

## Theme Session B

### Beyond geolocation: inferring and explaining the behaviour of tagged fish

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#### ICES CM 2009/B:01

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##### Assessing the lekking hypothesis for the mating system of Atlantic cod (*Gadus morhua*) using electronic data-storage tags

Timothy B. Grabowski, Vilhjálmur Thorsteinsson, and Gudrún Marteinsdóttir

Although the Atlantic cod (*Gadus morhua*) is one of the most intensively studied of marine fish, its mating system remains largely unknown. Recent studies suggest that cod employ a lekking mating system, but several tenets of this hypothesis remain untested in the field. We implanted electronic data-storage tags into cod from 2002 to 2007 to evaluate their behaviour in spawning aggregations around Iceland. The depth profiles recovered from these tags (females:  $n = 31$ , males:  $n = 27$ ) were used to identify patterns consistent with published descriptions of cod courtship and spawning behaviour. Male cod spent approximately twice the amount of time participating in spawning aggregations that females did on both per aggregation and per season basis. In general, males participated in approximately 57% more spawning events than did females. In both sexes, larger individuals and/or individuals that spent a longer period of time within an aggregation participated in a larger number of spawning events. Males larger than 850 mm  $T_L$  participated in a larger number of spawning events per aggregation visited than females of the same size, whereas smaller males did not exhibit any difference from females of comparable size. Despite spending less time in spawning aggregations per season than males, female cod visited more aggregations per hour spent in aggregations during a season. Our results indicate that male and female Atlantic cod exhibit different patterns of spawning behaviour consistent with that predicted by the lekking hypothesis.

Keywords: spawning behaviour, mating systems, Atlantic cod, lek, electronic data-storage tags.

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#### ICES CM 2009/B:02

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##### Initial results of satellite-linked archival tagging in the Patagonian toothfish (*Dissostichus eleginoides* Smitt, 1898) around the Falkland Islands

Judith Brown, Paul Brickle, and Alexander Arkhipkin

Understanding the movements of Patagonian toothfish (*Dissostichus eleginoides*) is an essential component of their fishery management. As only one demersal longline vessel participates in this fishery in Falkland Islands' waters over a vast slope area, the use of conventional tags to provide data on migration and stock assessment is not viable. In contrast, archival pop-up tags have allowed the examination of toothfish movements without having to recapture tagged individuals with reasonably high success rates. In all, 15 toothfish >132 cm  $T_L$  were tagged between 19 September 2007 and 9 February 2009 on the northeastern part of the Falkland Islands' slope and northern and eastern slopes of the Burdwood Bank. The data from eight tags that successfully released and uploaded data contradicted a hypothesis concerning the extent of migrations between toothfish spawning and feeding grounds. The data revealed strong site fidelity, with the majority of toothfish (five) moving less than 40 km from their release position over a six-month period. In addition, four individuals moved 100 km or more (from the south of the Burdwood Bank to the north of the bank or out towards the Scotia Ridge). Furthermore, our data revealed that toothfish undertake diurnal vertical migrations, with movements ranging between 8 and 584 m over 6-h periods. During the austral summer three fish moved into deeper waters and one of these returned

to shallower waters during the following autumn. The results of these data have made it necessary for us to re-examine the spawning behaviour of toothfish in the South Atlantic.

Keywords: archival pop-up tags, Patagonian toothfish, spawning migration, diurnal migration, Falkland Islands.

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### ICES CM 2009/B:03

#### Estimating spatially and temporally dependent behaviour switching of tagged marine animals

Martin Wæver Pedersen, Toby Patterson, and Uffe Høgsbro Thygesen

We present a method for simultaneously estimating movement and behaviour of marine animals from data from electronic data loggers. The method is an extension of the hidden Markov model geolocation technique and can, in theory, encompass infinitely many behaviour states. However, for models with more than two states, estimation becomes difficult, especially with smaller and noisier datasets. A typical two-state behaviour model would include a resident state, which represents foraging, resting, or spawning in a relatively confined area, and a migratory state that represents fast and often directional persistent movement. The method gives the posterior probability distribution of positions and behaviour states at all time-steps from which we can create informative marginal distributions by summing over time, space, and/or behaviour state. These marginals can uncover how movement behaviour relates to certain locations and certain seasons. We can also pose a collection of nested, yet differently parameterized models and conduct likelihood-based model selection. In doing so we can test the statistical significance of a one-state model relative to a two-state model, or the significance of a two-state model including advection terms relative to one without. To illustrate the performance of the method we present results from a simulation study where the accuracy of the switching estimation, the movement estimation and model selection were analysed. We also present an analysis of PSAT data from southern bluefin tuna in Australian waters that uses an observation model based on light (longitude) and sea surface temperature (latitude) data.

Keywords: geolocation, behaviour switching, likelihood-based model selection, tuna.

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### ICES CM 2009/B:04

#### From “where” and “when” to “what” and “why”: archival tags for monitoring “complex” behaviours in fish

J. D. Metcalfe, R. P. Wilson, O. S. Kjesbu, M. J. Challiss, A. Gleiss, J. E. Skjæraasen, and S. Clarke

Understanding the movements (“where” and “when”) and behaviour (“what” and, it is to be hoped, “why”) of individuals and populations is key to answering fundamental questions in fish ecology. The use of archival tags in telemetry studies of marine fish have, by and large, involved recording “simple” measurements of variables such as pressure (giving depth), temperature, and light over extended time-scales. These have then been used to provide information about location and movement of individuals. However, our understanding of more complex behaviours (i.e. what fish are doing as different from spatial movements) has usually been inferred from movement data because it has not been possible to record directly specific behavioural events such as feeding or spawning. This is because the events are usually infrequent, irregular, and often quite brief and so not amenable to a technology based on taking regular but infrequent records of continuously available variables. The recent implementation of new sensors (e.g. physical movement, three-axis accelerometers), rapid (<30 Hz) sampling capabilities, enhanced memory, and more complex data-capture protocols has led to the development of archival tags that can be used to detect and record

complex behaviours such as feeding and spawning. We describe recent developments with archival tags and their use to monitor feeding and spawning in fish together with the application of three-axis accelerometry that can be used to quantify behaviour and metabolic rate. These can then be used to assess the cost of behaviours with a view to understanding how appropriate they are as responses to environmental variability.

Keywords: telemetry, behaviour, data-storage tag.

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## ICES CM 2009/B:05

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### Orientation of homing Atlantic salmon (*Salmo salar* L.) mapped in relation to geomagnetic field

Johannes Sturlaugsson, Sigmar Gudbjornsson, and Hagen Stockhausen

A migration study on the homing of Atlantic salmon (*Salmo salar* L.) has been carried out in coastal and oceanic waters off western Iceland. Data were sampled on the salmon behaviour and environment using a new registration tag, recently developed by Star-Oddi, in cooperation with the Institute of Marine Research (Bergen, Norway). This new data-storage tag is a magnetic recording device with eight built-in sensors and is used to measure the earth's magnetic field and the tilt (in three directions) plus corresponding information on fish depth (pressure) and sea temperature. The sampled data have been used to present new information on salmon behaviour with a special focus on orientation. The study involves a new approach for positioning free-ranging fish using information on the earth's magnetic field sampled during the homing of the salmon.

Keywords: Atlantic salmon, migration, homing, orientation, navigation, data-storage tags.

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## ICES CM 2009/B:06

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### Ocean scale hypoxia-based habitat compression of Atlantic istiophorid billfish

Eric D. Prince, Jiangang Luo, C. Phillip Goodyear, John P. Hoolihan, Derke Snodgrass, Eric S. Orbesen, Joe E. Serafy, Mauricio Ortiz, and Michael Schirripa

Oxygen minimum zones have been reported to occur as distinct strata in large areas of the eastern tropical Pacific and Atlantic Oceans. In the eastern tropical Pacific Ocean (ETP), this stratum restricts the depth distribution of high-oxygen-demand tropical pelagic marlins, sailfish, and tunas by compressing the suitable physical habitat into a narrow layer at the surface of the ocean (i.e. habitat compression). This surface mixed layer is defined by a shallow thermocline, above a barrier of cold hypoxic water ( $>3.5 \text{ ml l}^{-1}$ ). The cold hypoxic environment below the thermocline constitutes a lower habitat boundary for tropical pelagic fish in the eastern tropical Pacific, often at 25–50 m. However, hypoxia-based habitat compression has not been demonstrated in the eastern tropical Atlantic Ocean (ETA), which has oceanographic characteristics similar to those of the ETP. Here, we compared vertical habitat use of eastern and western Atlantic sailfish and blue marlin monitored via pop-up satellite archival tags. Highly significant differences were evident, with shallowest vertical habitat use occurring in the eastern Atlantic where dissolved oxygen (DO) is limited with depth, and much greater vertical habitat use for both species in the western Atlantic, where DO is not limited with depth. Given these results, we offer a mechanistic approach for incorporating compression impacts directly into stock assessments of tropical pelagic species that utilize the ETA. Application of a statistical habitat standardization approach would, in theory, adjust catch rate data according to the increased vulnerability of these fish to surface gears created by the compression phenomenon.

Keywords: habitat compression, tropical pelagic fish, hypoxia.

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**ICES CM 2009/B:07**

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**Lessons from a global-scale behavioural analysis of air-breathing datasets: what you can do when you know where you are**

Toby Patterson, Mark Bravington, Mark Hindell, Martin Biuw, Mike Fedak, Christophe Guinet, and Dan Costa

Much effort has gone into developing robust solutions to the problem of estimating location from data-logging tags in fish. Tags deployed on large, air-breathing vertebrates, such as marine mammals, allow for the collection of location data with a relatively high degree of accuracy. This means that behavioural analyses can deal with biological questions without the hindrance caused by spatial uncertainty found in the case of fish. In the case study considered here, tracks from 66 southern elephant seals, spread across four subpopulations in the Southern Ocean, were analysed using three types of hidden Markov model—a two-state model with resident and transit modes and two different three-state models consistent with central place foraging animals. Switches between movement modes were updated with long-term ocean descriptors and *in situ* covariates. Eleven variants on each model, each with different covariate interactions were considered. The large dataset and number of candidate models highlight the potential of state-space approaches in the analysis of individual movement data, the possibility of meaningful comparisons regarding habitat usage and behavioural differences between populations, and also the challenges of computation, modelling and covariate selection and making predictions of behaviour from new data. Models such as those presented here have potential for use on large-scale tracking datasets from fish and their use in this case study highlight potential pitfalls along the way.

Keywords: behaviour switching, model selection, population comparisons.

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**ICES CM 2009/B:08**

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**Adaptive behaviour of Baltic cod feeding in hypoxic water**

Stefan Neuenfeldt, Uffe Høgsbro Thygesen, and Jane Windfeldt Behrens

Data-storage tag data have indicated that some Baltic cod spend about a third of their time in oxygen saturations below 50%, possibly to forage. Because the vertical difference between normoxic and hypoxic conditions in the Baltic Sea is less than 10 m, the individual fish can easily regulate their residence time in hypoxic conditions. Maximum residence time per visit in such hypoxic water was limited to 10 h or less, allowing for the digestion of consumed prey items in waters with sufficient dissolved oxygen. We developed a simple conceptual model to investigate whether the fish regulate the length of time spent in hypoxic water in order to optimize energy gain. The energy budget takes into account food acquisition, swimming activity, and repayment of potential oxygen debt. The model results are discussed compared with existing laboratory studies.

Keywords: cod, adaptive behaviour, hypoxia, foraging activity.

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**ICES CM 2009/B:09**

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**Behaviour of large Atlantic cod at ship wrecks and similar rough bottom structures in the northeastern part of the central North Sea**

Junita D. Karlsen, Hans J. Olesen, and Niels G. Andersen

There is a substantial difference of opinion between fishers and the scientific community about the biomass development of large Atlantic cod in the North Sea during the latest decade. Although knowledge of the distribution of cod on a small geographical scale is important to interpret the catch rates of both commercial vessels and scientific surveys, the dynamics of the small-scale spatial distribution of cod is poorly understood. Together with other related research activities, a study was therefore conducted during summer 2008 at ten selected ship wrecks known to hold large cod (>70 cm). The aims were to examine the time budget of cod at these wrecks by use of acoustic telemetry and to investigate the effects of a variety of variables on the observed absence/presence patterns. As foraging was considered a major incentive to locomotion of cod outside the spawning season, stomach samples were collected from wrecks during the study period. A total of 121 cod were tagged with acoustic tags during three different tagging sessions. Two listening buoys were deployed at each wreck. Over a field period of more than four months (May–September), 56 cod at six wrecks were detected more than 100 times. Several hundred stomach samples were collected. Preliminary results indicate that the diet of large cod at wreck sites is dominated by prey types from smooth bottom and that absence/presence patterns differ among wrecks. The influences of physical variables are also presented.

Keywords: acoustic telemetry, rough bottom structures, behaviour of Atlantic cod, foraging, physical variables.

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## ICES CM 2009/B:10

### A comparative analysis of the vertical dynamics of cod (*Gadus morhua*) in four different ecosystems using data from data-storage tags

S. Subbey and K. Michalsen

This paper presents a comparative analysis of data-storage tag data recovered from tagged cod (*Gadus morhua*) from four different ecosystems. The aim was to investigate the relationships between patterns and characteristics of vertical movements with respect to temperature (and/or salinity), in order to determine ecological aspects of the water column use, such as avoidance of the upper layer of thermocline (halocline), temperature tolerance, and behavioural thermoregulation. Such information is relevant in predicting the vertical behaviour of cod stocks in different ecosystems, and how the stocks might respond to environmental changes (e.g. temperature rise). A brief discussion of the relevance of the analysis to resource management is presented.

Keywords: cod, wavelets analysis, water column usage, rhythmic patterns, comparative temperature tolerance, environmental change.

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## ICES CM 2009/B:11

### Inferring patterns from tagging surveys: how to merge heterogeneous datasets

Francois Royer, Philippe Gaspar, Beatriz Calmettes, Inna Senina, and Patrick Lehodey

Electronic tags have allowed the monitoring of pelagic species over a new range of space and time-scales. The technology has evolved rapidly, however, and there is now a large variety of tag types and models, relying on internal storage or satellite transmission, or both. The accumulation of these large, heterogeneous datasets over the years raises several points, such as the need for data standardization, reliable storage, and consistent processing, analysis, and interpretation. In addition, the accumulation of these datasets now leads researchers to tackle new questions about temporal variability, such as “Are my dispersion patterns similar over all these years?”, or “Are these two years similar, despite the difference in sampling size and tag technology?”. We present in this paper some solutions available to today’s modellers and discuss the challenges of producing homogeneous datasets and results and how adequate post-processing can help us in this task.

Keywords: electronic tag, biologging, inference, modelling.

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**ICES CM 2009/B:12**

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**Understanding the ecology of Atlantic cod (*Gadus morhua*) stocks in UK waters: the benefits of archival tagging programmes**

David Righton, Victoria Bendall, Colin Bannister, and Julian Metcalfe

Despite the development of complex mathematical models to help assess and manage fish stocks, we still depend upon the quality of the assumptions and knowledge that are used to construct them. In the case of cod, much of this valuable species' ecology has been poorly understood because observing cod in their natural environment is both difficult and costly. In recent years, however, sophisticated electronic devices or tags have been developed that can be attached to cod (and other species) to record their movements, habitat selection, and behaviour. These devices have helped make significant progress in our understanding of how cod behave in relation to their environment. In this paper, we highlight our current understanding of how UK cod stocks are structured, what are the preferred habitats of cod and why, and what we might expect to happen to cod as the seas and climate warms. Our goal is to demonstrate that the data collected using archival tags can be used in conjunction with other data to build a comprehensive understanding of how animals interact with their environment, and that this understanding is crucial to help develop the next generation of fishery models that are aimed at stock recovery under climatically uncertain conditions.

Keywords: Atlantic cod, archival tags, ecology.

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**ICES CM 2009/B:14**

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**Linking oceanography and bluefin tuna movements in the Northwest Atlantic**

Benjamin Galuardi, Francois Royer, and Molly Lutcavage

For highly mobile predators such as Atlantic bluefin tuna, appropriate oceanographic structure and biophysical interactions create optimal feeding opportunities. The location and persistence of appropriate water-mass features along their migration routes should influence tuna residence times, energy stores, larval and reproductive success, and vulnerability to capture. Gutenkunst *et al.* (2007) previously identified two movement modes—travelling and foraging—on coastal foraging grounds. However, time and spatial scales were limited (e.g. 48 h, 150 km tracks). Recent advances in satellite tagging technology and light-based geolocation have revealed the scope and complexity of Atlantic bluefin tuna distributions. Using spatial and behavioural results obtained from adult Atlantic bluefin tuna tagged with pop-up archival satellite tags for up to one year in the Northwest Atlantic, we examined the relationship between tuna behaviour and oceanographic conditions. Daily behaviour type (localized or long range) was derived from a speed-biased approach for 32 bluefin tuna tagged and released off Nova Scotia in 2005 and 2006. We tested the influence that proximity to persistent oceanographic features (sea surface temperature, chlorophyll *a* fronts) had on behaviour type and depth patterns, and examined the interplay of depth patterns and behaviour. By developing a complete picture of habitat utilization of Atlantic bluefin tuna we hope to better understand long-term shifts in their distribution and abundance, and contribute to population rebuilding efforts through better understanding of their ecosystem.

Keywords: none.

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**ICES CM 2009/B:15     Poster**

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**Simulated archival tagging programme of albacore tuna (*Thunnus alalunga*) in the Northeast Atlantic, including an analysis of factors affecting tag recovery**

Ronan Cosgrove, Igor Arregi, Deirdre Brophy, Haritz Arrizabalaga, Victoria Ortiz de Zarate, and Nigel Griffin

A simulated archival tagging study on albacore tuna (*Thunnus alalunga*) using simulated or “dummy” archival tags was carried out in the Bay of Biscay from 2005 to 2008. The study aimed to obtain an estimate of recovery rates of dummy tagged fish in order to assess the feasibility of conducting an authentic archival tagging study for albacore tuna in the Northeast Atlantic. A total of 353 fish were tagged and released and 9 fish (2.55%) were recaptured. Furthermore, a database of conventionally tagged fish in the Northeast Atlantic provided by the International Commission for the Conservation of Atlantic Tunas, was analysed to determine whether optimal conditions at the time of release could be identified and used to boost recovery rates in future tagging programmes. A binary logistic regression model using a response variable with two possible outcomes—recaptured or not recaptured—was carried out. Fish which were caught and released by the trolling fishing method, between 65 cm and 74 cm fork length, were found to have the highest probability of recapture, and a recapture rate over 5% was predicted if derived optimal conditions are followed in future tagging programmes.

Keywords: simulated archival tagging study, albacore tuna, Northeast Atlantic, factors affecting recovery, binary logistic regression model.

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**ICES CM 2009/B:16     Poster**

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**Movement patterns of winter flounder in the southern Gulf of Maine**

Greg DeCelles and Steve Cadrin

A two-year acoustic tagging experiment was conducted in the Plymouth Bay estuary to examine seasonal movement patterns of adult winter flounder. During the first year, 47 individuals were fitted with acoustic transmitters and tracked using an array of 15 Vemco receivers. During the second year, the passive array was expanded from 15 to 30 receivers and an additional 25 flounder were tagged within the array, allowing more direct tests of alternative hypotheses about spawning migrations. Telemetry data suggests that seasonal movements within the estuary were strongly associated with water temperature. A proportion of tagged flounder migrated into the estuary in spring as water temperature increased, whereas others remained in coastal waters. Of those individuals that entered the estuary in spring, the majority emigrated to coastal waters in June, when water temperatures in the estuary exceeded 15°C. A small portion ( $n = 5$ ) of tagged fish were detected re-entering the estuary in autumn, as water temperatures decreased to less than 15°C. Tagged flounder exhibited spatially and temporally diverse movements, and it appears that sympatric, contingent spawning groups of winter flounder may occur within this relatively small geographic area.

Keywords: winter flounder, *Pseudopleuronectes americanus*, acoustic telemetry, contingent.

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**The earth's geomagnetic field and geolocation of fish: first results of a new approach**

Hagen Stockhausen and Sigmar Guðbjörnsson

The earth's geomagnetic field is present throughout the globe and can be used, based on satellite measurement-derived magnetic field models, for geolocation of fish. A new data-storage tag has been developed that is capable of measuring geomagnetic field and the angles of pitch and roll, both in three components, in addition to depth and temperature. Despite the wealth of sensors the storage tag is still small enough to be used on fish the size of an average cod. In this study the basic outline of the geophysical background is presented and main aspects of the general approach (e.g. variations of the geomagnetic field) are addressed. Results from the first measurements using the new data-storage tags are presented and the precision of a geolocation based solely on the geomagnetic field as measured by the data-storage tag is discussed. Geomagnetic field values potentially constitute a valuable addition to an integrated approach to geolocation and migration research.

Keywords: geomagnetic field, geolocation, data storage tag, fish.

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**ICES CM 2009/B:20      Poster**

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**From signals to pattern: a new system reflecting environment in fish behaviour by telemetric assessed multiple parameters and pattern analysis**

D. Baganz, H. U. Balzer, O. Jauernig, and G. Staaks

The presented work reflects scientific research on an innovative telemetric sensor system for non-invasive and simultaneous monitoring of multiple physiological and behavioural parameters of free swimming fish. The miniaturization of the system allows the integrated measurement of temperature, heart rate, breathing rate, the electrical potential and resistance of the skin, and three-dimensional swimming acceleration. At present this system is only applicable in systems of restricted size (e.g. in aquaria, basins, or ponds). First measurements and analytical results are presented here. In the test scenario a shoal of fish was observed by the sensor system and a video system simultaneously. Single environmental parameters were changed to induce physiological or behavioural reactions in fish. An artificial neuronal network (ANN) was used to evaluate the assessed signals and to reveal correlations, dependencies, and complex patterns under the influence of external and internal factors. Changes in the environment will, via changed physiological and behavioural parameters, lead to changed regulatory patterns. During a preprocessing step a set of time-series analysis functions are applied to the sensor signals, to prepare them as input for the ANN. In the "teaching" phase of the ANN a human interpreter "informs" the ANN about the "meaning" of the video-sequenced behaviour on the basis of predefined regulatory patterns. Thus the ANN learns figuratively from the fish. The approach offers opportunities for further research on behavioural ecology, eco-physiology, and fish welfare. Additional prospects are emerging for applied research and aquaculture.

Keywords: telemetric sensor system, multiple monitoring, physiological and behavioural parameter, pattern analysis, neuronal network, indicating environmental changes.

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**ICES CM 2009/B:21**

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**Diel behavioural rhythms of the painted comber (*Serranus scriba*) at Palma Bay Marine Reserve (western Mediterranean)**

David March and Jacopo Aguzzi

In this study we focused on the analysis of diel behavioural patterns of the painted comber (*Serranus scriba*). Fifteen adult individuals were tagged and tracked by acoustic telemetry in Palma Bay Marine Reserve. The fish were surgically implanted with transmitters and monitored with an array of 25 acoustic listening stations. Time-series of detection counts over short periods (5–30 days) were analysed with different chronobiologic statistic protocols. We divided available methods of behavioural analysis into three main categories: time-series visualization, periodicity detection, and phase identification by waveform analysis. Then we contrasted behavioural data for fish with clear diel patterns, as evidenced by a larger number of detections during daytime, with fish displacements in relation to diurnal and nocturnal habitat use (i.e. from fixed kernel estimators) and physical relevant parameters (i.e. water currents, salinity, and temperature). Oceanographic data were collected with an oceanographic buoy located within the study area. Finally, we discussed our results by focusing on the role that seagrass (*Posidonia oceanica*) plays in the behaviour of this species (e.g. the resting of individuals under plants leaves at night).

Keywords: acoustic telemetry, *Serranus scriba*, fish behaviour, diel pattern, seagrass, time-series analysis, periodogram, waveforms.

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**ICES CM 2009/B:22      Poster**

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**Using biotelemetry to investigate cardiovascular trade-offs in cod feeding under hypoxic conditions**

Jane Windfeldt Behrens, Uffe Høgsbro Thygesen, and Stefan Neuenfeldt

Fish are constantly facing oxygen-demanding challenges such as digestion, locomotion, and repayment of potential oxygen debt, all placing demands on the cardiovascular system. Maximal cardiac output cannot, however, perfuse all tissues simultaneously. Consequently, when faced with multiple challenges where the total oxygen demands exceed the maximal supply, circulatory priorities must be made, a problem which is amplified in hypoxia. Post-prandial gut blood flow increases profoundly to ensure sufficient oxygen to the gastrointestinal tissue for the efficient absorption of nutrients. Swimming capacity, however, also depends on sufficient blood flow. The metabolic budgets for swimming and digestion may hence become mutually exclusive at high swimming speeds, during digestion of large meals, or under hypoxia, yet allocation of oxygen between competing systems is a key element of adaptability. This raises the question of how fish distribute blood flow when competing demands are placed on the circulatory system. Recent data-storage tagging data demonstrate that some Baltic cod visit hypoxic waters briefly but often, presumably to feed. Here we describe a newly developed, fully implantable biotelemetry system for measurements of cardiac output and gastrointestinal blood flow. The system allows the investigation of blood flow priorities that free-ranging cod may give when feeding under hypoxia, by establishing long-term records of these physiological variables. We discuss the background for the study compared with previous reports on blood flow allocation between competing systems, and the bioenergetic perspectives.

Keywords: cod, blood flow, oxygen consumption, feeding, locomotion, hypoxia, biotelemetry.

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**ICES CM 2009/B:23     Poster**

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**Scale-dependent foraging movements of a long-ranging diving predator in relation to the marine environment**

Annette Scheffer, Philip N. Trathan, and Charles-André Bost

Marine predators precisely target their prey in both space and time. To detect the locations with enhanced prey availability, they have to adjust their movements in response to the prey and the environmental conditions encountered. We used GPS tracking and time–depth–temperature recording to follow the movements of king penguins, a key diving predator of the South Atlantic Ocean. We tracked fine-scale movements during foraging trips directed towards the Polar Front, which is thought to be an important foraging area for marine predators as their prey aggregates near to associated oceanographic features. We used First Passage Time and track sinuosity to identify changes in surface movements at different scales, based on theoretical predictions of animal movements in a prey patch. To identify feeding events during the dives, we used indices from penguin underwater movements, especially during the bottom phase of their dives. Combining the observed behaviour with environmental data (such as water temperature, ocean colour, and bathymetry) we studied how animals adjust their horizontal and vertical movements at different scales in response to their environment. The thermal structure of the ocean appeared to have an important influence on foraging, with behavioural changes appearing with both horizontal and vertical temperature gradients. The observed dependence on temperature could be critical in terms of potential changes in the thermal structure of the ocean induced by climate change.

Keywords: GPS tracking, foraging behaviour, First Passage Time, oceanographic features, king penguin, marine predator.

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**ICES CM 2009/B:24     Poster**

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**Wavelet analysis of archival tag time-series data**

Chi H. Lam, Vardis M. Tsontos, and Dale A. Kiefer

An electronic archival tag is capable of sampling every 30 s to 2 min, returning months to years of data from a tagged fish, giving us information on at least three basic parameters: temperature, depth, and light. We can easily be overwhelmed by this vast volume of data, which is further complicated by the multiple tags recovered from a tagging expedition. The nature of tag data means that a collection of data points collected at various times can be analysed statistically with time-series methods. This study uses multiple time-series techniques to analyse tag data. Although the parameters (e.g. depth) are analysed mostly in the vertical aspect of the fish moving in the water column, we frame our analysis with reference to the horizontal displacement (i.e. track) of the fish. Literature studies have commonly used fast Fourier transform (FFT) to identify cyclical fish behaviours. However, this frequency–domain technique assumes stationary data that are easily violated by the archival tag. Wavelet analysis is another frequency–domain technique better suited for tag data that does not assume stationarity. We apply both techniques to three fish species and illustrate the types of fish behaviour uncovered by each technique. Initial work has identified the high density of data points as a confounding aspect. We demonstrate the challenges encountered in applying the methods and our answers to them. The paper concludes with a look at how frequency–domain and time–domain methods of time-series analysis can be used together to model fish behaviour.

Keywords: wavelet analysis, fast Fourier Transform, time-series, archival tag.

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**Evidence of reproductive isolation among ecologically and behaviourally distinct populations of Atlantic cod**

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There is increasing recognition of intraspecific diversity and population structure within marine fish species, yet there remains little direct evidence of the isolating mechanisms that maintain it. Atlantic cod (*Gadus morhua*) exhibit fine-scale population structuring across its range. However, the mechanisms allowing this structure are largely unknown. We analysed depth and temperature histories collected by electronic data-storage tags retrieved from 84 Atlantic cod at liberty over more than a year to determine the ecological niche and the timing of migration and spawning of the Icelandic stock. The Icelandic cod stock was found to consist of two distinct behavioural types—residential coastal cod and migratory frontal cod—within geographically distinct populations. The different groups occupied distinct thermal and bathymetric niches that generally demonstrated low levels of seasonal overlap. This ecological differentiation seems to place different demands upon the reproductive physiology of these populations, as evidenced by the timing of migratory and reproductive events as measured in degree-days. Yet the behavioural types within each geographically distinct population exhibit considerable temporal overlap, as measured in Julian days, during spawning. Despite being captured together at the same spawning sites, the behavioural types seem to be reproductively isolated as a result of fine-scale differences in spawning habitat selection, maintaining the complex population structure seen within this stock. It seems that spawning habitat segregation is an important isolating mechanism, maintaining population structure and intraspecific diversity in species with pelagic larva despite an open environment with potentially few barriers to dispersal and mixing.

Keywords: Atlantic cod, ecological niche, sympatric divergence, electronic data-storage tags, degree days.

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**Life in the big blue box: studying the marine life of European eels**

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European eel (*Anguilla anguilla*) catches, like those of *A. japonica* and *A. rostrata*, have declined dramatically in recent years. The stock is now judged to be outside safe biological limits, and recovery and management plans are currently being implemented. However, the potential for European eel stocks to recover is uncertain because many biological processes that influence eel stock size and sustainability are not fully understood. In particular, very little is known about the marine ecology of eels, and how biological, ecological, and environmental factors affect the migration success of silver eels and leptocephali. Eeliad is a four-year, EU-funded research project to investigate the ecology and biology of European eels during their marine migrations. The project integrates and takes advantage of significant recent improvements in sophisticated scientific methods (telemetry, population genetics, molecular diagnostics, otolith microchemistry, and advanced numerical modelling) to address long-standing uncertainties in eel biology such as oceanic behaviour, the location and timing of spawning, stock demographics/panmixia, and the role of environment in determining recruitment success. The information provided by the Eeliad Project will provide answers to these fundamental questions, and also provide information and tools for fishery managers to enhance current conservation measures and thereby the prospects of eel stock recovery.

Keywords: European eel, satellite tags, eeliad, eel management plans.

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