin, Clara Deal, and Jia Wang

Reduced sea ice cover and rising temperatures in polar and subpolar seas as a result of climate change have profound impacts on lower trophic level production and fishery production. A one-dimensional coupled ice–ocean ecosystem model that includes both pelagic and sea ice algal components has been developed and applied to investigate the impacts of varying seasonal sea ice cover on lower trophic level production in the

Bering, Chukchi, and Beaufort Seas. The model includes ten compartments: three phytoplankton (pelagic diatom, flagellates, and ice algae: D, F, and Ai), three zooplankton (copepods, large zooplankton, and microzooplankton: ZS, ZL, ZP), three nutrients (nitrate+nitrite, ammonium, silicon: NO_3, NH_4, Si) and detritus (Det). Model equations and the adjustment of model parameters under different ice conditions in the Arctic and Subarctic oceans were discussed. A combination of cold-favouring ice algae and warm-favouring diatoms and flagellates is needed in the model to reproduce both ice-associated and open water phytoplankton blooms in the sea ice-influenced seas. Temperature-dependent zooplankton grazing rates in the polar region can significantly influence the total primary production and community compositions of phytoplankton and zooplankton.

Keywords: ecosystem model, sea ice.

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ICES CM 2008/L:04

Eutrophication in the Baltic Sea and shifts in nitrogen fixation analysed with a three-dimensional ecosystem model

Thomas Neumann and Gerald Schernewski

Since the middle of the twentieth century the Baltic Sea ecosystem has changed significantly. An obvious indicator is the increase of winter nutrient concentrations, which is attributed to increased anthropogenic nutrient loads to the Baltic Sea. With a three-dimensional ecosystem model we made a hindcast simulation of eutrophication from 1960 to 2000. The model system was able to reproduce the main hydrographic and ecologic features of this period, but the observed strong increase in winter nutrient concentrations was underestimated by the model. The simulated nitrogen fixation shows a pronounced interdecadal variability. Nitrogen fixation increased in early 1990, while at the same time nutrient loads to the Baltic Sea were decreasing. The changes in nutrient loads cannot fully explain the increased nitrogen fixation; in fact, the primary trigger for this increase is an intensified windspeed in winter, which is correlated with changes in the North Atlantic oscillation (NAO).

Keywords: Baltic Sea, biogeochemical cycle, modelling, nutrients, nitrogen fixation.

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ICES CM 2008/L:05

Vistula Lagoon (southern Baltic) ecosystem presented in regionally scaled biogeochemical model

Mariusz Zalewski, Zbigniew Witek, and Magdalena Wielgat-Rychert

Extensive environmental observations, some occasional problems with *in situ* measurements, and at the same time a willingness to understand ecosystem processes lead to mathematical mapping of the environment. Here we present the latest version of our biogeochemical model for a shallow coastal lagoon in the southern Baltic Sea. In order to describe the Vistula Lagoon ecosystem we used a three-dimensional water-quality model, part of the Delft3D software developed by Delft Hydraulics, the Netherlands, and its zero-dimensional version constructed using STELLA software. We modified our first assumptions, which had been made during the MANTRA-East project, and the outcome provides a better understanding of the Vistula Lagoon ecosystem. Our model covers cycles of nitrogen, phosphorous, silicate, carbon, and oxygen in the water column and sediment. Model calibrations were based on field data collected by the various institutions carrying out studies in the Vistula Lagoon over the years 1998–2000. Monitoring data covered only vegetation periods, mostly from April to November. The modelling results obtained allowed us to specify the most important processes controlling the functioning of the Vistula Lagoon ecosystem, to check the data quality available, and to supplement the database. Our modelling results also enabled us to estimate seasonal and spatial variability in nutrient and chlorophyll concentration, and primary production. Based on modelling it was possible (i) to quantify roughly main fluxes of substances (inflow, outflow, primary production, mineralization, release from sediments, oxygen consumption, nitrification, denitrification, nitrogen fixation, net accumulation, etc.), (ii) to investigate the relationship between pelagic and benthic subsystems, and finally to describe the functioning of the Vistula Lagoon ecosystem.

Keywords: Southern Baltic, Vistula Lagoon, biogeochemical model, nutrient cycling, eutrophication.

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ICES CM 2008/L:06

Validation of three-dimensional hydrodynamic models in the Gulf of Finland based on a statistical analysis of a six-model ensemble

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Six three-dimensional hydrodynamic models were compared in their simulations of the hydrographic features of the Gulf of Finland in the summer/autumn of 1996. Validation was undertaken using more than 300 vertical hydrographic profiles of salinity and temperature. The analysis of model performance, including ensemble averaging of the results, was undertaken with a view to assessing the potential utility of the models in reproducing the physics of the Baltic Sea accurately enough to serve as a basis for accurate simulations of biogeochemistry once ecosystem models are incorporated. The overall performance of the models was generally satisfactory. The comparison between observations and ensemble simulations, however, indicated some drawbacks in the parameterization of vertical mixing. Also the choice of initial conditions, surface forcing, and differences between real topography and the one used in the models influenced the differences between observations and model results. Looking from another perspective we can state that the accuracy of the present hydrodynamic models determines the upper limit for that of ecosystem models. In turn, the reliability of the hydrodynamic models depends on the physical forcing, which is not always as accurate as one may expect. In the future, further development of hydrodynamic models is needed in the following areas: the description of vertical mixing and advection should be improved, description of forcing functions including bathymetry, atmospheric forcing, river discharge, and boundary conditions should be refined. In addition, more work should be focused on model comparisons to clarify the reasons behind the differences between the models and between models and data.

Keywords: Baltic Sea, hydrodynamics, modelling, intercomparison, statistical analysis.

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ICES CM 2008/L:07

Modelling zooplankton–phytoplankton interactions in the Nordic seas using a fully coupled three-dimensional *Calanus finmarchicus* individual-based model

Solfrid Hjøllo, Geir Huse, and Morten D. Skogen

Zooplankton are usually modelled individually, whereas phytoplankton models tend to be based on biomass concentrations. We have combined these two approaches specifically to address interactions between zooplankton and phytoplankton in the Nordic seas. *Calanus finmarchicus* is the dominant herbivorous mesozooplankton in the Norwegian Sea and has the potential to have a marked effect on the population dynamics of phytoplankton. We present a novel individual-based *Calanus* model with simulated evolution of behavioural traits, including vertical migration strategies and timing of ontogenetic migrations. The results show that the simulated *Calanus* population is able to remain viable in the Norwegian Sea basin over hundreds of years and evolves a life history that resembles the observed life history of *C. finmarchicus*. A two-way coupling between the IBM *Calanus* model and the three-dimensional physical, chemical, and biological ocean model NORWECOM has been performed. We demonstrate that such coupling has a profound effect on the population dynamics of phytoplankton, compared with the constant mortality parameter implementation previously applied in NORWECOM. Most notably, the phytoplankton bloom is prolonged and primary production increases. Examples from simulating climatically quite different years also demonstrate a significant bottom-up regulation of *Calanus* production and distribution, which may affect recruitment, growth, and migration patterns of planktivorous fish such as herring.

Keywords: *Calanus finmarchicus*, IBM, Norwegian Sea.

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ICES CM2008/L:08

Epibenthic macrofauna community structure of the Gulf of St Lawrence in relation to environmental factors and commercial fish assemblages: multivariate and geostatistic approaches

M. Lévesque, P. Archambault, D. Archambault, J-C. Brêthes, and S. Vaz

Bottom trawl observations in the northern Gulf of St Lawrence made by the annual summer survey of the Canadian Department of Fisheries and Oceans give a good opportunity to document the composition and

distribution of macro-epibenthic invertebrates. This study represents the first attempt to characterize the epibenthic fauna over that wide geographical area. The objective was to establish a relationship between the structure of invertebrate macrofauna communities and fish assemblages and environmental conditions. This relation could highlight critical habitats. In August 2006, 221 bottom-trawl stations were surveyed throughout the estuary and the northern Gulf of St Lawrence. Multivariate and univariate analyses are used to explore the structure and the diversity of the benthic epifauna assemblages (MDS, SIMPER, taxonomic distinctness). Relationships between these assemblages and environmental parameters, such as depth, sediment type, temperature, chlorophyll *a*, oxygen, and bottom currents, are described. About 40% of the macrofauna community structure variance could be explained by the available abiotic factors (canonical correspondence analysis). General linear models (GLM) were applied to predict the distribution of invertebrates according to significant environmental factors, resulting in a map of benthic habitat. Our findings will help in the development of guidelines for adequate conservation measures in the context of integrated marine resource management.

Keywords: epibenthos, community analyses, habitat, Gulf of St. Lawrence.

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ICES CM 2008/L:09

Spatial variability in *Calanus finmarchicus* phenology: application of a new individual-based model (IBM)

Anna B. Neuheimer and Wendy C. Gentleman

The copepod *Calanus finmarchicus* plays a key ecological role linking primary production and higher trophic levels throughout the North Atlantic. *C. finmarchicus* dynamics and production are affected by temperature and food, such that overall effects of environmental variability may be multiplicative or mitigating. Without realistic modelling, it is difficult to disentangle the relative influence of different environmental factors or to predict responses for different regions. Here we employ a new stage-based model of individuals to simulate the dynamics of two Northwest Atlantic *C. finmarchicus* populations that exhibit dramatic differences in peak abundance timing and magnitude. The model includes empirically derived relationships of temperature and food effects on development, mortality, and egg production rates, and is forced by regional temperature and chlorophyll data. Hypotheses about controlling factors are tested by statistical comparison with data for copepod abundance and stage structure. We also investigate the potential importance of omnivory and cannibalism by including microzooplankton consumption and linking mortality to egg and naupliar abundances. The implications of our results with respect to the influence of climate on copepod production and their trophic roles are discussed.

Keywords: individual-based model (IBM), *Calanus finmarchicus*, temperature, development, egg production, mortality.

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ICES CM 2008/L:10

Modelling retention and dispersion mechanisms of bluefin tuna eggs and larvae in the northwest Mediterranean Sea (Balearic area)

Patrizio Mariani, Brian R. MacKenzie, Daniele Iudicone, and Alexandra Bozec

Knowledge of the early life history of most fish species in the Mediterranean Sea is sparse and processes affecting their recruitment are poorly understood. This generalization is particularly true for bluefin tuna (*Thunnus thynnus*) even though this species is one of the world's most valued fish species. Here we develop, apply, and validate an individually based coupled biological–physical oceanographic model of fish early life history in the Mediterranean Sea. We applied the model to investigate transport and retention processes affecting the spatial distribution of bluefin tuna eggs and larvae during 1999–2003 and we compared modelled distributions with available field data collected in 2001 and 2003. Modelled and field distributions generally coincided and were patchy at mesoscales (tens to hundreds of kilometres); larvae were most abundant in eddies and along frontal zones. We also identified probable locations of spawning bluefin tuna using hydrographic backtracking procedures; these locations were situated in a major salinity frontal zone and coincided with distributions of electronically tagged bluefin tuna and commercial bluefin tuna fishing vessels. Moreover, we hypothesized that mesoscale processes are responsible for the aggregation and dispersion mechanisms in the area and showed that these processes were significantly correlated with atmospheric forcing processes over the northwestern Mediterranean Sea. Interannual variations in average summer air temperature can reduce the intensity of ocean mesoscale processes in the Balearic area and then potentially affect survival probability of bluefin tuna larvae. These modelling approaches can increase our

understanding of bluefin tuna recruitment processes and ultimately contribute to the management of bluefin tuna fisheries.

Keywords: IBM modelling, bluefin tuna, Mediterranean, retention, dispersion, transport, fronts, eddies.

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ICES CM 2008/L:11

A summer phytoplankton bloom triggered by high wind events in the Labrador Sea, July 2006

Yongsheng Wu, Trevor Platt, Charles C. L. Tang, Shubha Sathyendranath, Emmamuel Devred, and Shue Gu

In temperate latitudes, the onset of stratification in spring initiates the annual bloom of phytoplankton, which then usually continues until nutrients in the surface mixed layer become depleted. After the spring bloom, primary production is dependent on recycled nutrients, and further blooms of phytoplankton are not possible unless and until nutrients are resupplied to the surface layer. In the central Labrador Sea, the annual spring bloom starts around the middle of May when the thermal stratification is established, and ends around the middle of June when nutrients in the euphotic zone become depleted. After the end of the bloom, the chlorophyll concentration is a fraction of the value during the bloom. The summer is usually a period of relatively low phytoplankton growth. However, in mid-July 2006, when the annual spring bloom was already over, an intense bloom over a large part of the central Labrador Sea (hereafter referred to as the episodic bloom) was observed in satellite images. To interpret why the summer bloom happened, the mechanisms of nutrient resupply for an episodic phytoplankton bloom observed in the central Labrador Sea in July 2006 were investigated. Two physical processes, mixed-layer deepening and Ekman pumping, are proposed to account for the implied nutrient replenishment. The nutrient flux and chlorophyll concentration before and during the bloom were estimated from a simple coupled nitrate–phytoplankton model. The model results show that the enrichment of nutrients in the euphotic layer and the subsequent bloom were related to two wind events (storms) in the period 7–10 July. As the mixed layer deepened, nutrients from below the nitricline were entrained into the euphotic zone. The Ekman pumping, which was most intense at the storm centre, enhanced the transport of the nutrients by raising the nitricline. However, Ekman pumping alone was not able to transport sufficient nitrate to the euphotic layer to support the observed phytoplankton bloom.

Keywords: summer phytoplankton bloom, vertical mixing, Ekman pumping, new nutrient replenishment.

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ICES CM 2008/L:12

The impact of mussel farming on the biogeochemistry of the northern Adriatic coastal ecosystem: preliminary results from a modelling study

D. Brigolin, T. Lovato, S. Ciavatta, and R. Pastres

Half of the Italian production of mussels, approximately 12% of the total European production, is concentrated along the northwest Adriatic coast, where the number of culture sites is expected to grow further in the next decade. We present the preliminary results of a modelling study aimed at assessing the impact of longline mussel farming on the C, N, and P cycles in this region. The model was obtained by coupling on-line three different submodels: (i) an hydrodynamic model; (ii) a benthic–pelagic biogeochemical model; (iii) a population dynamic model of farmed mussel, based on an individual-based model (IBM) of the mussel (*Mytilus galloprovincialis*). The hydrodynamic model is based on shallow water equations and adopts a curvilinear, boundary fitted reference system. The biogeochemical model is based on a reaction–transport equation, which describes the dynamics of phytoplankton, zooplankton, dissolved macronutrients, and oxygen. The benthic–pelagic fluxes of macronutrients, remarkably enhanced by the mineralization of mussel faeces, are computed by means of an early diagenesis model. The mussel population dynamic has been embedded in the biogeochemical model, in order to take into account the effect of mussel filtration of seston and of the mussel biodeposition on the fluxes of C, N, and P at the bottom. Simulations were focused on the Emilia-Romagna coastal area. The model results indicate that the overall impact of mussel farming on C, N, and P cycles is significant, given the extension of licensed areas, and suggest the potential use of this type of model as a tool for the optimization of site selection and farm size.

Keywords: individual-based model, biogeochemical model, mussel farming, C N P cycles.

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ICES CM 2008/L:14

Evidence of catastrophic shifts in marine ecosystems – a challenge for predicting ecosystem impacts of global warming

Tore Johannessen

Repeated incidents of abrupt and persistent recruitment collapses in gadoid fish have been observed in relation to increasing pollution along the Norwegian Skagerrak coast. The present paper links the observed recruitment collapses to catastrophic ecosystem shifts caused be gradually increasing anthropogenic eutrophication and provides evidence of a mechanism. The main results and conclusions are as follows:

(i) There are alternative stable states with different environmental optima in marine ecosystems.

(ii) The change from one stable state to another appears as a catastrophic shift.

(iii) Different stable states may persist under overlapping environmental conditions, suggesting that marine ecosystems are highly resilient and resistant towards invasions.

(iv) Predator–prey synergism between phytoplankton and herbivorous zooplankton is identified as the mechanism underlying ecosystem resilience. Synergism implies that herbivores stimulate the production of their preferred algal prey while negatively affecting other algae. The opposing hypothesis of herbivores affecting their algal prey negatively is incompatible with high resilience.

(v) The eutrophication-induced shifts are linked to increasing turnover rates in the algal community with increasing primary productivity. This favours small, fast-growing algal species, which are then grazed by smaller herbivorous zooplankton.

The fact that marine ecosystems may not respond in a gradual dose–response manner, but shift abruptly between alternative stable states seriously challenges our present approach of managing ecosystems and their constituent species, and the way we monitor potential impact of environmental changes and predict future scenarios by modelling. This is of particular concern with the prospect of global warming.

Keywords: recruitment, eutrophication, cod, catastrophic shift, synergism, ecology, global warming.

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ICES CM2008/L:15

Modelling biogeochemical processes on the North American east coast continental shelf

Katja Fennel, Moritz Lehmann, John Wilkin, and Ruoying He

Continental shelves are the marine ecosystems that most directly affect and are most directly affected by human activities. Shelf processes such as primary production and sediment denitrification also play an important role in the global cycling of nitrogen and carbon. We developed coupled physical–biogeochemical models of the North American east coast continental shelf, including the Scotian Shelf, the Gulf of Maine, and the Mid-Atlantic Bight, and its adjacent deep ocean with the objectives of quantifying elemental fluxes in these systems, improving our understanding of their environmental drivers, and predicting ecosystem variability. Our models are nested within larger scale North Atlantic models, allowing us to resolve coastal processes and shelf/open ocean exchange at relatively high resolution (less then 10 km in the horizontal direction) while retaining larger scale circulation features and capturing variability that is forced outside of our local model domain. Our biogeochemical model components are based on relatively simple representations of nitrogen cycling in the water column and sediment, and are coupled with inorganic carbon and oxygen dynamics, including the air–sea gas exchange of carbon dioxide and oxygen. We will present results of model validation exercises comparing model-predicted fields with climatological satellite products and *in situ* data and discuss insights gained in ecosystem variability and elemental cycling. We believe that these increasingly realistic models offer tremendous potential for predicting the effects of anthropogenic perturbations to coastal ecosystems, especially when combined with the multidisciplinary data streams now beginning to emerge from ocean observation systems.

Keywords: coupled physical-biological model, continental shelf, coastal ocean, carbon, nitrogen.

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ICES CM 2008/L:16

Mechanisms affecting the transport of early stages of Norwegian coastal cod—a fjord study

Mari Myksvoll

The fjord system of Sørfolda and Nordfolda in northern Norway is a spawning site for the Norwegian coastal cod (CC). The two fjords have a joint opening towards Vestfjorden, one of the main spawning sites for the Arcto-Norwegian cod (ANC). The ANC eggs are lighter than the surrounding water masses in Vestfjorden, resulting in a pelagic distribution, with concentration highest close to the surface and decreasing exponentially with depth. Their vertical distribution is sensitive to variations in wind-induced mixing. The CC eggs in Sørfolda and Nordfolda are heavier than the ANC eggs and within the low-salinity water inside the fjord system they are mesopelagically distributed. A numerical model is used to investigate how the vertical distribution affects the transport of eggs. The results elucidate the mechanisms separating ANC and CC. The simulation was set up for 1960 and 1989, representing a cold and dry year and a warm and wet year. The major difference between the simulations is the fresh-water input, which causes variations in the estuarine circulation. Changes in salinity structure affect the vertical distribution of CC eggs, and might cause them to be transported out of the fjord system and become mixed with ANC eggs. A strong stratification causes the eggs to be concentrated lower in the water column and to remain inside the fjord. The retention of CC eggs is subject to variations within a season, between years, and at different spawning grounds.

Keywords: fjord modeling, Norwegian Coastal Cod, vertical distribution.

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ICES CM 2008/L:17

Challenges in model validation by comparison with satellite chlorophyll data

Bente Tiedje, Andreas Moll, and Lars Kalesche

This presentation outlines an approach used to compare chlorophyll *a* distributions derived from the three-dimensional marine ecosystem model ECOHAM with satellite data for the northwest European continental shelf. The model was validated for the years 2003–2004 against observed temperature, nutrient, and *in situ* chlorophyll data on a monthly basis to reflect the quality of the model in different regions. The comparison with satellite data was realized on different temporal and spatial scales: seasonal chlorophyll skill maps were used for the spatial comparison between the surface satellite chlorophyll concentration and the model estimates. In addition, the 2004 chlorophyll annual cycle of weekly satellite data was averaged over particular areas in the northern and southern North Sea and compared with corresponding model and *in situ* data.

Keywords: ecosystem model, chlorophyll *a*, satellite data.

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ICES CM 2008/L:18

Validation of simulated *Pseudocalanus elongatus* population dynamics during the GLOBEC-Germany cruises in 2004 using ECOHAM4

Christoph Stegert and Andreas Moll

A three-dimensional ecosystem model for the North Sea, which includes competition between *Pseudocalanus elongatus* and the rest of the zooplankton biomass, was applied to describe the seasonal cycle of zooplankton in the German Bight in 2003–2004. The paper presents a comparison of simulated stage-resolved abundances with copepod counts during the GLOBEC-Germany project from February to October 2004. The validation shows that the model is able to calculate reliably the distribution of zooplankton biomass as well as the stage development and abundance spectrum of *P. elongatus*, and thus the ratio of population biomass to total biomass. In the German Bight, the population rate is below 20% in spring, increasing up to 50% during summer. The number of generations of *P. elongatus* was estimated at 4–7 in the southern North Sea. The model is able to quantitatively analyse the seasonal dynamics and physiology of *Pseudocalanus* as well as to calculate zooplankton prey fields for further use in larval fish models.

Keywords: stage-structured zooplankton population model, ecosystem model, copepod, *Pseudocalanus elongatus*, generation time, German Bight.

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ICES CM 2008/L:19

Impact of early spawning on survival and growth in Norwegian spring-spawning herring

F. B. Vikebø, Å Husebø, A. Slotte, and E. K. Stenevik

The spawning grounds of Norwegian spring-spawning (NSS) herring (*Clupea harengus* L.) are along the central Norwegian continental shelf from 58 to 69°N, particularly off the coast of Møre. Hatching occurs in the coastal waters from mid-March until mid-April. The eggs are fixed to the bottom, while hatched larvae ascend in the water column and are advected with the water masses. The circulation features from the spawning grounds to the nursery grounds in the Barents Sea are dominated by the relatively warm and salt Atlantic Water trapped along the shelf break (Norwegian Atlantic Current), and the cool and fresh wedge-shaped coastal water (Norwegian Coastal Current) between the Atlantic Water and the coast. Assuming that larval behaviour is affected by light conditions in such a way that short daylengths early in the season cause the larvae to spend more time in shallower parts of the water column than later in the season when the daylength increase, then mean vertical larval habitat selection at a given age generally deepens with hatching time as light conditions improve. As a result of wind-generated mixing, near-surface objects are typically spread more in the horizontal than objects farther down in the water column. Enhanced horizontal mixing increases the chance of being displaced out into the Norwegian Atlantic Current and thereby advected quickly into the nursery grounds of the Barents Sea. The implication for the NSS herring offspring is that early hatching may result in shorter transportation time from spawning to nursery grounds. At the same time the winds typically weaken during spring, which enhances the differences in horizontal spreading for early- and late-hatched larvae.

Such a rapid transport from the spawning grounds to the nursery areas in the Barents Sea is hypothesized to increase larval survival as a result of reduced overlap with predators along the Norwegian coast. By simulating the dispersal of larval NSS herring where vertical habitat selection is a function of light, we have explored the impact of hatching time on transportation time from spawning to nursery grounds. Possible implications for recruitment are also discussed.

Keywords: Herring larvae, Northeast North Atlantic, dispersal, time of spawning, numerical modellling.

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ICES CM 2008/L:20

Coupling Eulerian and Lagrangian models to understand sediment transport, ecosystem dynamics, zooplankton population fluctuations, and larval fish feeding success in upper Chesapeake Bay

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Physical–biological interactions in the Chesapeake Bay Estuarine Turbidity Maximum (ETM) influence many processes, from sediment transport to zooplankton and fish production. Sediment bed characteristics, shear, and stratification in the water column, and aggregate formation processes (both biological and physical) interact and influence sediment transport. These processes are affected by changes in fresh-water flow on episodic, seasonal, and annual time-scales. Variations in fresh-water flow also force shifts in the salt front location, affect circulation and sediment trapping, and impact biological production. When spring flows are above average, the copepod *Eurytemora affinis* occurs in higher abundance, and the feeding success, growth, and survival of fish larvae are enhanced. We are building a coupled Eulerian–Lagrangian model system to investigate how changes in fresh-water flow influence physical characteristics and ecosystem dynamics of the upper Chesapeake Bay. Here we discuss physical and biological model (PBM) and individual-based model (IBM) model coupling and structure as well as parameterization and validation efforts that rely on information derived from an extensive field programme, which is ongoing. Preliminary validation metrics and model results are presented.

Keywords: coupled biological-physical models, estuarine turbidity maximum.

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Grand Banks white hake recruitment in relation to the Labrador Current

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White hake (*Urophycis tenuis*) is a temperate bottom-dwelling fish with the northern extent of its distribution on the southern Grand Banks. Survey data from the 1970s to 2004 indicated exceptionally good recruitment

of the 1999 year class. Here we investigated potential dispersal patterns of eggs, larvae, and young juveniles under the reconstructed circulation fields, which were obtained from a three-dimensional ocean model and satellite altimetry. The results indicate that the weakening of the Labrador Current is an important mechanism for the recruitment success of the 1999 year class.

Keywords: dispersion, the Labrador Current, white hake, numerical simulation

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Application of variational data assimilation to coupled physical–biological models of the North Atlantic bloom

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Lagrangian floats and seagliders have been deployed in the North Atlantic south of Iceland from late March to early July 2008 to sample the evolution of the spring bloom at high spatial and temporal resolution. We used the physical, chemical, and bio-optical data produced by these autonomous platforms along with complementary *in situ* data from a cruise in May 2008 to develop a biological model describing the bloom and its associated carbon fluxes. Toward this end we set up the General Ocean Turbulence Model (GOTM) for a North Atlantic site at 60°N, 20°W and are forcing it with windspeed, air pressure, air temperature, and humidity data. We coupled this physical model with a simple biological model and made predictions of the bloom evolution during the deployment period. We are currently modifying and improving the model based on our assessment of the consistency between simulated and measured data, applying variational data assimilation to optimize the biological model parameters so that the model–data consistency of different model variants can be assessed in a systematic way. The final model will be used to estimate carbon fluxes and export during the bloom.

Keywords: variational data assimilation, coupled physical–biological model, North Atlantic spring bloom, carbon export.

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Application of two statistical data assimilation procedures to a one-dimensional biological model of the BATS site

Paul Mattern, Katja Fennel, and Michael Dowd

Modern statistical data-assimilation techniques can be used to improve the accuracy of numerical ecosystem models in particular and ocean models in general by comparing them with available data. We present an application of the Ensemble Kalman Filter (EnKF) and the Sequential Importance Resampling (SIR) to a one-dimensional, depth-resolved biological model of the upper ocean at the Bermuda Atlantic Time Series Study (BATS) site. The biological model is nitrogen-based, and simulates phytoplankton, detritus, and dissolved inorganic nitrogen. Chlorophyll with photoacclimation and oxygen with gas exchange at the ocean surface are also modelled. The physical setting is provided by the General Ocean Turbulence Model (GOTM) which includes a k-epsilon mixing scheme and atmospheric forcing. The EnKF and the SIR approaches are illustrated by quantifying the improvement of the model fit to observations over a model without data assimilation.

Keywords: data assimilation, Ensemble Kalman Filter, Sequential Importance Resampling, coupled physical–biological model, North Atlantic.

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Index modelling for coastal ecosystem health assessment

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Coastal ecosystems are faced with a variety of environmental stresses, and the concept of ecosystem health has become increasingly attractive to both regulators and the public. Many indicators of ecosystem health have been derived, many of them data-intensive, such as those relying on benthic biodiversity. In addition to large effort, they yield information after the occurrence of impacts or other detriments to environmental quality. Prediction of impacts *a priori* would be more useful from a management standpoint. Although

various models have predictive capability, their spin-up time may be long, requiring data that are not available for a given site. In a new research programme, therefore, we use system-level properties (flushing, morphology, pollutant load, etc.) to develop index-type models for coastal ecosystems. Moreover, we examine the statistical properties of their construction (error terms, non-linearity) to make them more quantitative in application. Ground-truthing of index models will be undertaken at coastal study sites using data from well-known sites. In addition, a decision-support tool based on combining/weighting the indices will be developed.

Keywords: coastal, ecosystem health, index, model.

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Scientific parameterization and its validation: comparing the universal models of fishery economics with the invalid modelling of stock assessment

Christopher J. Corkett

Here I compare the valid parameterization of fishery economics with the data-fitted parameters of a stock assessment's modelling, invalid models whose predictions cannot be falsified (which is another way of saying the models are not universal). The distinction between (i) a model's valid universal prediction and (ii) a model's invalid prediction that cannot be falsified can be summarized in terms of a model's parameterization, as: high falsifiability = paucity of parameters = simplicity.

The universal laws of physics, for example, are simple: they have few parameters and a high degree of falsifiability. It is this high degree of falsifiability or negation that guides all engineers by showing them what cannot be achieved and should not therefore be tried as part of "trial and error" engineering. By contrast, models of fish stock assessment are not simple: their data-based parameters change with the changing data. These models are not universal; they apply only to a particular fishery situation and are incapable of guiding all fishery managers (all social engineers) by indicating what cannot be achieved. Under Karl Popper's limited (and formal) definition of empirical science, data-fitted models proffer policy advice to fishery management that is formally invalid.

Keywords: parameterization, validation, universal laws, economics.

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Climatic impact on hake recruitment in the Iberian Peninsula and implications for fishery management: an InExFish project study

H. Mendes and M. F. Borges

One of the objectives of the INEXFISH project is to incorporate external factors into fishery management. The estimation and forecasting of recruitment has occupied fishery scientists for decades because of the critical importance of incoming recruitment to the fishable stock. The southern stock of hake (ICES Divisions VIIIc and IXa) along the Atlantic coast of the Iberian Peninsula has been declining over the past years because of overfishing and, probably, unfavourable environmental changes. We investigated the relationships between recruitment, parental stock, and physical environmental variables. The winter North Atlantic oscillation (NAO) index, upwelling indices, and sea surface temperature data were collected and related to the recruitment estimated from the ICES stock assessment for the period 1982–2005. Relationships were explored using linear and additive modelling, in addition to the Beverton–Holt and Ricker SR relationships. The additive model achieved better results in describing recruitment variability with a significant response of hake recruitment to spawning size and NAO, that acted as a proxy for climate forcing with apparently more significance than other more reliable and biologically important factors such as the local sea surface temperature or seasonal upwelling The concept of climate-forced fish productivity could be included in population dynamics, for fishery management advice. To assess for uncertainty in stock recruitment levels and consider the implications for fishery management strategies, we used our model to simulate biomass reference points at different NAO values. In our case study, we concluded that Iberian hake production ratio (recruitment/SSB) is much higher at negative and neutral NAO scenarios, with implications on the overall stock size.

Keywords: hake, recruitment, NAO, additive models, biomass reference points.

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A bio-optical product from a coupled bio-physical ocean circulation model of the western North Atlantic

Moritz K. Lehmann, Katja Fennel, Ruoying He, and John Wilkin

Autonomous observation platforms supply information on the biological, physical, and chemical state of the ocean that lends itself to validation of and assimilation into coupled biophysical circulation models. However, conversions are necessary to relate observed quantities to modelled variables. Traditionally, these conversions are performed on observations, for instance, relating the ratio of blue and green light intensity to chlorophyll concentration in the water. We implemented a coupled biophysical Regional Ocean Modelling System (ROMS) with bio-optical equations to produce fields directly comparable to routine observations from optical sensors on moorings, gliders, floats, and satellites. We contrast modelled fields of water leaving radiance at standard wavelengths with corresponding fields from satellite sensors.

Keywords: biophysical modelling, bio-optics, ROMS, optical observations.

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