

## Theme Session E

### Climate impacts on marine fish: discovering centennial patterns and disentangling current processes

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#### ICES CM 2009/E:01

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##### **Accelerated warming and emergent trends in fishery biomass yields of the world's large marine ecosystems**

K. Sherman, I. Belkin, K. D. Friedland, J. O'Reilly, and K. Hyde

Information on the effects of global climate change on trends in global fishery biomass yields has been limited on spatial and temporal scales. Results are presented of a global study on the impact of sea surface temperature (SST) changes over the last 25 years on the fishery yields of 63 large marine ecosystems (LMEs) that annually produce 80% of the world's marine fishery catches. Warming trends were observed in 61 LMEs around the globe. In 18 of the LMEs, rates of SST warming were 2–4 times faster during the past 25 years than the globally averaged rates of SST warming reported by the Intergovernmental Panel on Climate Change in 2007. Effects of warming on fishery biomass yields were greatest in the fast warming northern Northeast Atlantic LMEs, where increasing trends in fishery biomass yields were related to zooplankton biomass increases. In contrast, fishery biomass yields of LMEs in the fast warming more southerly reaches of the Northeast Atlantic declined in response to decreases in primary productivity and zooplankton abundance. The LMEs around the margins of the Indian Ocean where SSTs were among the world's slowest warming, revealed a consistent pattern of fishery biomass increases during the past 25 years, driven principally by human need for food security from fishery resources. As a precautionary approach toward more sustainable fishery utilization, management measures to limit the total allowable catch through a cap and sustain approach are suggested for the developing nations recently fishing heavily on resources of the Agulhas Current, Somali Current, Arabian Sea, and Bay of Bengal LMEs.

Keywords: ocean warming, fishery biomass yields.

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#### ICES CM 2009/E:02

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##### **Climate-induced changes in the growth rate of flatfish species in the North Sea by means of food competition.**

R. Van Hal, F. Stuke, I. Tulp, and A. D. Rijnsdorp

North Sea flatfish species overlap largely in their spatial distribution and stomach samples indicate that their diets at least partially overlap. This overlap may induce competition between them, leading to suppressed growth rates caused by a lack of food. Such competition may have been enhanced as a result of temperature-related changes in species composition and increased metabolism. Using research vessel survey data on spatial distribution and abundance, stomach sampling data on dietary overlap, and otolith data on growth, we test the hypothesis that the observed decrease in growth of commercial flatfish species (plaice and sole) is related to the combined effect of an increased abundance of solenette and scaldfish and an increase in temperature.

Keywords: growth rate, competition, North Sea, temperature, flatfish.

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**ICES CM 2009/E:03**

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**Analysing warm and cold climate phases to understand differences in survival and connectivity of larval cod: possible implications for climate change**

T. Kristiansen, K. Drinkwater, and J. Zavala-Garay

Environmental variation can cause significant fluctuations in the survival of larval fish and plankton. Understanding these fluctuations is critical for developing more accurate fishery models, which are needed for both scientific and socio-economic research, especially when facing the challenges of climate change. In the absence of complete climate models, however, we can learn from retrospective analyses of warm and cold periods. During the 1970s the North Atlantic Ocean experienced a general cooling period, whereas the 1990s was characterized by an intense warming period. By contrasting these two phases of the North Atlantic Ocean we can analyse and observe how cold and warm periods affect the ocean currents and the distribution of heat, and how such changes propagate through trophic levels from primary production to fish. Although the spawning time for Atlantic cod remained relatively consistent between years, warm and cold phases probably had a strong impact in the timing of the spring bloom and thereby the production of food for larval fish. Differences in climate may also alter the general ocean currents, leading to variations in the drift trajectories between warm and cold phases. Here, we combine a mechanistic individual-based model (IBM) with a high-resolution three-dimensional physical and biological model (ROMS+BIOFASHAM) to explore how the 1970s and the 1990s differed in modelled larval growth, drift, and connectivity between spawning and nursery grounds along the coast of Norway. Based on these results we describe differences in ecosystem properties in cold and warm periods and how these patterns relate to cod recruitment.

Keywords: individual-based modelling, climate change, Atlantic cod, ecosystems, connectivity.

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**ICES CM 2009/E:04**

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**The spatial dimension of climate-driven temperature change in the Baltic Sea**

Rüdiger Voss, Christoph Petereit, and Hans-Harald Hinrichsen

Assessment of climate change in the Baltic Sea has revealed significant positive trends in the annual mean temperature. During the last 10–15 years in particular, extremely high NAO+ (North Atlantic Oscillation) phases have been registered, coupled with high sea surface temperatures. Studies of past and recent ecosystem changes have demonstrated the sensitivity of the Baltic Sea ecosystem to changing temperatures. For example, increased production and survival rates of the sprat population during the last decade have covaried with high temperatures and related climate indices. These trends are expected to continue into the future, because the identified trends are consistent with regional climate change scenarios. In this study we investigated spatially resolved temperature trends over a 25-year period in the Baltic Sea. The temperature data were obtained from hydrodynamic model simulations. The underlying hypothesis is that climate-driven changes in temperature will affect the Baltic Sea area in a non-uniform way, in that besides a general temperature increase, westerly airflows have intensified, increasing the upwelling potential in some areas, which in turn is coupled to lower than average temperatures. We calculate temperature trends in a spatial resolution of  $\frac{1}{4}$  ICES rectangle (ca. 15 × 15 nm) and a depth resolution of 10-m intervals. We concentrate on months and depths strata that are most important for recruitment processes of the commercially important species cod and sprat. Correlation analysis of climate indices and temperature conditions are performed. A spatially resolved evaluation of temperature-dependent key processes for recruitment is also performed (e.g. egg mortality, egg phase duration, window of opportunity).

Keywords: Baltic Sea, climate change, spatial trends, temperature change, recruitment.

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**ICES CM 2009/E:05**

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**Climatic impact on northeast Arctic cod year-class strength: relevance of the Ricker and Beverton–Holt models for determination of "recruitment stock" dependence**

B. N. Kotenev, V. P. Serebryakov, M. V. Bondarenko, and A. D. Morozov

The northeast Arctic cod stock is characterized by high-amplitude fluctuations in abundance of its year classes. In the period 1946–2002, only a few strong generations determined the stock abundance and biomass. The mortality–survival relationship during the cod early life history is far less dependent on spawning stock abundance than on environment effects. The year-class survival index (ratio of recruitment of the stock to number of eggs laid or spawning biomass) could be used as a universal indicator of environment quality. Comparison of variations in the survival conditions with variability of physical factors demonstrated that on the decadal and interdecadal scales of global and regional climatic variability there was a clear link between favourable survival conditions and climate. Analysis of global and regional climatic features on the decadal and interdecadal scales is not sufficient, however, to identify links between unfavourable conditions and year-class survival or to find climatic predictors of interannual variations in survival conditions. It is likely that this aim could be attained with analysis of climatic variability directly in the areas of spawning grounds and larval drift in the northeast Arctic cod distribution area. Comparison of recruitment calculated with the Ricker and Beverton–Holt models with long-term observations demonstrated a large difference, which meant that we were unable to consider these models as an adequate expression of the recruitment stock dependence for this population.

**Keywords:** northeast Arctic cod, recruitment stock dependence, spawning-stock biomass, survival index, climatic variability, Ricker and Beverton–Holt models.

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**ICES CM 2009/E:06**

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**Climate-driven long-term evolution of oxygen concentration in the Baltic Sea: potential consequences for the Baltic cod stock**

H.-H. Hinrichsen, B. Huwer, A. Makarchouk, S. Neuenfeldt, C. Petereit, M. Schaber, and R. Voss

Oxygen conditions in the Baltic Sea ecosystem are influenced through a number of mechanisms. In general, the frequency and magnitude of major Baltic inflows have been identified as the major process for the renewal of oxygen-depleted water masses in the Baltic. It has also been suggested that oxygen consumption has increased in recent decades because of enhanced degradation of suspended organic matter by bacteria. Finally, long-term variations in oxygen content and saturation are affected by global warming, because the observed increase in temperature has led to a general decrease in oxygen solubility of water masses. The present study provides a detailed analysis of observed negative long-term trends in oxygen content and saturation within different areas of the Baltic. Based on field data and laboratory experiments, oxygen-dependent relationships were used to analyse the impact of the observed negative long-term trend of oxygen content in the Baltic Sea ecosystem on cod stock-specific processes (e.g. survival rates of eggs, settlement probability of juveniles, condition of juveniles, habitat utilization of adult spawning fish, age structure of successful spawners, consumption rates of adult fish). The study attempts to suggest how the Baltic Sea ecosystem and in particular the Baltic cod stock may respond to future changes in the oxygen environment.

**Keywords:** oxygen environment, negative trend of oxygen content, oxygen-related cod stock-specific processes.

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**ICES CM 2009/E:07**

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**Long-term fluctuations of Baltic cod egg production in relation to major inflow events**

E. M. Karasiova, G. Kraus, and R. Voss

Results of long-term ichthyoplankton investigations in the deep basins of the Baltic Sea during the period 1957–1996 were used to estimate annual cod egg production on the three main spawning grounds: the Bornholm Basin, the Gdańsk Deep, and the southern and central parts of the Gotland Basin. After a period of continuously increasing egg production from 1961 to 1966, the interannual variability of cod egg production in the Bornholm Basin until 1980 demonstrated mainly moderate fluctuations around an average value without obvious trends. A similar increase, but until the end of the 1960s, was also observed in the eastern basins, but interannual variability was much more pronounced with few strong peaks. After the drastic cod egg production decline at the beginning of the 1980s on all cod spawning grounds, a period of substantially increasing egg production values was only observed in the Bornholm Basin during the mid 1990s, whereas a minor increase was detected in the Gdańsk Deep in 1994, but not in the Gotland Basin. The comparison of the interannual cod egg production dynamics with dates of major inflows into the central Baltic Sea via the Danish Straits suggested that these events exerted the major positive effect upon cod egg production and subsequent reproductive success, especially in the eastern basins (most pronounced in the central Gotland Basin) before the early 1980s. In contrast, after the major inflow activity in 1993/1994 only egg production in the Bornholm Basin was significantly affected. The biological implications of inflow events on eastern Baltic cod reproduction and implications for further applications of egg production time-series are discussed.

Keywords: Baltic cod, cod egg production, cod spawning grounds, inflow.

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**ICES CM 2009/E:08**

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**Potential responses of anchovy (*Engraulis encrasicolus*) larval dispersal to climate change in the Bay of Biscay**

Martin Huret, Pierre Petitgas, and Fabien Léger

Transport of fish early life stages is key in the recruitment process. It defines which environmental history eggs and larvae will encounter for growth and predation. In the context of climate change, characteristics of the dispersal will be modified through changes in the hydrodynamics, temperature, or prey fields. In a modelling framework, we tested its sensitivity to recent climate variability as well as to projected scenarios of climate change. First, we defined indices to describe the dispersal kernel of anchovy larval distribution in the Bay of Biscay from simulations of Lagrangian trajectories in a three-dimensional hydrodynamic model. Our indices relate to three main characteristics of the distribution: (i) mean transport (distance, orientation), (ii) inertia, and (iii) patchiness. Then these indices were calculated over recent years using different scenarios of atmospheric forcing change. Scenarios are based on results of global model runs assessed in the IPCC framework. Because of strong uncertainties in these results at regional scale as well as unsolved technical challenges, we have not processed a downscaling of these IPCC scenarios. Instead, we modified atmospheric forcing (air temperature, wind, river run-offs, and a combination of them) of two contrasting years, 2001 and 2002, with respect to the IPCC likely projections over the Bay of Biscay. The dispersal kernel is mostly affected by temperature rise though reduction of the drift duration. Results are also interpreted considering adaptation of the adult population to changes: earlier spawning implies change in the seasonality of the dispersal kernel.

Keywords: dispersal kernel, indices, climate change, scenarios, biophysical modelling, Lagrangian trajectories, anchovy, Bay of Biscay.

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**ICES CM 2009/E:09**

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**Climate-driven changes in the recruitment of North Sea herring: bottom-up control on the survival of early life stages identified using a biophysical individual-based model**

Marc Hufnagl, Myron A. Peck, Mark Dickey-Collas, Richard D.M. Nash, and Thomas Pohlmann

North Sea herring (*Clupea harengus*) has experienced poor recruitment in recent years despite having high spawning-stock biomass and relatively low fishing mortality. Field survey data suggest that poor year classes stem from processes acting during the first months of life, when cohorts of larvae passively drift eastward across the North Sea from western spawning grounds during the boreal winter. We investigated how intra- and interannual changes in climate-driven bottom-up processes might affect early larval growth and survival by developing a coupled three-dimensional, individual-based, biophysical model for Atlantic herring larvae in this region. Physiologically based foraging and growth subroutines allowed us to examine the impact of key abiotic (e.g. water currents, temperature, light, turbulence) and biotic (prey size and prey concentration) factors on the feeding, growth, and survival of young larvae. Model foraging and growth estimates were validated using a variety of field and laboratory studies previously conducted on larval herring and a sensitivity analysis of model parameters was performed. Model simulations employed extensive (>35 year) time-series data on larval herring abundance and distribution and indicated large interannual differences in prey concentrations required for the survival and growth of this species in this region. In many years, climate-driven changes in average winter water temperature and zooplankton phenology were predicted to markedly influence the survival of the youngest larvae originating in selected spawning grounds. Although projecting future trends remains challenging, climate-driven changes in bottom-up processes can be used when considering changes in stock productivity and thus appropriate targets for the effective management of North Sea herring.

Keywords: herring, recruitment, IBM, climate, bottom-up.

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**ICES CM 2009/E:10**

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**Do climate patterns explain by themselves the oscillations observed in the bluefin tuna (*Thunnus thynnus*) at the western Mediterranean "almadrabas" trap catches from the 1500s to the 1960s?**

Ángela M. Caballero-Alfonso, A. Trujillo-Santana, U. Ganzedo-López, A. Santana del Pino, and J. J. Castro-Hernández

In the western Mediterranean Sea, bluefin tuna (*Thunnus thynnus*) has been caught for centuries using "almadrabas". The first evidence of their use dates from about 900BC. Historical records of these catches reveal a decreasing, almost regular trend between 1525 and 1960, with some cyclical fluctuations. The marked and heterogeneous seesaw in the "almadraba" records appears to show the influence of climatic factors on the fisheries. In this study time-series analyses were carried out for different climatic variables over the last 400 years and compared with bluefin tuna catch time-series obtained from various "almadrabas" datasets from the Mediterranean Sea. Results highlight the temperature drop that occurred during the "Maunder Minimum" (Little Ice Age, 1640–1715), which might have produced a significantly decrease in tuna recruitment and abundance in the North Atlantic and Mediterranean Sea. A similar phenomenon might also have taken place between 1560 and 1625 and from 1795 to 1870. Our results indicate that environmental factors play a key role in the population dynamics of tuna as well as the efficiency with which the "almadrabas" sample them.

Keywords: bluefin tuna, *Thunnus thynnus*, almadraba, climatic factors, Maunder Minimum, North Atlantic, Mediterranean Sea.

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**ICES CM 2009/E:11**


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**Regional effects of climate change on North Sea bottom fish assemblages**

F. Sell, S. Ehrich, V. Stelzenmüller, and G. Wegner

It has recently been demonstrated that North Sea bottom fish assemblages are influenced and can be distinguished by the water masses with which they are associated. Five significantly different groups have been identified. Here we follow the hypothesis that these regionally different fish assemblages are affected differently by climate-dependent changes in hydrography. We compare the long-term trends in their development over the last 20 years, using multivariate statistics and geostatistical tools. Our investigation is based on the German Small-Scale Bottom-Trawl Survey (GSBTS) and comparative analysis of IBTS data.

Keywords: climate change, bottom fish assemblages, North Sea.

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**ICES CM 2009/E:12**


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**Fishing and jellyfish eradicated fish 180 years ago**

Brian R. MacKenzie and Bo Poulsen

Sustainable fish populations require both healthy ecosystems, in which they can live and grow, and protection from overfishing. A rare historical example from the first half of the nineteenth century allowed us to describe the chronology of how the vulnerability of a herring (*Clupea harengus*) population to ecosystem variability was increased by the effects of fishing on the population and foodweb interactions within the ecosystem. Both the population and fishery collapsed when several years of increasing exploitation were followed by an extreme climatic–hydrographic perturbation in 1825, which affected herring survival and changed the foodweb structure (jellyfish bloom). Estimated levels of fishing mortality in the years leading up to the collapse of the Limfjord herring were three- to fivefold higher than natural mortality rates and similar to those which later led to collapses of three major herring populations in the North Atlantic (North Sea Norwegian spring-spawning herring, Georges Bank). These high exploitation rates suggest that fishing was a key factor which increased the vulnerability of the Limfjord herring to collapse. Changes in trophic interactions in the Limfjord after 1825 were therefore facilitated by fishing, which had reduced the abundance of jellyfish food competitors (herring) to low levels, and consequently expanded a niche in the ecosystem for other zooplanktivores with opportunistic life histories. Lowering the risks of future collapses of fish populations and of trophic reorganizations to less desirable configurations, including gelatinous dominance of foodwebs, requires low exploitation rates that buffer against environmental variability and measures to support well-functioning and structured ecosystems.

Keywords: herring, exploitation, fishing, jellyfish, sustainability, ecosystems, regime shift.

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**ICES CM 2009/E:13      Withdrawn**


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**ICES CM 2009/E:14**


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**Factors affecting year-to-year and within-river variability of one-sea winter Atlantic salmon in Norwegian rivers**

Jaime Otero, Arne J. Jensen, Jan Henning L'Abée-Lund, Nils Chr. Stenseth, Geir O. Storvik, and Leif Asbjørn Vøllestad

Many populations of Atlantic salmon are decreasing throughout the distributional range of the species as a result of several factors acting in concert. A number of studies have documented the influence of freshwater and ocean conditions, climate variability, and “man-made obstacles”, including dams and aquaculture, but most of this research is focused on analyses of single, or a few, rivers. By using a multi-river mixed-effects model we estimated impacts of ocean temperature and water discharge on both year-to-year and within-river variability across 60 time-series of one-sea winter (grilse) *Salmo salar* from Norwegian rivers over 29 years (1979–2007). Warm coastal temperatures at the time of smolt entrance into the sea and increased water discharge during upstream migration were associated with higher rod catches of grilse, suggesting that both ocean and riverine conditions are decisive for controlling interannual fluctuations. Moreover, catches of grilse increased significantly after the ban of the Norwegian driftnet fishery in 1989. However, a general decreasing trend was detected during the study period, although less pronounced in northern Norway. In addition, the river-specific effects (i.e. the random deviations from the common fixed effects to all rivers) were related to watershed characteristics and human impacts such as salmon farming pressure and the presence of hydropower stations.

Keywords: Atlantic salmon, *Salmo salar*, river run-off, sea surface temperature, time-series modelling, Norway.

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## ICES CM 2009/E:15

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### **The impact of variations in oceanographic conditions on distribution, aggregation structure and fishery pattern of redfish (*Sebastes mentella* Travin) in the pelagial of the Irminger Sea and adjacent waters**

S. P. Melnikov, A. L. Karsakov, V. I. Popov, V. L. Tretyakov, and I. S. Tretyakov

Analysis of data from acoustic trawl surveys of *Sebastes mentella* in the Irminger Sea pelagial suggests that the extension of redfish distribution to the southwest observed since the mid-1990s was caused by migration of some aggregations from the traditional feeding areas caused by an increased advection of Atlantic waters by the Irminger current and higher temperatures of the surface layer (TSL). However, the use solely of the data from surveys conducted every other year limits our ability to study the impact of variations in oceanographic conditions on the distribution, aggregation structure, and fishery pattern of redfish in the long term, although such information is essential to the development of sustainable harvesting strategies for fish resources. Data on monthly mean TSL fields at the regular grid nodes for 1982–2008 were used as additional oceanographic indices. To identify and forecast TSL data, the aliquant frequency method was used. In addition, the calculations used air temperature data for 1949–2008 to derive a trend component, which was then applied to fill in the gaps in the basic TSL data and make a projection. Interannual spatial bathymetric variability of some population parameters of redfish in the Irminger and Labrador Sea was analysed. Catch per unit effort (CPUE) for the northeastern and southwestern fishing area was calculated. A statistically significant correlation between catch per unit of effort (cpue) and TSL was revealed, which suggests that cpue indices directly depend on primary production conditions during spring. Cpue forecast for 2009–2010 demonstrates a decreasing trend in the Labrador Sea. A strong impact of oceanographic conditions on different fishery patterns for redfish was demonstrated. It was concluded that the proposed division into the northeastern and southwestern fishing areas, as well as the use of two components in the management of the redfish stock in the pelagial of the Irminger Sea and adjacent waters are not efficient and lack scientific substantiation.

Keywords: aggregation structure, fishery pattern, the Irminger Sea, *Sebastes mentella*, oceanographic conditions.

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**ICES CM 2009/E:16**

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**Clupeid fish in the Canaries–African coastal transition zone: transport dynamics and links to climate**

Marta Moyano, Jose María Rodríguez, and Santiago Hernández-León

The Canaries–African coastal transition zone exhibits dynamic hydrography characterized by a variety of mesoscale structures generated from interactions between the Canary Current, coastal upwelled waters, and the trade winds. The Canary Archipelago forms an obstacle to the Canary Current and generates additional mesoscale structures in the form of warm-water wakes and cyclonic and anticyclonic eddies. These mesoscale structures influence transport processes of plankton, resulting in marked variability of the species composition, abundance, and distribution of larval fish. In this work, we review the findings of studies conducted in the vicinity of Gran Canaria Island and focus on processes influencing intra- and interannual variability of the ichthyoplankton assemblage. Clupeid species (mainly sardine and anchovy) appear to be good tracers of upwelling filaments generated in the Cape Juby–Cape Bojador area. Larvae transported by filaments may return to the African coast via entrainment within the quasi-permanent cyclonic eddy trapped between the islands of Gran Canaria and Fuerteventura and the African shelf. On the other hand, these larvae may simply disperse offshore, often reaching the easternmost islands of the Canary Archipelago with unknown consequences for habit connectivity and life cycle closure. During the last two decades, larvae of round sardinella have increased in comparison with sardine and anchovy in the Canary region. This shift, documented in Gran Canaria, coincides with larger scale (European-wide) shifts in clupeid fish assemblages related to climate-driven changes in atmosphere–ocean coupling.

Keywords: fish larvae, Canary Islands, upwelling filaments, larval transport.

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**ICES CM 2009/E:17**

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**Can we estimate the effects of temperature change on herring growth? A macroecological analysis of temperature- and density-dependence on North Atlantic herring growth**

Thomas Brunel and Mark Dickey-Collas

The effects of temperature and density-dependence on the growth of Atlantic herring (*Clupea harengus*) are investigated through a comparative study applied to 15 North Atlantic stocks and based on 48 years of data. The von Bertalanffy equation is used to describe the growth of the stocks, both on average over the whole period studied and for each cohort level. Water temperature was found to be a determinant factor for herring growth at the species level. Among North Atlantic herring stocks, those living in cold water areas exhibited a lower growth rate ( $k$ ), higher longevity, and a higher asymptotic weight ( $w_{inf}$ ) than those living in warmer water. The average  $w_{inf}$  of a stock was also positively correlated to average density, but this relationship was most likely explained by the negative correlation between stock density and mean temperature. At the within-stock level, when looking at the variability of growth parameters between cohorts,  $w_{inf}$  was still significantly negatively correlated to temperature, but this effect was no longer significant for  $k$ . When considering a single stock, the range of temperature experienced is probably too narrow to see an effect on growth, an effect which may be confounded by other factors, such as density-dependence. According to this macroecological pattern, global warming should enhance the growth of the youngest ages but the counterpart would be a reduced growth for the older individuals and a shorter lifespan.

Keywords: growth, temperature effects, density-dependence, meta-analysis, weight-at-age, climate.

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**ICES CM 2009/E:18**

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**Impact of environmental change on North Sea Atlantic cod (*Gadus morhua*): scenario modelling in the North Sea**

Ute Daewel, Corinna Schrum, and Myron Peck

We examined the potential survival and growth of early life stages of Atlantic cod (*Gadus morhua*) in response to changes in physical forcing and lower trophic level dynamics of the North Sea ecosystem. In order to disentangle the impact of different processes potentially influencing the vital rates of cod early life stages, we developed and utilized a three-dimensional interlinked model system that included modules for hydrodynamics and lower trophic level production as well as a physiologically based individual-based model (IBM). Three types of simulation were performed, including a base case that assessed interannual differences in survival using the fully coupled model system. Next, influences of perturbations in key abiotic factors (e.g. temperature, west wind intensity) on lower trophic level production and potential prey fields derived from an ecosystem (NPZD; nutrient, phytoplankton, zooplankton, detritus) model were examined. Finally, we examined the impact of changes in both abiotic and biotic (prey field phenology and characteristics) factors on the potential survival and growth of cod early life stages in the North Sea. Our coupled model system suggested that match–mismatch dynamics of first-feeding cod and suitable prey were driven not only by changes in winter water temperatures but also by changes in west wind intensity. The latter were just as important as the former owing to its influence on larval retention within favourable feeding areas. Our results emphasize the importance of accounting for a suite of different processes to project future (bottom–up) impacts on cod productivity in the North Sea.

Keywords: biophysical modelling, IBM, North Sea, Atlantic cod, scenario modelling.

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**ICES CM 2009/E:19**

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**Recruitment in a changing environment: the role of oceanographic processes in blue whiting population dynamics**

Mark R. Payne, Hjálmar Hátún, Asbjørn Christensen, and Jan Arge Jacobsen

Blue whiting is a pelagic gadoid that spawns in waters to the west of the British Isles, including on the continental shelf and around Rockall. In recent years, this stock has displayed dramatic changes in population size, increasing nearly fourfold in the space of five years, before returning towards previous levels at a comparable rate. The almost explosive growth in the population was driven by an order of magnitude increase in the survival of blue whiting eggs to juveniles, and demonstrates good correlation with the dynamics of the North Atlantic Subpolar Gyre. Recent work has demonstrated that this gyre also controls the spawning distribution of the stock, suggesting a correlation between survival and the location where eggs are spawned. In this work, we investigate the possibility of such a linkage with a view to elucidating the underlying mechanisms. We employ individual-based hydrographic drift models to gain an insight into the physical environment (temperature, salinity), the biological environment (proxies of plankton abundance, competition with conspecifics), and drift outcomes (trajectories) likely to be experienced by an individual spawned at a given point in time and space. By generating such metrics over a wide temporal and spatial domain, we gain insight into the role that oceanographic dynamics play in the early life history of this species, and thereby potential recruitment. Given recent advances in forecasting the dynamics of the Subpolar Gyre, and the understanding of the subsequent implications for recruitment developed here, this work suggests that it may be possible to forecast recruitment to this stock some years in advance.

Keywords: blue whiting, North Atlantic Subpolar Gyre, recruitment, individual-based modelling.

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**ICES CM 2009/E:20**

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**Are there climatic signals in fishery data for sardine (*Sardina pilchardus*) along the Iberian Atlantic coast?**

G. J. Pierce, M. B. Santos, J. M. Cabanas, I. Riveiro, and C. Porteiro

The Iberian sardine (*Sardina pilchardus*) is distributed along the whole shelf of the Iberian Peninsula and the highest catches are taken from southern Galician waters and northern Portugal. Landings consist mainly of young fish, reflecting the proximity of the main recruitment area of the stock to the fishing grounds. The fishery depends on the strength of the recruitment in this area and recruitment processes seem to be driven by a combination of oceanographic (local) and climatic (global) events. In an exploratory analysis we examined whether the variability observed in landings from ICES areas VIIIc and IXa from 1940 to 2005 and in estimated annual recruitment and spawning stock size for the whole stock could be related to environmental conditions at large and local scales, taking into account temporal autocorrelation in the response variables. Landings for areas VIIIc and IXa show differing trends and were most strongly related, respectively, to the multidecadal Atlantic oscillation (AMO) and to sea surface temperature (SST; being higher above 15°C). Recruitment was negatively related to AMO. There appears to have been a shift in the general trends in the environmental variables in 1995 which coincided with a consecutive series of poor recruitment years at the end of the 1990s. We discuss possible mechanisms underlying these observed patterns and whether the apparent climatic relationships have any predictive value.

Keywords: sardine, climate, fisheries.

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**ICES CM 2009/E:21**

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**Spatial variation and structural change of the Barents Sea fish community**

M. Fossheim, E. Johannesen, R. Primicerio, and M. Aschan

We document the spatial and temporal changes in the Barents Sea fish community in relation to environmental parameters, analysing data from the ecosystem surveys covering the entire Barents Sea during 2003–2008 and comparing them with earlier investigations of the deeper areas from the period 1992–2004. Changes in the ecosystem, expected on the basis of changing climate and harvest regimes, often go undetected because of a strong focus on oceanography and commercial species in monitoring programmes. In this study fish species that are not targeted by fishery are included in the analyses, providing valuable, additional ecological information on structural alterations. We identified species assemblages associated with different water masses and range of productivity of sea areas and compared the distribution of the fish assemblages with the distribution of previously identified benthic type communities. Major changes in the structure of the fish community occur in this previously thought healthy, resilient, and well-managed large marine ecosystem. The spatiotemporal analyses of the Barents Sea survey data from this decade demonstrates that a new fish community structure is in place compared with the general community structure of the previous decades. An ecological regime shift in the 1990s might be speculated. The change is concurrent with a climatic regime shift and may be persistent.

Keywords: species assemblages, spatiotemporal change, regime shift.

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**ICES CM 2009/E:22**

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**Long-term hindcast and climate change forecast of habitat suitability using a bioenergetics model: anchovy in the Bay of Biscay and the North Sea**

Caroline Struski, Pierre Petitgas, and Martin Huret

Mechanistic tools such as bioenergetics models allow prediction of changes in fish distribution and productivity under global change scenarios. Here we used a dynamic energy budget (DEB) model that was developed for adult anchovy to estimate the suitability of environmental conditions for that species. The DEB model calculates the energy for somatic maintenance, growth and reproduction, given temperature, and food forcings. In the DEB theory, allocation for somatic maintenance has priority over other functions. This means that the DEB model can identify physiologically limiting conditions: when assimilated food is insufficient at a given temperature the energy stored for reproduction will be reallocated to pay for somatic maintenance costs. We used this approach to define an index of habitat suitability, which was the rate of reallocation of reserves to pay for maintenance costs. The DEB was run with constant temperature and food conditions, and the rate of reallocation of reserves assessed. This run was repeated for a wide range of temperature and food conditions, which led to the construction of charts that related environmental conditions to the suitability index. Biophysical NPZD (nutrient, phytoplankton, zooplankton, detritus) models were used to hindcast climate-forced variability of prey fields and temperature over the Bay of Biscay and the North Sea. Suitability was mapped based on the suitability charts and the long-term hindcasted conditions. The spatiotemporal extent of suitable habitats revealed the long-term pattern of anchovy presence, critical seasons, and core habitats in the Bay of Biscay and the North Sea.

Keywords: bioenergetics, DEB, habitat suitability, climate change, anchovy.

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## ICES CM 2009/E:23

### Is the growth of Faroe saithe density-dependent or climate-dependent?

Eydna í Homrum, Petur Steingrund, Lise H. Ofstad, and Hjálmar Hátún

Since 1961, the mean weight-at-age of Faroe saithe has fluctuated by a factor of two, the lowest mean weights-at-age coinciding with large stock sizes. One causal mechanism could be density-dependence, with limited local food resources being shared by the total stock. Another possible factor is immigration of individuals from other areas that have experienced a different growth during their life. This may be related to the fact that the stock size of Faroe saithe fluctuates in much the same way as the combined stock size of saithe in Icelandic and Norwegian waters. At the same time, it is found that the stock size variations of Faroe saithe are very well correlated with the Subpolar Gyre index, which is associated with food availability in the area. The Subpolar Gyre index is controlled by climatic variations, which probably also affect migration of saithe. Stomach content analyses have been conducted twice annually on the Faroe Plateau since 1997, and here we use these and other data on saithe to clarify whether density-dependence explains the observed variations in mean weight-at-age.

Keywords: density-dependence, growth, saithe, stomach content analysis, Subpolar Gyre index.

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## ICES CM 2009/E:24

### Back to the future: 115 years of climate and fisheries in the North Sea

John K. Pinnegar, Steven Mackinson, and Georg H. Engelhard

Much has changed in the North Sea over the past 100 or so years; particular fisheries have come and gone, certain species (e.g. bluefin tuna, halibut, and sturgeon) have virtually disappeared and at the same time environmental conditions have changed appreciably with a general warming of surface waters (although there were also periods of cooling), a degradation and subsequent recovery in coastal water quality, and modification of both offshore and inshore habitats. In this study we make use of a complex foodweb model constructed to represent the period immediately prior to the onset of intensive steam trawling (i.e. the 1880s and 1890s), and we "force" this model

forward in time up to the present day, using reconstructed time-series of international fishery catch data as well as climate indices. We examine the relative importance of fishing and climate when trying to “fit” the model to observed data on fish or planktonic biomasses. We consider whether the widely reported “gadoid outburst” of the 1960s and 1970s was largely driven by bottom-up (environmental) or top-down (exploitation) processes, and whether the most recent warming period might be constraining population recovery in certain depleted fish stocks. We present hitherto unpublished dataserries on sea temperatures in the North Sea throughout the twentieth century, as well as a 115-year time-series of fisheries data based on ICES reports and statistical bulletins. We pay particular attention to species that are poorly sampled by trawl surveys (e.g. sandeels and certain large bivalve molluscs) and which may have been significantly less or more abundant in the past compared with the present day. This study considers long-term changes in the structure and functioning of marine foodwebs, and attempts to draw conclusions with regard to underlying processes and their impact upon marine fish resources.

Keywords: Ecopath with Ecosim, catches, forcing, fitting, climate change, foodweb.

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## ICES CM 2009/E:25

### **Summarizing with multiple factor analysis (MFA) the seasonal and interannual variability of the long-term hindcasts of lower trophic ecosystem models: applications in the North Sea and Bay of Biscay**

Pierre Petitgas, Martin Huret, Fabien Léger, Myron Peck, Adriaan Rijnsdorp

Operational biophysical NPZD (nutrient, phytoplankton, zooplankton, detritus) models are now available to generate long-term hindcasts of climate-forced variability of the physical and lower trophic environment of fish populations. The paper presents a method to simply evaluate the seasonal and interannual variability of the hindcast outputs of NPZD models. First indices are defined to describe the hindcasted environment with a fish population perspective. Then multiple factor analysis (MFA) is applied on the indices multi-table dataset to characterize the seasonal pattern and its repeatability in time. Correlation of the indices on the principal components helps identify the drivers of the variability. The timing of the life cycle of various species is matched with the MFA results to identify the kind of environmental variability each life stage will be faced with and hence identify potential critical periods. Applications of the procedure are performed in the North Sea and in the Bay of Biscay for sprat, anchovy, and sole, which are present in both areas.

Keywords: multiple factor analysis (MFA), operational oceanography, NPZD, climate change.

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## ICES CM 2009/E:26

### **Development of a climate-to-fish-to-fishers model: progress, issues, and some solutions**

Enrique N. Curchitser, Kenneth A. Rose, Kate Hedstrom, Jerome Fiechter, Shin-ichi Ito, Salvador Lluch-Cota, and Bernard A. Megrey

An ecosystem approach to understanding large-scale patterns in exploited systems caused by both climate change and human activity increasingly relies on the use of numerical models. In the past, physical, lower, and higher trophic level models have been developed, tested, and implemented independently of each other. Recently, the advances in physics and biology have created the needed pieces for a comprehensive (end-to-end) ecosystem model, including humans as a dynamical component. The challenge is to integrate all the components, and examples of fully coupled end-to-end models are relatively rare. This is partly because of the perception that

blending separate yet complex submodels is impractical because of demanding computational requirements and partly because the respective communities work independently. In this presentation, we present our progress to date on the development of an end-to-end model modelling framework within the widely used ROMS (Regional Ocean Modeling System) circulation model. The NEMURO nutrient–phytoplankton–zooplankton (NPZ) submodel provides the lower trophic level dynamics and a multispecies individual-based submodel simulates fish population and community dynamics, including fishing fleets as one of the predator species. All these models exist in various forms, but the individual submodels have never been harmonized together into one integrated analysis tool useful for synthesis, integration, and prediction. This model framework was designed to investigate the effects of climate and fishing on marine ecosystems within one model that includes dynamical feedbacks among the different systems. We describe the conceptual and technical challenges involved in assembling and implementing such a model and we present some early results of a test-bed (proof of principle) application developed to study the low-frequency fluctuations of sardine and anchovy.

Keywords: end-to-end model, ecosystem, low-frequency fish fluctuations.

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### ICES CM 2009/E:27

#### Do striped bass (*Morone saxatilis*) spawn in response to high river flow events?

Ginger L. Jahn and Elizabeth W. North

The estuarine turbidity maximum (ETM) of the upper Chesapeake Bay serves as an important nursery habitat for striped bass (*Morone saxatilis*) eggs and larvae. Event-scale phenomena alter the physical and biological conditions within the ETM. Pulses in river flow change water temperatures and deliver organic material. Flow events could cue striped bass spawning and stimulate production of prey for their larvae. These hypotheses were evaluated with field surveys and analyses of historical data. Historical records indicate that the occurrence of pulsed flow events is highly variable; from zero to five pulses occurred each year during the spawning season (April–May) from 1993 to 2004. Water temperatures in April and May were negatively correlated with river flow (1956–2002), suggesting that water temperatures decrease during flow events and then increase as pulsed flow diminishes, potentially providing a cue for spawning. Surveys of striped bass egg and larval abundances and zooplankton abundances were conducted in upper Chesapeake Bay during 2007 and 2008 and were combined with historical data to identify whether pulses and associated temperature changes could act as cues for striped bass spawning and stimulate larval food production. Analyses of field and retrospective data suggest that striped bass spawning occurs after pulses in river flow, and that the number of pulses in flow during the spawning season is positively related to striped bass recruitment variability. The implications of pulsed events and potential effects of climate change on striped bass spawning, larval survival, and biological productivity in the ETM is discussed.

Keywords: *Morone saxatilis*, striped bass, river flow, estuarine turbidity maximum, spawning, Chesapeake Bay.

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### ICES CM 2009/E:28

#### Effect of the Siberian High on the catch fluctuation of Pacific cod (*Gadus macrocephalus*) in the Yellow Sea

H. Kim, H. J. Hwang, D. H. Kim, M. H. Sohn, J. B. Kim, K. H. Choi, and I. Yeon

The Yellow Sea and the East/Japan Sea, divided by the Korean Peninsula, have different Pacific cod populations. The catch of Pacific cod in the Yellow Sea comprised over 50% of total catches since

2003 when it started to show an increasing trend. The catch fluctuations of Pacific cod in the Yellow Sea are probably influenced by two environmental factors: first, the effect of the strength of the Siberian High on the winter monsoon in the main spawning season, and second, the formation and distribution properties of the Yellow Sea bottom cold water (YSBCW) because of changes in the Siberian High. The main spawning season of Pacific cod is December–January and the hatching water temperature is less than 12°C. The water temperature in winter, including the hatching period through to spawning time, is influenced directly by northwesterly winds caused by the Siberian High. Hydrographic conditions play an important role in determining the early survival of the Pacific cod. The main catching temperatures of Pacific cod in the Yellow Sea ranged from 6 to 10°C, indicating the temperature range of the YSBCW. The YSBCW was limited to the middle area of the Yellow Sea in the early 1990s when the catches of Pacific cod were lowest, but was distributed over the entire Yellow Sea in 2007 when catches were highest.

Keywords: Pacific cod, Siberian High, winter monsoon, Yellow Sea bottom cold water.

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### ICES CM 2009/E:29

#### Changes in growth rates of reef fish in the Gulf of Mexico: evidence of climate change or overharvesting?

Sean P. Powers, F. Joel Fodrie, Nicole Shaffer, Matthew W. Johnson, and Robert L. Shipp

Several reef fish species in the Gulf of Mexico (e.g. red snapper and gag grouper) are considered to be overfished and experiencing overfishing. During the last 30 years and coincident with increasing fishing mortality, atmospheric temperatures have also increased. We reconstructed yearly growth rates of three long-lived fish, red snapper (*Lutjanus campechanus*), gag grouper (*Mycteroperca microlepis*), and red drum (*Sciaenops ocellatus*), via incremental analysis of sagittal otoliths. For red snapper, a species with an extended history of overfishing, a general trend of increasing growth rate was observed from 1960 to 2000: ages 1, 2, and 3 doubled their annual growth rate. This trend could be caused by density-dependent processes (reduced population density as a result of fishing, increases in fish habitat) and density-independent processes (climate-related changes). Over the past 30 years, we documented regional increases in air and sea surface temperatures of +3°C). To determine which mechanism was responsible for changes in growth rate, we performed similar retrospective growth analyses on gag grouper, another reef fish species whose overexploitation is recent, and red drum, a species where a complete moratorium on harvest has been in place for the last 20 years. Analysis of both red drum and gag grouper otoliths will be completed in July. Increases in growth in all three species would imply a density-independent process related to climate changes, whereas decreases in red drum coupled with increases in gag grouper or red snapper would imply a density-dependent explanation. An increase in artificial habitat in the Gulf of Mexico opens up bottlenecks for red snapper populations.

Keywords: overfishing, climate changes, red snapper, temperature, density-dependent.

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### ICES CM 2009/E:30

#### Fish production regime shifts in the West Iberia upwelling system and their relation to climate patterns: a review

Maria de Fatima Borges

Regimes over a period of a decade or more are features of natural climate change caused by the intrinsic variability of the atmosphere and ocean in combination. In this work we first examine patterns of fish production by collating and reviewing historical documented information and retrospective studies on as long a scale as possible for past fluctuations in the West Iberia

upwelling ecosystem. Second, we identified the processes defining possible causal links between climate variability and interannual changes in the production of commercially exploited marine fish species in this region. Finally, we propose the operational application of a new indicator that is able to measure the ability of fish production to adjust and respond to climate fluctuations and its use in an ecosystem approach to fishery management strategies.

Keywords: natural climate change, climate pattern, regime shifts, fish production, operational indicator, upwelling ecosystem, West Iberia.

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**ICES CM 2009/E:31****Climate and fishing: disentangling factors affecting growth in Scotian Shelf haddock (*Melanogrammus aeglefinus*)**

Anna B. Neuheimer and Christopher T. Taggart

Fish growth is affected by variations in a number of factors including climate (temperature) and size-selective fishing. The effects of these factors on resulting size-at-age variation must be disentangled to allow for the development of successful management strategies. Of the factors affecting variation in growth, temperature is a controlling factor governing growth via reaction rates at the cellular (metabolic) level and the effects of temperature on size-at-age variation must be examined foremost. Disentangling the effects of temperature on size-at-age requires a metric relevant to the integrated growth metric that is size-at-age. In previous work, we show this physiologically relevant metric as the growing degree-day (GDD, °C d). Here we employ the GDD metric to quantify the influence of temperature variation on a 30-year decline in length-at-age among mature, eastern Scotian Shelf (Northwest Atlantic Fisheries Organization statistical divisions 4VW) haddock (*Melanogrammus aeglefinus*). We present evidence that remaining, temperature-independent variation in length-at-age among year classes is consistent with sustained size-selective fishing of large (i.e. fast-growing and late-maturing) fish. We argue that size-selective fishing is the most parsimonious explanation for the systematic declines in size-at-age and age-at-maturity found in Scotian Shelf haddock.

Keywords: climate, size-selective fishing, growth, size-at-age, growing degree-day, haddock (*Melanogrammus aeglefinus*).

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**ICES CM 2009/E:32      Poster****New data on composition and structure of the Kara Sea ichthyofauna**

V. Dolgov, O. V. Smirnov, K. V. Drevetnyak, and O. Yu. Chetyrkina

The Kara Sea is one of the northern Eurasian seas that is completely covered by ice almost all year. This peculiarity limits research activity in this area and explains our rather poor knowledge of the composition and structure of the Kara Sea ichthyofauna. Only a few marine expeditions have been conducted in the Kara Sea during the twentieth century, but comparatively comfortable ice conditions caused by a recent warming period in the North Atlantic have allowed observations to be taken in the Kara Sea and adjacent areas of the northeastern Barents Sea in summer 2007–2008. New data on species composition and fish community structures of the Kara Sea were obtained from demersal and pelagic trawls. In total, 46 species were found in catches, including five new species for this area (*Arctozenus risso*, *Benthoosema glaciale*, *Myctophum punctatum*, as well as commercially important deep-water redfish and Greenland halibut). The recent Kara Sea ichthyofauna list includes 70 fish species. Coldwater Arctic species predominated in the fish community. The most abundant species are polar cod (*Boreogadus saida*) and Greenland halibut (*Reinhardtius hippoglossoides*). In addition, a number of non-target species such as *Liparis fabricii*,

*Lycodes pallidus*, *Triglops nybelini*, *Leptagonus decagonus*, *Gymnacanthus tricuspis*, and *Liparis gibbus* are abundant. Our results were compared with those of previous investigations.

Keywords: bottom survey, fish community, ichthyofauna. Kara Sea.

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**ICES CM 2009/E:33      Poster**

**Environmental changes caused recent increase in abundance of rock cod (*Patagonotothen ramsayi*) in the Southwest Atlantic**

Vladimir Laptikhovsky and Alexander Arkhipkin

The rock cod (*Patagonotothen ramsayi*; Nototheniidae) is an abundant demersal small fish (adult size 30–35 cm) widely distributed on the Patagonian Shelf in the Southwest Atlantic. This species was a common bycatch during bottom-trawl fisheries around the Falkland Islands with a total annual catch of 400–4000 t in 1990–2004. Since 2005, rock cod abundance have started to increase, with total annual catches attaining 30 157 t in 2007 and 60 209 t in 2008. Such an explosion in abundance started with the generation born in an unusually cold year (2002) that was followed by a chain of warm years (2003–2007) with increasing water temperatures on the shelf. This probably induced fish growth and survival and provoked an important increase in biomass. Fish also probably did start grow faster—subadult size on the southeast shelf gradually increased from 15–21 cm in 2003 to 22–26 cm in 2008. Possible effects of the recent environmental changes on fishery management in the Falkland Islands are discussed.

Keywords: *Patagonotothen*, abundance, environment, Falkland.

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**ICES CM 2009/E:34      Poster**

**Response of yellowtail (*Seriola quinqueradiata*) in the Japanese waters to seawater temperature over the last century and potential effect of global warming**

Yongjun Tian, Hideo Sakaji, Ken Watanabe, and Masahiro Kuno

The yellowtail (*Seriola quinqueradiata*) is one of the most important large-predatory fish in Japanese waters. Using historical catch data of yellowtail and a sea surface temperature (SST) dataset for the waters around Japan over the last century, the long-term variability of the abundance of yellowtail and its relation to SST was examined. The total catch of yellowtail increased from 14 446 t in 1894 to 77 462 t in 2000 with an evident increasing trend over the last century. However, the trend is not linear but decadal, with significant shifts occurring around 1912, 1932, 1957, 1974, and 1990, strongly suggesting an effect of water temperature. Analysis between the catch by fishery regions and SSTs demonstrated that the catch trend was approximately in accordance with SSTs. In particular, the catch from the Japan Sea significantly and positively correlated with winter SST in the northern Japan Sea, indicating that the increasing water temperature in the Tsushima Current region has a positive effect on the migration and recruitment of yellowtail to the Japan Sea. SST mappings show that northward movements of distribution and overwintering areas of yellowtail in the Japan Sea in the 1990s resulted from increased SST. These results suggest that migration patterns, distributions, and overwintering areas are affected by SST. The potential impacts of global warming on migration, distribution, and fishery grounds of yellowtail in the Japan Sea are discussed under the predictions scenarios of the IPCC.

Keywords: yellowtail, abundance, distribution, sea surface temperature, Japan Sea.

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**ICES CM 2009/E:35      Poster**

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**The rise and fall of blue whiting stock**

Harald Loeng and Øystein Skagseth

After several years with mainly low recruitment, the blue whiting had eight years in a row with good year classes (1996–2004). From 2005 onwards the recruitment has been low again. This success and failure in blue whiting recruitment might be explained by different physical oceanographic conditions and/or changes in the food availability for fish larvae. The present study focuses on different process-oriented explanations for the rise and fall of the blue whiting stock resulting from good and bad recruitment. The research covers a broad range of spatial and temporal scales and levels of biological organization.

Keywords: climate, recruitment, blue whiting.

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**ICES CM 2009/E:36      Poster**

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**Climate effect on populations of Atlantic salmon (*Salmo salar*) in the Barents and White Sea basins (seventeenth to twentieth centuries)**

D. L. Lajus, Ya. I. Alekseeva, Z. V. Dmitrieva, A. V. Kraikovskiy, and J. A. Lajus

We analysed catch records of Atlantic salmon (*Salmo salar*) for the period from the seventeenth to the twentieth century from several locations in the Barents and White Seas areas, situated at the northeastern border of the species' distribution range. Atlantic salmon is an anadromous fish representing both freshwater and marine ecosystems of the North Atlantic. Historical records found in Russian archives allow analysis of long-term series of catches covering four centuries. These data are comparable with respect to fishing effort because there have been only minor changes in fishing methods and locations during the entire period. Notable fluctuations in catches and in the average weight of salmon were found. Comparison of the indices of population abundance with temperature time-series showed that the abundance decreased during colder periods. Although this is a predictable pattern for a boreal species occurring near the edge of its distribution range, the value of the results is in the long-term view, which clearly demonstrates that climate was the main force driving population abundance of salmon before considerable human pressure such as overfishing, dam construction, timber industry occurred in the area. These effects became a dominant force only from the mid-twentieth century. The research was carried out within the framework of the international programme "History of Marine Animal Populations" (part of Census of Marine Life global project).

Keywords: Atlantic salmon, historical data, Barents Sea, White Sea, climate effect.

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**ICES CM 2009/E:37      Poster**

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**Larval fish growth physiology and climate impacts: species-specific differences**

Authors: Maja Walter, Muriel-Marie Kroll, and Myron A. Peck

Identifying critical thresholds of abiotic and biotic factors that constrain the survival and growth of marine fish early life stages may allow us to more accurately project future climate-driven changes in the distribution and productivity of marine fish stocks. If common physiological patterns exist

among species, this may allow generalizations to be made concerning how assemblages of species (e.g. winter/spring vs. summer spawners) react to changes in regional and/or local environmental conditions. Here, we summarize the impacts of temperature on key parameters of the balanced energy budget of marine fish larvae, focusing on rates of energy loss obtained via respiration ( $O_2$  consumption) measurements. These energy losses represent critical thresholds that individuals must surpass for survival and growth. The review summarizes thermal tolerance (range) and sensitivity (thermal quotients) among species and also attempts to link thermal growth physiology to other attributes of the balanced energy budget in particularly well-studied species. In this regard, emphasis is placed on comparing and contrasting information available on flatfish, gadoids, and small pelagics inhabiting temperate shelf seas.

Keywords: climate, survival, early life stages, temperature.

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**Climate-driven changes in suitable habitats for North Sea fish: physiological constraints on the survival of early life stages**

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We illustrate a physiologically based approach to gaining estimates of climate-driven, spatio-temporal changes in suitable habitats for early life stages of commercially important marine fish species. This method combines empirical estimates of species-specific egg and larval thermal and feeding physiology with hydrodynamic and NPZD (nutrient, phytoplankton, zooplankton, detritus) model-based estimates of key abiotic and biotic factors. We applied the method to generate maps of the temporal and spatial extent of North Sea habitats that were estimated to be suitable for Atlantic herring (*Clupea harengus*), Atlantic cod (*Gadus morhua*), and sprat (*Sprattus sprattus*). Model hindcasts for the period 1980–2005 predicted marked seasonal limitation of the survival of eggs (based on temperature) and larvae (based on temperature  $\times$  prey requirements for growth and survival) that agree well with known spawning times in the North Sea. Model estimates indicated that Atlantic cod was restricted to a relatively short “window of opportunity” during the early spring with marked interannual variability of suitable habitats. In contrast, sprat was restricted to spawning later in spring and summer (owing to higher prey requirements). Climate-driven variability of bottom-up controls were predicted to be relatively weak for Atlantic herring, which agrees with the plasticity in life-history strategy of that species in the North Sea. The capacity for species-specific adaptation notwithstanding, future scenarios including a mean atmospheric warming of 3°C eliminated the North Sea as a suitable habitat for Atlantic cod early life stages. Weaknesses and strengths of this physiological-based forecasting/mapping method are discussed.

Keywords: climate, eggs, larvae, survival, habitat mapping, forecasting.

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