

Theme Session F

Size is almost everything! Size- and trait-based processes and models in ecosystems and management

ICES CM 2008/F:01

Foodweb models—theory, processes, and parameterization

Wolfgang Fennel

This contribution describes and analyses a NPZDF model, which links a biogeochemical model interactively to a fish production model. The Baltic Sea is chosen as an example system, where the bulk fish dynamics can be represented by two prey species (sprat and herring) and one predator (cod). The linkage of the model components is established through feeding of prey fish on zooplankton and recycling of fish biomass to nutrients and detritus. The fish dynamics is driven by size (mass)-dependent predator–prey interactions, reproduction, and mortality. A challenge is the quantitative description of the multitude of processes involved. The model formulation is constraint by strict mass conservation. A series of experimental runs with fishing and nutrient loads provide scenarios about how fish catches respond to nutrient inputs and allow us to analyse the sensitivity of the model with regard to variations in parameters. Changes in reproduction and mortality are most critical.

Keywords: full foodweb model, sprat, herring cod, size (mass)-dependent predator–prey interactions.

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ICES CM 2008/F:02

Variability of a linear non-local spectral ecosystem model due to nutrient donor–nutrient acceptor interaction characteristics

Amit Tandon, Brian Rothschild, and Jason Olejarz

Size-based or ecosystem biomass energy-based spectral ecosystem models can help us to understand the efficiency of an ecosystem. In this work, we examine how the nutrient donor and acceptor interaction in a spectral ecosystem model govern the efficiency of the ecosystem. Following earlier size-based models we pose a minimal model which allows comparison of the efficiency of two models that only differ in size-dependent predator–prey interaction characteristics. We first present a hierarchy of simple spectral biomass energy models, leading to a new non-local but linear spectral ecosystem model. It is shown that predator–prey interaction characteristics introduce inherent intrinsic time variability, particularly when the size spectrum of an ecosystem is perturbed. A local perturbation at very small sizes is shown to introduce time variability at large sizes.

Keywords: ecosystem efficiency, size based ecosystem model, predator prey interaction kernel.

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ICES CM 2008/F:03

Predator–prey mass ratios and the variability of marine fish populations

Julia L. Blanchard, Richard Law, Matthew D. Castle, Carolyn Barnes, and Simon Jennings

For the past century scientists have tried to understand why some fish species fluctuate more than others. A lack of understanding about the causes of fluctuations remains a major barrier to successful long-term management of fish stocks. Explanations for greater fluctuations in abundance in some species than in others include: smaller age/size of maturity, shorter lifespans, higher reproductive rates, and heavier exploitation. Although dynamical processes, such as predator–prey interactions, are also well known to affect population and foodweb stability, there has been no direct evidence that these processes influence the natural variability of fish populations. Here we present data from 20 marine fish species showing that species feeding on prey much smaller than themselves tend to fluctuate more than those that feed on prey closer to their own body size. We show that this behaviour is consistent with the dynamic properties of a mathematical model of a size-structured foodweb. Furthermore, a measure of stability computed from the model using empirical feeding parameters of the species correlates strongly with the temporal variability observed in these species.

Keywords: foodweb, size spectrum, body size, population dynamics, community.

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ICES CM 2008/F:04

A new multispecies, physiologically structured fish ecosystem model

Emma Guirey

We present a dynamic, physiologically structured, multispecies fish ecosystem model developed to investigate the impacts of changes in fishing pressure on community structure. The modelling approach recognizes that many marine ecosystem processes are a function primarily of the size of the organisms involved. Individual fish are classified by length and species. The interconnected processes of growth, predator-prey interactions, mortality, and reproduction are parameterized in the model by length, and aim to capture the major processes shaping the fish community. In order to simplify the complex ecosystem of which fish are a part, detail of representation is greatest for the focal fish species, where “focal” depends on the questions being asked of the model, and increasing reduction in biological detail is made up and down the trophic scale away from the focal species. Hence, fish species are modelled as size-structured, whereas significant sources of prey and predation (e.g. zooplankton and benthos) are modelled dynamically but unstructured. Although developed for the North Sea fish community, the general approach is applicable to any region; the model has the potential to be a tool both for exploring the response of an “abstract” fish community to changes in fishing pressure and for making quantitative predictions for a particular region and, as such, is in support of the drive towards an ecosystem approach to fishery management.

Keywords: size-based modelling, fishing pressure, ecosystem approach to management, multispecies.

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ICES CM 2008/F:05

Using moment-based approaches to investigate the structure and behaviour of size spectra

J. G. Pope

This paper describes size spectra in terms of their statistical moments and those of their stock components. It uses proto-moments, a length-based delay difference model, to estimate steady state solutions for size spectra. It is suggested that this provides a simple description of how individual species fit into a steady state size spectrum and react to fishing pressure when they are subject to size-based predation, Bertalanffy growth and Beverton and Holt stock recruitment processes. How well this approach can deal with questions such as the effect of food-dependent growth or recruitment on such size spectra and the stability of the size spectrum in response to perturbations is also discussed.

Keywords: size spectra, proto-moments, fishing effects on ecosystems, growth, spawning stock recruitment relationships.

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ICES CM 2008/F:06

Long-term shifts in the feeding preferences of North Sea fish over the past 100 years: old data and new modelling approaches

John K. Pinnegar and Julia L. Blanchard

Over the past 100 years there have been marked changes in North Sea fish communities, in part the result of heavy fishing pressure but also as a result of long-term environmental variability. At the same time dramatic changes in benthic community structure have been observed, and thus it is likely that the functioning of marine foodwebs has changed substantially, with many predators now feeding on a different portfolio of prey compared with 100 years ago. In this study we have digitized an extensive dataset of fish stomach content records from the period 1902–1905, and compared these with recent data spanning 1991–2007. Initial analyses have revealed that species such as cod, grey gurnard, and whiting previously consumed far fewer prey fish than has been the case in recent years, concentrating on decapod crustaceans rather than species such as sandeels. In the present paper we use a suite of size- and species-based ecosystem models to determine whether we could have predicted such changes in North Sea foodwebs, given what we know about the historical patterns of exploitation and changes in climate. Dynamic size-based models have been used to determine what the community might have looked like in the absence of fishing pressure and whether or not the situation in 1902–1905 is similar to that which might have been expected for a “virgin” ecosystem.

Keywords: size spectra, ecosystem model, stomach contents, fishing, climate change.

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ICES CM 2008/F:07

Fisheries-induced evolution of body size and other life history traits: the impact of gear selectivity

David S. Boukal, Erin S. Dunlop, Mikko Heino, and Ulf Dieckmann

Commercial fishing uses a variety of gears, all of which are selective with respect to at least some phenotypic characteristics of individuals such as body size or girth. Empirical evidence is mounting that such fishing induces rapid evolutionary changes, with consequences for the size structure and dynamics of the exploited stocks. Here we present the results of life history models designed to study fishery-induced evolutionary changes in body size at maturation, growth, and reproduction in a stock fished by trawls, gillnets, or baited lines. We examine evolutionary endpoints of, and selection pressures on, three corresponding life history traits. We also analyse changes in these traits over decadal time-scales, the latter being especially relevant to fishery management. We show that fishing usually selects for earlier maturation at smaller size, higher reproductive investment, and in many cases for faster growth. Trawls and gillnets, which are primarily size-selective, have qualitatively similar impacts on life history evolution. Interestingly, baited lines, which are also directly selective on behavioural traits influencing growth, can lead to disparate evolutionary responses, some of which are opposite to those we predict for the other gears. Our results also highlight how the evolutionary effects of fishing are sensitive to changes in mesh size and fishing mortality, commonly regulated in fishery management.

Keywords: life histories, maturation, reproductive investment, growth rate, trawls, gillnets, baited lines.

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ICES CM 2008/F:08

Length-based approaches compared to age-based approaches to determining the significance of seal feeding on cod in ICES Division VIa

J. G. Pope and S. J. Holmes

Studies of grey seal feeding in ICES Division VIa based on scat sampling have indicated that consumption of commercially exploited fish species is increasing and that, in the case of cod, estimated annual consumption by seals is comparable to single-species estimates of the cod biomass. The current cod stock assessment does not as yet incorporate seal feeding. Insufficient data exist to produce natural mortality estimates based on multispecies virtual population analysis (VPA) and the seal-feeding data are only available for two years (1985 and 2002). This paper outlines and presents results from a length-based delay difference method called proto-moments modelling. The proto-moments method is thought to be potentially well suited for assessments where few age data exist. Results from this method are compared with those obtained by interpolating seal feeding on cod and including these results in the current assessment method. Both approaches provide historical assessments with increased cod biomass compared with an assessment omitting seal predation but similar trends through time. Medium-term predictions are possible with the proto-moment method and scenarios of cod stock response to different levels of fishing effort and seal predation are presented.

Keywords: assessment, cod, consumption-at-length, consumption-at-age, proto-moments, seals.

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ICES CM 2008/F:09

Trophic cascades in size spectra

Ken H. Andersen

Size spectra models are useful simulation tools for exploring the response of whole communities to perturbations (e.g. commercial fishery). They include both the direct effect of the perturbation—removal of biomass in a given size range—and indirect effects through lower predation mortality on prey of the removed fish and lower food availability for predators. Here a previously published “charmingly simple” model is extended and used for simulation of the community response to fishing and the recovery when fishing mortality is lowered. The model consists of pseudo-species characterized by their asymptotic size. The model is extended to include food-dependent growth and a theoretical justification for the stock–recruitment

function. Consumer fishery on large fish results in a damped trophic cascade all the way down the size spectrum of fish and into the zooplankton. Introducing a recovery plan where the fishing mortality is lowered is demonstrated to influence the stocks of both smaller and larger fish. The temporal development of the recovery of the fished stocks will in the first years be pronounced, but is then expected to experience a set-back until it settles down on the new level.

Keywords: size spectrum, trophic cascade, ecosystem recovery.

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ICES CM 2008/F:11**Interannual and seasonal variability in biomass size spectra of estuarine larval and juvenile fish communities**

W. J. Connelly and E. D. Houde

Biomass size spectra can describe the structure and responses of biological communities to perturbations in marine ecosystems. However, size spectra parameters and their variability have rarely been evaluated at small temporal and spatial scales, and most applications consider only the slopes and intercepts of size spectra. Our objectives were to evaluate size spectrum parameters with respect to temporal variability in larval and juvenile fish communities and compare the parameters regionally within Chesapeake Bay. Fish and ichthyoplankton were sampled in the upper Chesapeake Bay and two tidal tributaries from 2001 to 2004. Salinity gradient, species richness, and species diversity were similar among the systems. Results from multivariate analyses and normalized biomass size spectrum models demonstrated how species composition, abundance, and size distribution varied seasonally, annually, and spatially along the salinity gradient of each system. In normalized size spectra, multiple biomass subdomes characterized the larval and juvenile fish communities. Statistical parameters describing the subdomes were responsive to variable production of larvae of anadromous fish in spring, followed by more consistent production of larvae by summer-spawning fish. This pattern led to strong interannual differences in biomass size spectra in spring but more uniformity by autumn. Levels and variability in growth and mortality rates of ichthyoplankton and fish were estimated for larvae and juveniles from statistical properties of the biomass subdomes. At temporal and spatial scales relevant to estuaries, size spectra appear to be sufficiently sensitive to detect immediate shifts in estuarine fish community structure resulting from recruitment variability and able to portray longer lasting, interannual changes caused by that variability.

Keywords: biomass size spectra, recruitment, fish communities.

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ICES CM 2008/F:12**Size-based or trait-based effects of fishing? Biomass and species diversity size spectra in demersal fish of the Aegean Sea**

C. Longo, G.J. Pierce, P. Peristeraki, and G. Tserpes

Fishing disturbance is changing community properties in marine ecosystems worldwide. The Mediterranean basin is not only heavily exploited by fisheries but is also witnessing the rapid spreading of alien species, enhanced by the connection with tropical waters provided by the Suez Canal. Thus both the size-structure and the species compositions of Mediterranean fish communities are currently changing and should be monitored. Size spectra (the distribution of a community metric across individual body size classes) provide a simple modelling method to capture aspects of marine communities such as trophic structure and energy flow. Furthermore, biomass size spectra parameters have often been proposed as indicators of fishing exploitation. Biomass size structure, however, being a highly conservative property of communities, is not always sensitive to disturbance. It is also not informative of changes in species composition. Species diversity and size structure may not be independent within fish communities. In fact, since fish change diet and spatial patterns as they grow in size, different ecological constraints may be determining the number of species coexisting (species richness) and the relative proportion of species abundances (species evenness) at different fish size ranges. To test the effects of fishing on both size- and trait-based aspects of demersal fish communities of the southern Aegean (Crete and Cyclades Islands), we present here an analysis of the fishing-induced changes in patterns of biomass and species diversity (evenness, richness) across body size. Fishing effects were assessed through a spatial comparison between heavily fished and lightly fished areas, having habitat characteristics as similar as possible.

Keywords: biodiversity, size spectra, South Aegean, demersal fish, fisheries.

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ICES CM 2008/F:13

Size structure, age–size dynamics and life history variation

Mikko Heino, David S. Boukal, Tone Falkenhaus, Uwe Piatkowski, Filipe M. Porteiro, and Tracey T. Sutton

Here we present a new technique for the study of life history variation when only length distributions of populations are known. Shape of length distribution in a population is to a significant extent determined by the degree to which an average individual approaches its asymptotic maximum size. Statistically, the shape of a length distribution can be characterized by its skewness, measuring the degree of symmetry in the distribution. Positive skew (long right tail) in a length distribution suggests that relatively few individuals survive long enough to approach asymptotic size in a population, whereas the opposite is true for negative skew (long left tail). With a simple model of age–size dynamics in a population showing indeterminate growth, we show that skewness is strongly correlated with the ratio between mortality rate and the growth parameter k in the von Bertalanffy growth model; this ratio is a dimensionless number that is one of Beverton's "life history statics". We demonstrate the new technique with data from deep-pelagic fish collected during the 2004 MAR-ECO expedition along the northern Mid-Atlantic Ridge.

Keywords: life history, growth trajectory, mortality.

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ICES CM 2008/F:14

Non-linearities in the size structure of a benthic/demersal community heavily fished in the Caribbean Sea of Colombia

P. G. Gómez-Canchong, R. A. Quiñones, and L. M. Manjarrés

Bycatch of the shrimp trawl fishery operating in the Colombian Caribbean Sea (CCS) reaches 93%, of which around 80% is discarded. Owing to the shallowness (12–65 m depth) of the fishing grounds this discard represents an important energy input to the benthic system which is reflected in a significant increase in scavenger abundance. We conducted an analysis of the size structure of these benthic and demersal communities heavily affected by fishing activity in the northern and southern zones of the CCS. Data were obtained by observers on board the commercial fishing fleet between August 2004 and July 2005. Zones are very different from a taxonomic and environmental standpoint. Normalized biomass size spectra (NBSS) have slope values ranging from -0.71 to -1.52 . No significant differences ($p < 0.05$) were found when comparing the NBSS parameters from both zones. All NBSS present dome-like patterns, with a peak in the middle size classes (16–64 g) and troughs at both sides. The Pareto type II distributions fits well with the biomass size distribution of these overexploited communities. The slope and intercept of the NBSS of specific zones are inversely correlated with each other through the year (monthly scale). Based on the biomass size distribution, no indication of coupling between benthic and demersal systems was found, suggesting that the systems could already have incorporated the impact of this fishery in their mass balance. Presence of non-linearities in NBSS as well as the application of Pareto II distribution in the analysis of heavily fished tropical communities is discussed.

This research was funded by the Instituto Colombiano para el Desarrollo de la Ciencia y la Tecnología COLCIENCIAS (Grant No. 1117–09–13273), COPAS Center (FONDAP-CONICYT, Chile), and the Deutscher Akademischer Austausch Dienst (DAAD, Germany).

Keywords: benthic–demersal coupling, Caribbean Sea, Pareto II distribution, shrimp trawling, size spectra, size structure, tropical fisheries.

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ICES CM 2008/F:15

Variability in the parameters of biomass size-spectra as a response to topological changes in virtual ecological networks

P. G. Gómez-Canchong, R. A. Quiñones, and U. Brose

The study of biomass size distribution has become an important tool in the investigation of aquatic ecosystem complexity. However, there is a need to analyse the relationship between parameters/variables reflecting the structure and function of taxonomically described communities with the parameters of normalized biomass size spectra (NBSS). Here, based on the generation of virtual communities and a dynamic predator–prey model we simulated biomass trajectories through time in size-dependent communities having different network topology. The analysis is focused on the relationship between the NBSS parameters and the following topological variables of virtual ecological networks: connectance, functional response, predator interference, metabolic types (invertebrates, ectothermic vertebrates), carrying capacity, initial species richness, number of basal species, and the slope of the relationship between trophic level and body size (slopeTL-BS). The simulations show that the slopes of the NBSS fit with theoretical expected values for steady state systems and with empirical NBSS reported for several aquatic ecosystems. The slope of the NBSS is related to the number of size classes and to the slopeTL-BS. The simulation also shows that a small number of size classes or slopeTL-BS closer to zero generate an increment in the range of possible values for the slope of NBSS. The predator–prey ratio plays a critical role in the linear patterns observed in the NBSS. The presence of a type II functional response generates instability, with non-chaotic limited cycles, in species abundance of the virtual community. The simulation of topological changes in virtual ecological networks shows a clear conservative trend in the NBSS.

This research was funded by the COPAS Center (FONDAP-CONICYT, Chile), the Deutscher Akademischer Austausch Dienst (DAAD, Germany) and the Ecological Network Lab (Darmstadt University of Technology, Germany)

Keywords: ecological networks, modelling, size spectra, network topology.

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ICES CM 2008/F:16

Does natural mortality depend on individual size?

Henrik Gislason, Jake C. Rice, and John G. Pope

The natural mortality of exploited fish populations is notoriously difficult to estimate. It is therefore often inferred from Pauly's equation using estimates of growth parameters and ambient temperature. Contrary to the results derived from multispecies and size spectra models, however, Pauly's equation assumes that natural mortality is independent of individual size. This assumption has large implications for size-based fish population models and for the success of size-dependent management measures such as mesh size regulations. Here we reanalyse the existing empirical estimates of natural mortality using a model in which individual size, growth characteristics, and ambient temperatures are all accounted for.

Keywords: natural mortality, growth, temperature, size-based, asymptotic size.

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ICES CM 2008/F:17

An adaptive-based approach for downscaling complexity in plankton ecosystem models

Agostino Merico, Jorn Bruggeman, and Kai Wirtz

Although predator–prey cycles can be easily predicted with mathematical models, it is only recently that oscillations observed in a chemostat predator–prey (rotifer–algal) experiment have offered an interesting workbench for testing model soundness. These new observations have highlighted the limitations of the conventional modelling approach in correctly reproducing some unexpected characteristics of the cycles. Simulations are improved when changes in algal community structure resulting from natural selection operating on an assemblage of algal clones differing in competitive ability and defence against rotifer predation, is considered in multi-prey models. This approach leads to extra complexity, however, in terms of state variables and parameters. We show here that multi-prey models with one predator can be effectively approximated with a simpler (only a few differential equations) model derived in the context of adaptive dynamics and obtained with a moment-based approximation. The moment-based approximation has been discussed in the literature before, but mostly in a theoretical context, therefore we focus here on the strength of this approach in downscaling model complexity by presenting an application to the chemostat predator–prey experiment. We suggest that this approach would also be of great benefit for reducing complexity in biogeochemical modelling studies at the basin or global ocean scale.

Keywords: ecosystem modelling; Predator-prey cycles; Population dynamics;

Complexity; Moment-based approximation; Trait; Evolution;.

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ICES CM 2008/F:18

The trophic level-based ecosystem modelling approach: an overview on theoretical interest and practical use

D. Gascuel, S. Guénette, and D. Pauly

The trophic level-based ecosystem modelling approach is articulated around the idea that an ecosystem can be represented by its biomass distribution across trophic levels (TL). Thus, trophic ecosystem functioning can be modelled as a continuous flow of biomass surging up the foodweb, from lower to higher trophic levels, because of predation and ontogenetic processes. Such an approach, wherein species as such disappear, may be regarded as constituting an ultimate stage in the use of the trophic level metric for ecosystem modelling, providing an oversimplified but useful caricature of ecosystem functioning and impact of fishing. Here we propose the EcoTroph model, based on simple assumptions and equations, as a theoretical extension of the Ecopath with Ecosim (EwE) approach. We simulated fishing impact on a virtual ecosystem and we showed that the model is able to mimic the effects of various exploitation patterns on ecosystem biomass expected from theory. Specifically, the model provides consistent relationships between catches or biomass and fishing mortalities; it exhibits complex patterns (e.g. cascading effects and “fishing down the foodweb”); and it provides a theoretical basis to explain the effect of strong top-down controls and fast flow kinetics on ecosystem resilience. Using an inverse form of the EcoTroph model, we also present catch trophic spectrum analysis (CTSA) as a method for estimating biomass and fishing mortalities at the ecosystem scale. Such a method may be seen as the “VPA” (virtual population analysis) of ecosystem approaches and provides reliable estimates when catches per trophic level and primary or secondary production are known. We illustrate the usefulness of the trophic level-based approach for specific case study analysis by applying it to the Guinean ecosystem, where a rapid increase in fishing pressure has occurred over the past 25 years. Biomass estimates from CTSA appear consistent with results of an independent Ecopath with Ecosim model. EcoTroph provides diagnostic tools for assessing the impact of fishing on the Guinean ecosystem. We show that increasing fishing efforts led to a threefold decrease in the biomass of the higher trophic levels, inducing an overexploitation for these levels and a significant decrease in the mean trophic level of biomass and catches. These results confirm and generalize previous single-species assessments. Forecasting suggests that higher yields might be obtained by exploiting lower trophic levels, but this would result in a higher impact on the ecosystem and a qualitative degradation of the health of the ecosystem.

Keywords: trait-based ecosystem approach, trophic level, ecosystem modelling, EcoTroph.

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ICES 2008/F:19 Poster

A simulation study of the effects of spatially complex population structure for Gulf of Maine Atlantic cod

Danielle Ameen Reich and Joseph Thomas DeAlteris

There is growing evidence that numerous fish stocks may be made up of several smaller reproductively isolated units that vary in their ability to successfully produce new recruits each year. Spawning aggregations appear to exist in the Gulf of Maine Atlantic cod (*Gadus morhua*) stock and half of the historical aggregations may be locally depleted. A spatially explicit, age-based model was developed to investigate the effects of complex population structure and spatially variable recruitment on Gulf of Maine Atlantic cod. The results of this study demonstrate the significant disparity in estimates of spawning-stock biomass, yield, and recruitment that results when a stock with a complex population structure is treated as a single stock. To achieve rebuilding of the simulated stock within 10 years, it was determined that zero fishing mortality is required. Even when fishing mortality is removed, the simulated stock has lost its biological capacity to return to the original unfished condition and only rebuilds to half of the initial carrying capacity. Based on the simulations in this study, the behaviour of the Gulf of Maine Atlantic cod stock is consistent with a stock with a complex population structure rather than a truly single stock. In the light of this information, the management measures for this stock and other stocks with the potential for complex population structure should be carefully evaluated. Managing such stocks as a single unit may be an inappropriate strategy and may lead to inadequate protection of the resource and reduced fishery yields.

Keywords: spawning aggregations, fishery management, localized stocks, subpopulations.

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ICES CM 2008/F:20

Poster

Tropho-parasitic relations of arrow squid (*Todarodes sagittatus*) in the waters of the northwestern African ecosystem and their conditionality by squid size

Ch. M. Nigmatullin, O. A. Shukhalter, and V. V. Laptikhovsky

An isolated population of arrow squid inhabits the shelf and slope waters of North African coast from 11° to 26°N. The stomach contents of 491 squid (mean length 5–30 cm) and parasitic helminths of 180 squid (mean length 8–25 cm) were studied. The food spectrum includes more than 50 food groups of copepods, amphipods, euphausiids, shrimps, munids, squids, and small teleosts. Main foods were myctophids, shrimps, squid, and euphausiids. Eight species and larval forms of helminths were found: Trematoda: Didymozoidae mtc II (prevalence 40.9%, intensity 1–10), *Hirudinella ventricosa* (0.5%, 1); Cestoda: *Scolex pleuronectis unilocularis* (22.3%, 1–2), *S. pleuronectis bilocularis* (3.2%, 1), *Phyllobothrium* sp. (1.1%, 1); Nematoda: *Porrocaecum* sp. (0.5%, 1), and *Spinitectus* sp. (4.2%, 1–2). All helminths found were in the larval stage, had broad specificity, their life cycles are based on trophic chains, and the squids were infected from their prey. By food and parasite data it can be seen that there are well-marked multi-stage squid life cycles that are conditional on predator–prey size relations. Arrow squid play an important role in pelagic and demersal ecosystems as consumers of II–IV orders, and are an important transport host for helminths between invertebrates and small teleosts (intermediate and transport hosts) on the one hand, and sharks, large teleosts, and mammals (definitive hosts) on the other hand.

Keywords: arrow squid, *Todarodes sagittatus*, northwestern African coast, feeding and parasite relations.

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