



Bergen, Norway, 20 - 25 June 1998

Hosted by



Institute of Marine Research

Convener:

E. Moksness (Norway)

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Foreword

Dear participants,

More than four years have passed since the First International Symposium on Fish Otolith Research and Application took place at Hilton Head, South Carolina, USA, in January 1993. Many of the participants then felt it was one of the best scientific meeting they had ever attended, including myself. The meeting was well organised and the organisers were able to create a special atmosphere at all times. From that point of view, this present Symposium has a lot to achieve for comparison. High quality work were presented in four major sessions «Otolith Growth and Morphology», «Estimation of Fish growth», «Otoliths in studies of Populations» and «Otolith Composition». In addition to the contributions, the session chairmen, commented on their sessions, and in some cases indicated future directions. Selected papers from the Symposium were later published in the Symposium proceedings. However, we know that a lot of things have taken place in the years passed. Several countries have identified the importance of improved accuracy and precision in age determination of fishes and the possibility of the new technology like otolith microchemistry, and have established national laboratories to focus on the possibilities and problems.

We are all looking forward the achievements we will be able to obtain at this Symposium. Personally I feel that the Scientific programme looks exciting and hopefully the social programme will be as successful as that in Hilton Head and that we are able to create a special atmosphere at all times.

Finally, I hope you will enjoy Bergen and the Symposium and wish you all the best.

Erlend Moksness
(Convener)

Symposium Background

The First Symposium on Fish Otolith Research and Application took place in Hilton Head, South Carolina, USA in January 1993. The symposium, attended by 292 participants from 30 countries, presented the state-of-the-art and probable future directions of this increasingly important area of research. The most common applications of otolith-derived data are to determine growth rates of fish and the age structure of populations. However, it is clear that otoliths can be used to address a broad spectrum of problems in areas ranging from fisheries management to global change. Otoliths act as dataloggers, recording information in zones formed over time scales ranging from sub-daily to annual. The width of daily or annual increments, integral to the growth estimation process, provides an estimator of the growth history of individual fish. Otolith researchers employ several chemicals to mark the otoliths of living fish with easily discernable bands that can serve as reference points for otolith-based investigations of age, growth, mortality and migration. The pattern and spacing of zones formed by fishes in the wild can be used to differentiate among populations. Taking a lesson from the effects of the natural environment, researchers are now marking the otoliths of large numbers of hatchery reared fish with bar codes produced by temperature manipulation or chemical markers. Years later these bar codes or chemical markers can be used to identify fish from specific releases into the wild. Otolith chemical composition can be used to differentiate among stocks, determine temperature histories of a fish's environment, follow migratory patterns, and provide data to investigate ocean circulation, global carbon flux, and climate change. Based on the phenomenal advances in otolith research presented at the first Symposium it is clear that these structures have far more to offer than our current understanding allows. The success of this Symposium on otolith research highlighted the need for a future meeting to discuss this rapidly advancing field and, as a result, a second Symposium has been planned for 1998.

Symposium Objective

The objectives of the 2nd International Symposium are to bring together scientists and exchange knowledge on fish otolith research and to provide a forum where group discussion will result in the clarification of issues and the development of new directions in this rapidly evolving field. The Symposium is organised in four sessions:

Otolith Physiology and Morphology, emphasizing studies on biomineralization of otoliths, evolutionary aspects of otolith function and morphology, physiological basis of increment and check formation, and factors affecting otolith growth and shape.

Estimation of Fish Growth, focusing on age and growth studies, age validation, backcalculation of growth, link between somatic and otolith growth, analysis and interpretation of growth data.

Otoliths in Studies of Populations, considering recruitment and population dynamics, estimation of mortality rates, hatch date distributions, mark-recapture studies, and accuracy of age estimation.

Otolith composition, focusing on organic and inorganic composition of otoliths, isotope and trace element studies, reconstruction of environmental and physiological histories, migration studies, pollution monitoring, radiochemical age validation, stock identification, and chemical mass marking techniques.

Key note speakers

Session 1: Otolith Physiology and Morphology

Tomasz Linkowski (Poland): Otolith microstructure of vertically migrating vs. non-migratory mesopelagic fishes

Sophie G. Dove (Australia): Understanding the black box: Otoliths as environmental monitors

Arthur N. Popper (U.S.A.): Structure-function relationships in fish otolith organs

Session 2: Estimation of Fish Age and Growth

Daniel Kimura (U.S.A.): Some considerations and methods when analyzing age and growth data

Beatriz Morales-Nin (Spain): Daily increments in otoliths: endogenous versus exogenous growth regulation

Jacques Panfili (France): Interpretation of otolith structures: old tools, new tools and hopes

Iain Suthers (Australia): Faster growth is better? Condition and recent otolith growth

Session 3: Otoliths in Studies of Populations

R. Christopher Chambers* and David A. Witting (U.S.A.): Phenotypic reconstruction from otolith information: inferring size, growth, and history

Eric C.Volk (U.S.A.): Bar Codes and Micro-Beams: Using Otolith Structural and Chemical Attributes to Monitor Salmonid Populations

Kevin M. Baily*, A.L. Brown and S.J. Picquelle (USA): Population dynamics of larval walleye pollock, *Theragra chalcogramma*, in the Gulf of Alaska

Session 4: Otolith Composition

John Kalish (Australia): A glance at 50,000 years of otoliths

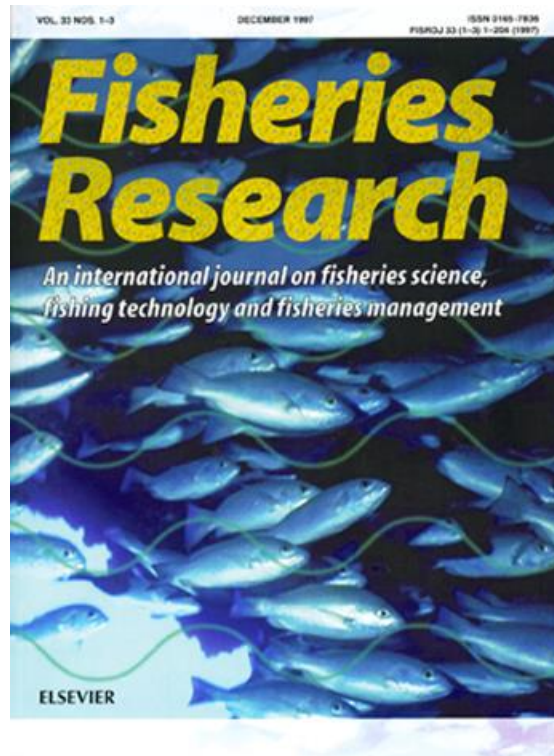
Steve Campana (Canada): Otolith elemental fingerprints as biological tracers of fish stocks

David Secor (U.S.A.): Is otolith strontium a useful scalar of life-cycles in estuarine fishes?

Simon Thorrold (U.S.A.): Reconstructing variability in coastal ocean environments through stable isotope analysis of fish otoliths

Symposium Proceeding

Selected peer reviewed papers will be published in *Fisheries Research* during summer 1999
Eds.: P. Fossum (Norway), J.M. Kalish (Australia) and E. Moksness (Norway).



THE INSTITUTE OF MARINE RESEARCH



is a national centre for research on coastal and ocean life and the marine environment.

THE TASKS OF THE INSTITUTE ARE :

- *To study and monitor life cycles and interactions of different organisms in the ocean and coastal marine environments*
- *To continuously update present knowledge of marine resources of importance to the fishing and aquaculture industries*
- *To develop a biological basis and technology for future-oriented fishing and aquaculture industries*
- *To give the fisheries authorities and industry advice on the management of our marine environment and resources*
- *To inform about research results in a manner which promotes the interests of the fishing and aquaculture industries and society in general.*

The Institute of Marine Research plays a central role in international marine research. In collaboration with NORAD (Norwegian Agency for Development Co-operation), the Institute supports the development of fisheries in third world countries.

MARINE RESOURCES

The rich fish resources in our marine regions are reflected in the pattern of our coastal settlements. One of the central tasks of the Institute of Marine Research is to measure fish stocks and provide prognoses on the development of these resources. Our most important commercial fish stocks are currently in a phase of positive development. During the past few years, studies have indicated that there are large quantities of cod, haddock and herring fry in northern waters. Under a responsible and well-managed harvesting policy, these should provide the basis for higher fishing quotas.

Studies of recruitment, size, rates of growth, age distribution, migrations and nutrition are central aspects of our research on our most important fish species. In order to offer reliable advice to the fisheries authorities, we must collect reliable catch statistics and data on predation by other species. Recruitment and the growth of individual fish increases fish stock size, while fishing and predation reduces it.

"Who eats whom?" The interactions between different fish stocks are mapped and quantified, and the data entered into a multi-species model. In the future, this will provide a basis for an integrated, sustainable management of all types of marine resources. Data on the stomach contents of cod,

capelin, herring, minke whale and harp seals are currently entered into this model. Data on plankton, ocean currents and nutrient salts will also be added.

Sustainable development of resources is based on catching fish that provides the greatest amount of added value, i.e. adult fish. By not taking young fish or unwanted by-catch, the growth potential of a fish is exploited to the full. The Rio Conference called this "responsible fishing". The Institute of Marine Research has a research group that utilizes studies of fish behaviour and fish capture technology to develop fishing gear that are selective for certain species and sizes.

MARINE ENVIRONMENT

All life in the ocean is dependent on the state of the ocean environment. It is therefore a central task for the Institute of Marine Research to monitor the physical and biological environment of the ocean, to study changes in these factors, and to estimate their influence on ecological production systems in our marine regions.

The inflow of Atlantic water into the Norwegian Sea is one of the most important causes of climatic variation in our ocean regions. Annual variations in transport and amount of heat in the inflow have enormous effects on the geographic distribution, growth and recruitment of fish stocks. Studies of the mechanisms that influence variations in the Atlantic inflow are of importance to the Institute's work in various regions of our ocean. Studies of plankton, salinity, temperature, nutrient salts and ocean current help us understand the nutrient basis and growth conditions for fish and marine mammals.

The Institute also conducts comprehensive surveys, for example in the Barents Sea, of chemical environmental toxins and radioactivity. Pollution seems to be a growing problem also in the Arctic area. The Skagerrak and the eastern region of the North Sea are key areas for transport of pollution into Norwegian waters. The algae bloom in 1988 provided a warning that our ocean region is out of balance. For this reason, one of the important tasks of the Institute of Marine Research is to monitor conditions of nutrient salts, eutrophication and algae growth. The Institute's continuous work in monitoring levels of pollution in all our ocean regions is vital to recognising potential ecological damage, and provides a safeguard to the contamination of the purity of Norwegian fish products.

AQUACULTURE

For the Institute of Marine Research it is an important task to support sustainable aquaculture management, and create added value in an aquaculture industry based on ecological and genetic principles.

An important aspect of this work is the development of production lines for aquacultural species that improve the profitability and competitiveness of the industry. We measure the most important factors that influence the growth and survival of a species after it has been released into the sea. We also study how light and temperature affect sexual maturation of these species.

Fish diseases have caused severe losses in the industry. The Institute's research on fish disease is aimed at preventive health care, diagnostics, development and testing of vaccines and vaccination strategies. This work concentrates on furunculosis, infectious salmon anaemia and infectious pancreatic necrosis in salmon, along with bacterially induced diseases in marine species. The salmon louse is a problem for the aquaculture industry. The Institute is developing preventive measures and on new delousing methods.

The rapid growth of the aquaculture industry has left environmental stresses in its wake, and in some cases, leads to the degradation of the environment around fish farms. We work on identifying better means of evaluating the localization and size of farms adapted to local conditions. Since the beginning of the eighties, the Institute has carried out research on rational and safe methods for the production of marine species. This research concentrates first and foremost on cod, halibut, turbot, catfish and scallops. Since 1988, the Institute has released cod, salmon and lobsters in "sea ranching" trials. In the long term, appropriate ecologically sea ranching may support the value adding process to the coastal communities. We will also attempt sea ranching of other shellfish.

Social Programme

Saturday 20 June

1900-2030 Reception at "Sardinen". Host: University of Bergen
2030 Get-together at "Sardinen". Music by: "Cajun Gumbo"

Get-together party

"Sardinen" is an old canning factory in the centre of Bergen. During the last decade the building has become a very attractive and popular centre for cultural events. We think the old cannery will be a good site for our come-together party. We start at 7 p.m. with a reception given by the University of Bergen, represented by Kåre Rommetveit, the Director of the University. Shortly thereafter the former director of the cannery will tell us a bit about production during earlier days and show us some of the products. Later on "Cajun Gumbo" will play for us until half past midnight.

Welcome!

Monday 22 June

1930-2130 Reception at the Institute of Marine Research. Host: Institute of Marine Research

Tuesday 23 June

Daytime

Trip 1: "Norway in a Nutshell"; a one day trip by train, boat and bus through some of the most spectacular landscape in Norway. Nice fjords, mountains and waterfalls from the start to finish. 8,5 hours. 500 NOK. Max 20 persons.

Trip 2: Trip to Øygarden. Øygarden is a beautiful archipelago west of Bergen. After visiting a scallop hatchery, lunch will be served at the newly opened coastal museum and we try our luck fishing in one of the tidal streams. 6 hours. 150 NOK. Max 48 persons.

Trip 3: "Gå over vidden" means a hike in the mountains encircling Bergen. It is an old tradition of the Bergensers. We start with the funicular to Ulriken, then walk in the mountains where we have lunch. We will bring our own lunch from the hotel and prepare coffee over an open fire. At the end of the trip we will take the funicular down from Fløyen and enjoy the

nice view of the city. A reasonable level of physical fitness is required. 7 hours. 100 NOK.
Max 20 persons.

Trip 4: A guided walk to the historical sites of Bergen. We walk from the conference hotel and look at and listen to the history of places like; Bryggen, Håkonshallen, Rosenkrantzårnet a.o. 2 hours walk , 10 a.m. and 2 p.m. 50 NOK.

Trip 5: A guided tour of the new Bergen aquarium. The aquarium is famous for its collection of invertebrate animals due to the deep intake of clean water. Nice collection of fish from the Norwegian coast and grey and harbour seals. 10 a.m. and 2 p.m. 60 NOK.

Trip 6: Trip to Austevoll. Austevoll is a beautiful archipelago south west of Bergen. We visit the aquaculture station and have lunch at Storebø, the center of the county. 6 hours. 200 NOK. **Max 48 persons.**

Midsummer night

Trip 7: Midsummer night has traditionally been celebrated with bonfires, boat trips and music. This midsummer night we will celebrate together with you in our traditional manner. "Beinveien" will pick us up next to the conference hotel at 7 p.m. and bring us out to Norlandia Marsteinen Fjordhotel. The boat trip will last approx. 1 hour. At the hotel we will be served three different types of grilled fish together with a baked potato and salad. We plan to have a bonfire and listen to music until the boat picks us up again at 1 a.m. The trip back to Bergen should provide us with a beautiful view of all the other boats and bonfires along the shore.

Price for the boat tour and dinner: **185 Nok**
Max 178 persons

Thursday 25 June

1900 Reception at Fløien Folkerestaurant. Host: Bergen Town
2000 Banquet (Fløien Folkerestaurant)

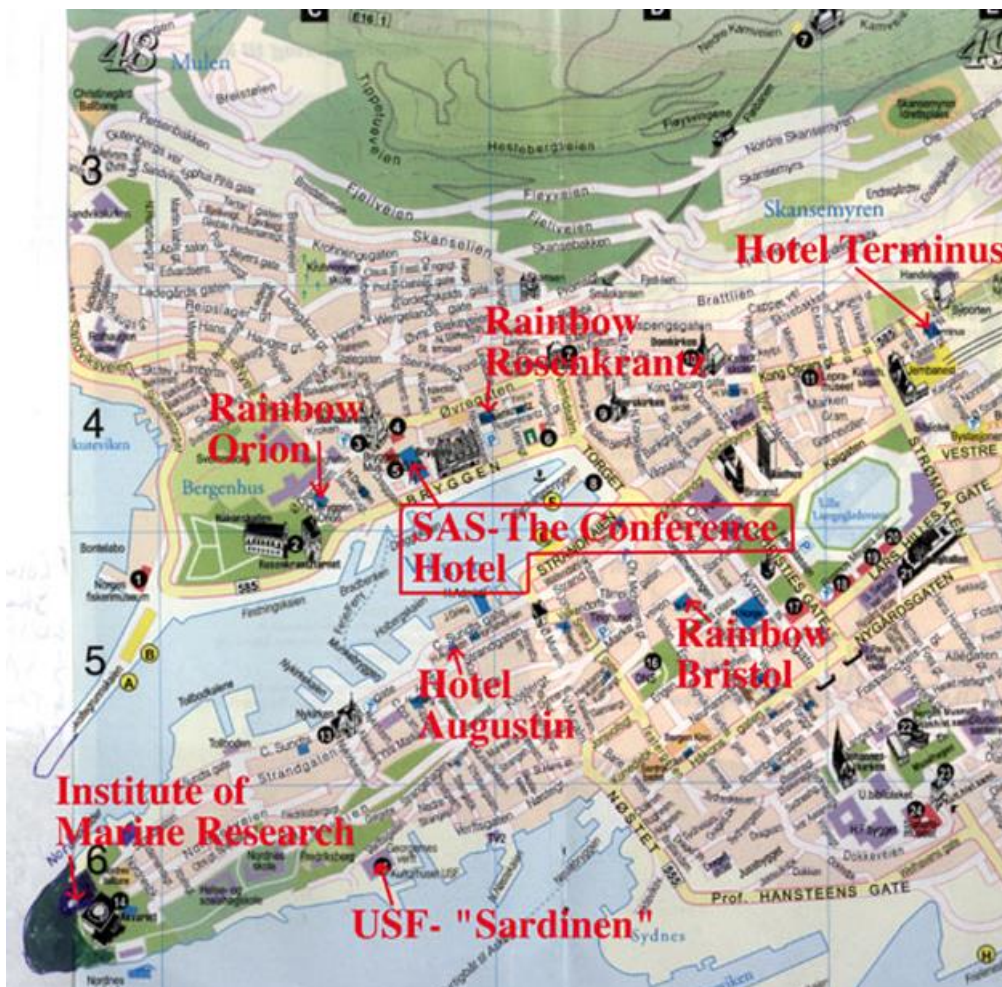
Scientific Programme

Saturday 20 June, 1400-2200

1400-1900 Registration at **Radisson SAS Royal Hotel**, Bergen

1900-2030 Reception at “Sardinen”. Host: University of Bergen

2030 Get-together at “Sardinen”. Music by: "Cajun Gumbo"



* = Key note speakers

Number in brackets = Abstract page number

Sunday 21 June, 0800-1330

0800-0900 Registration at **Radisson SAS Royal Hotel**, Bergen

0830-0900 Opening Symposium at **Radisson SAS Royal Hotel** by **Director Roald Vaage** (Institute of Marine Research). Music by **Bergen Kammerkor**

Session 1. Otolith Physiology and Morphology

Chairman: **Henrik Mosegaard (Denmark)**

0900-0930 **(35) Tomasz Linkowski* (Poland)**: Otolith microstructure of vertically migrating vs. non-migratory mesopelagic fishes

0930-0945 **(36) D.V. Lychakov (Russia)**: Evolution of the otolithic apparatus

1000-1030 Coffee

1030-1045 **(38) Yasuaki Takagi and Akiyoshi Takahashi (Japan)**: Characterization of Otolith Soluble-Matrix Producing Cells in the Saccular Epithelium of Rainbow Trout Inner Ear

1045-1100 **(39) Dana G. Dunkelberger, Jibin Zhao, James J. McGee, and Charles A. Wilson (USA)**: Organic Framework of the Otolith

1100-1115 **(40) Franceschini Gianluca, Crivellari Serena, Bertotto Daniela, Finoia Maria Grazia, and Giovanardi Otello (Italy)**: Influence of temperature and food on otoliths of reared early life stages of sand smelt *Atherina boyeri*

1115-1130 **(41) Miranda E. Waldron and Michael Kerstan (South Africa)**: Age validation in horse mackerel (*Trachurus trachurus*) otoliths

1130-1145 **(42) E. Pizzul, P. Casseti, M. Specchi, S. Vanzo and M. Avian (Italy)**: First observations on otolith morphology of north-easter Italy cyprinids

1145-1200 **(43) Carlos A. Assis (Portugal)**: Fish phylogeny and systematics using otoliths. *Asterisci* and *Lapilli*, the neglected pairs

1200-1215 **(44) P. Payan, A. Edeyer, G. Borelli, H. De Pontual, G. Boeuf and N. Mayer-Gostan (France)**: Heterogeneity of endolymph chemistry in the inner ear of two teleosts (*Oncorhynchus mykiss* and *Psetta maxima*) : relation to otolith growth?

1215-1230 **(45) N. Mayer-Gostan, M. Pizam, A. Edeyer, G. Boeuf, C. Le Moal, A. Rambourg, and P. Payan (France)**: Structure and Ultrastructure of the saccular epithelium in two teleosts: *Oncorhynchus mykiss* and *Psetta maxima*

1230-1330 Lunch

Sunday 21 June, 1330-1745

Session 1. Otolith Physiology and Morphology

Chairman: **Beatriz Morales-Nin (Spain)**

1330-1400 **(46) Sophie G. Dove* (Australia)**: Understanding the black box: Otoliths as environmental monitors

1400-1415 **(47) Pamela Fallon - Cousins, Peter Wright and John Armstrong (UK)**: Experimental determination of the relationships between otolith accretion, metabolism and somatic growth in three species of teleost fish

1415-1430 **(48) Françoise Lagardère, Karine Thibaudeau and Rachid Amara (France)**: Seasonal formation of opaque and translucent zones in sagittal otoliths of the common sole (*Solea solea*) of the Bay of Biscay (France)

1430-1445 **(49) Helge Paulsen (Denmark)**: Eye size related to growth rate and nutritional status in a growth stunted population of the fresh water clupeid *Limnothrissa miodon*

1445-1500 **(50) Alexander Morison (Australia)**: Otoliths and onions! A new model of otolith macrostructure

1500-1515 **(51) A. Edeyer, H. de Pontual, P. Payan, H. Troadec and N. Mayer-Gostan (France)**: Daily variations of saccular endolymph and plasma composition on turbot *Psetta maxima*

1515-1530 **(52) G.J. Torres, A. Lombarte, B. Morales-Nin (Spain)**: Variability of the sulcus acusticus in the sagitta otolith of the genus *Merluccius*

1530-1700 **POSTER SESSION** (Include. Coffee break)

1700-1730 **(53) Arthur N. Popper* (U.S.A.)**: Structure-function relationships in fish otolith organs

1730-1745 **(54) D.G. Dunkelberger (USA)**: Ultrastructure of Otolith Formation - Secretory Activity

Sunday 21 June, 1530-1700

Posters Session

Session 1. Otolith Physiology and Morphology

- (55) **D.V. Lychakov (Russia)**: Otolithic apparatus in Acipenser fry
- (56) **D.V. Lychakov, A. Boyadzhieva-Mikhailova, I. Christov and I.I. Evdokimov (Russia/Bulgaria)**: Otolithic apparatus in Black Sea elasmobranchs
- (57) **D.V. Lychakov (Russia)**: Otolithic apparatus in the adult river lamprey
- (58) **D.V. Lychakov (Russia)**: Anomalous otoliths of Black Sea teleosts
- (59) **D.V. Lychakov and Yu.T. Rebane (Russia)**: The possible role of the otolith shape
- (60) **D.V. Lychakov (Russia)**: Otolith regularities
- (61) **Steven E. Campana (Canada)**: A digital photographic atlas of fish otoliths of the Northwest Atlantic
- (62) **Peter John Wright (Scotland, UK)**: The occurrence, composition and role of otoconia in otolith formation
- (63) **S.M. Kuehner, E.C. Volk, D.M. Greenlee and D.J. Joswiak (USA)**: A multi-analytical investigation into the aragonite-vaterite (CaCO₃) phase transition in otoliths from COHO salmon (*Oncorhynchus kisutch*)
- (64) **M.S. Shevelev (Russia)**: Morphological peculiarities and growth of spotted catfish (*Anarhichas minor* OLAFSEN) otoliths
- (65) **Pablo Abaunza and Blanca Land'n (Spain)**: On the morphometry of horse mackerel, *Trachurus trachurus*, otoliths with comments on growth and current age reading validation
- (66) **P. Conesa, L.J. Lopez Abellan and M.T.G. Santamaria (Spain)**: Morphological variation in otoliths (Sagitta) of *Pondinus kuhlii* (Bowdich), 1825) in relation to size and sex
- (67) **V. Vassilopoulou (Greece)**: Preliminary results on the otolith morphology and microstructure of the flatfish *Lepidorhombus boscii*

- (68) **Alejandra V. Volpedo, and Dinorah D. Echeverría (Argentina):** Morphologic patterns of the *Sagitta* in fishes associated to the bottom of the marine shelf of the mar Argentino
- (69) **G.J. Torres, B. Morales-Nin and A. Lombarte (Spain):** Fractal dimension applied to the study of the morphology of the sagitta otolith
- (70) **N.A. Lepesevich (Russia):** Identification of cod groupings by otolith structure
- (71) **Nicolas Diaz, Jean-Louis Mansot, Laurence Romana, and Max Louis (France):** Study of the otolith marginal daily growth ring building for the yellowtail snapper (*Ocyurus chrysurus*, Lutjanidae)
- (72) **Piotr Czerkies, Celestyn Nagiec and Maria Nagiec (Poland):** Ontogenesis of pike (*Esox lucius*) otoliths
- (73) **Robert M. Cerrato (USA):** What Fish Biologists Should Know About Bivalve Shells
- (74) **A.L. Brown and M.S. Busby (USA):** Walleye Pollock (*Theragra chalcogramma*) During Transformation From the Larval To Juvenile Stage: The Relationship Between Otolith And Osteological Development

Monday 22 June, 0830-1330

Session 2: Estimation of Fish Age and Growth

Chairman: **Arild Folkvord (Norway)**

0830-0900 **(76) Daniel Kimura* (U.S.A.):** Some considerations and methods when analyzing age and growth data

0900-0930 **(77) Beatriz Morales-Nin* (Spain):** Daily increments in otoliths: endogenous versus exogenous growth regulation

0930-0945 **(78) Roy E. Crabtree (USA):** Two examples of difficult-to-age fish from Florida waters: how good are the ages and how biased are the growth parameter estimates?

0945-1000 **(79) Constantina Karlou-Riga (Greece):** Age and growth of Mediterranean horse mackerel, *Trachurus mediterraneus* (Steindachner), in the Gulf of Saronikos Gulf (Greece) - growth in early life associated with different otolith types

1000-1030 Coffee and cakes

1030-1045 **(80) Garry Russ, Dong C. Lou and Stephanie Slade (Australia):** The use of otolith weight to predict age structure of coral trout (*Plectropomus leopardus*) populations on the Great Barrier Reef, Australia

1045-1100 **(81) John D.M.Gordon, Sarah C. Swan and Roger A. Coggan (UK):** Age old problems in deep-water fish growth

1100-1115 **(82) A.V. Dolgov (Russia):** The Use of Prey Otoliths to Check Reliability of Estimates of Commercial Fish Species Consumption by the Barents Sea Cod

1115-1130 **(83) Michael J. Schirripa and Joel C. Trexler (USA):** Effects of Mortality and Gear Selectivity on Back-Calculation Using Simulated Otolith Data

1130-1145 **(84) Arild Folkvord, Geir Blom, Arne Johannessen and Erlend Moksness (Norway):** Growth dependent age estimation in herring (*Clupea harengus* L.) larvae

1145-1200 **(85) Casimiro Quiñonez Velázquez, Reyna Alvarado-Castillo and Roberto Félix-Uraga (México):** Growth and year class size variations of Pacific sardine (*Sardinops sagax caeruleus*) in Bahía Magdalena, Baja California Sur, México

1200-1215 **(86) Robert L. Humphreys, Jr. (USA):** Progress in ageing juvenile Pacific swordfish via sagittal otoliths

1215-1230 (87) **M. Appelberg, E. Kleiven, H. M. Berger, E. Bergstrand, K. Nyberg, R. Saksgård, R.-M. Svensson and C. Ångström (Sweden/Norway/Finland):** Precision and accuracy in ageing eurasian perch (*Perca fluviatilis* L.) and roach (*Rutilus rutilus* L.): Differences between structures and readers

1230-1330 Lunch

Monday 22 June, 1330-1830

Session 2: Estimation of Fish Age and Growth

Chairman: **John Butler (USA)**

1330-1400 **(88) Jacques Panfili* (France)**: Interpretation of otolith structures: old tools, new tools and hopes

1400-1415 **(89) R.J. Beamish and G.A. McFarlane (Canada)**: Retention of oxytetracycline (OTC) marks up to 19 years

1415-1430 **(90) Helge Paulsen (Denmark)**: Use of otolith size to investigate growth rates in turbot *Scophthalmus maximus*

1430-1445 **(91) Simon Robertson and Alexander Morison (Australia)**: The Application of Artificial Neural Networks to Automatic Fish Ageing

1445-1500 **(92) H. Troadec (France)**: Age estimation by digital image processing : some fundamentals

1500-1630 **POSTER SESSION** (Include. Coffee)

1630-1700 **(93) Iain Suthers* (Australia)**: Faster growth is better? Condition and recent otolith growth

1700-1715 **(99) A.H. Andrews, K.H. Coale, and G.M. Cailliet (USA)**: Age and growth of the Pacific grenadier (Family *Macrouridae*, *Coryphaenoides acrolepis*) with age estimate validation using an improved radiometric ageing technique

1715-1730 **(95) C. Clemmesen, T. Doan, C. Hoch and E. Moksness (Germany/Norway)**: How are growth rate and nutritional condition reflected in the otolith structure and RNA/DNA ratio- coupled analysis on herring larvae from the mesocosm

1730-1745 **(96) C. M. Jones (USA)**: Backcalculating size at age: use and misuse in estimating growth

1745-1800 **(97) S. Beauchemin, P. Bose, A. Chalifour, S. Djeziri, F. Nonboud, L. Bouchard and M. Larose (USA/Canada)**: Pattern recognition applied to morphological analysis of daily and annual bands on otoliths: estimation of fish age and growth

1800-1815 **(98) Javier Tomás Olague and Jacques Panfili (UK/France)**: Otolith microstructure examination and growth patterns of *Vinciguerria nimbaria* (Photichthyidae) in the tropical Atlantic Ocean

1930-2130 **Reception at the Institute of Marine Research.** Host: Institute of Marine Research

Monday 22 June, 1500-1630

Posters Session

Session 2: Estimation of Fish Age and Growth

- (100) **Ramesh C. Sharma and Deepak Singh (India)**: Age and growth of *Clarias batrachus* (Linn.) as determined by otolith
- (101) **Miguel Araya and Lilian Martinez (Chile)**: Use of the back-calculation in studies of growth: Case study of the Chilean horse mackerel *Trachurus murphyi* (Caragnidae)
- (102) **Alexander V. Buslov (Russia)**: A comparison of age determination from scales and otoliths for Kamchatkan stocks of walleye pollock (*Theragra chalcogramma*)
- (103) **Marek R. Lipinski (South Africa)**: Ageing squid using statoliths: Noise and some data
- (104) **Michael J. Schirripa (USA)**: An Evaluation of Back-Calculation Methods with Simulated Otolith Data
- (105) **Yves Désaunay, Daniel Guérault and Patrick Grellier (France)**: Validation of daily increments in the otoliths of *Anguilla anguilla* (L.)
- (106) **M. Cardinale, F. Arrhenius and B. Johnson (Sweden)**: Potential use of otolith weight for the determination of the age-structure of cod (*Gadus morhua*) and plaice (*Pleuronectes platessa*)
- (107) **Valeri Vassilkov (Russia)**: Automation ageing of sea marketibal fish
- (108) **María Cristina Cassia(Argentina)**: Age and growth of the southern blue whiting *Micromesistius australis* in the Argentine Sea.
- (109) **Shinsuke Morioka and Analia R. Giussi (Argentina)**: Otolith daily increments and growth of 0 year-old of *Macruronus magellanicus*, and first annuli formation, in Argentine waters.
- (110) **L.Vigliola and M. Harmelin-Vivien (France)**: Backcalculation of fish length and planktonic larval duration from marks on otoliths: validation of methods for three *Diplodus* species in the Mediterranean sea
- (111) **J.M. Lorenzo and J.G. Pajuelo (Spain)**: Age and growth of black seabream *Spondyliosoma cantharus* off the Canary Islands, Central-east Atlantic

- (112) **J.G. Pajuelo and J.M. Lorenzo (Spain)**: Growth of axillary seabream *Pagellus acarne* off the Canary Islands, Central-east Atlantic
- (113) **Jan Eklund, Raimo Parmanne and Gunnar Aneer (Finland/ Sweden)**: On the uncertainty of herring otolith ages
- (114) **Reiner Eckmann and Hannu Huuskonen (Germany/Finland)**: The influence of light period and feeding frequency on the distinctness of daily otolith increments in larval coregonids (*Coregonus* spp.)
- (115) **Volker Köchlin and Reiner Eckmann (Germany)**: Fluorochrome marking of embryo otoliths with Alizarin Red S
- (116) **Yasuji Masuda (Japan)**: Age and Growth of Flathead *Platycephalus* sp. from the Coastal Waters of West Kyushu, Japan
- (117) **R.J. Allman, C.B. Grimes, C.C. Koenig and F.C. Coleman (U.S.A.)**: The temporal and spatial dynamics of spawning, settlement and growth of the gray snapper (*Lutjanus griseus*) determined using otolith microstructure
- (118) **Pedro Bordalo Machado and Ivone Figueiredo (Portugal)**: A new ageing technique for Birdbeak dogfish (*Deania calcea* Lowe, 1839) dorsal spines
- (119) **Franceschini Gianluca, Pranovi Fabio, Crivellari Serena, Angela Granzotta, and Torricelli Patrizia (Italy)** : First observations on otoliths of grass goby populations in Venice Lagoon
- (120) **María Cristina Cassia (Argentina)**: Otolith daily increments and first annuli formation of *Micromesistius australis* in the Argentine sea
- (121) **G.M. Pilling, R.S. Millner, M.W. Easey, C.C. Mees, S. Rathacharen, R. Azemia (UK/Mauritius/Seychelles)**: Validation of annual growth rings in the otoliths of the lutjanids *Pristipomoides filamentosus* and *Aprion virescens*, and the lethrinid *Lethrinus mahsena*, from sites in the tropical Indian Ocean
- (122) **Miguel Araya, Luis A. Cubillos and A. Sepúlveda (Chile)**: Evidence of the relationship weight of otolith age for the Chilean horse mackerel *Trachurus murphyi* (Carangidae)
- (123) **Luis A. Cubillos, Claudio Pino, Aquiles Sepúlveda and Miguel Araya (Chile)**: Growth of the Chilean hake (*Macruronus magellanicus* L.) of the Center-South Chile using otolith weight-age relationship
- (124) **Dariusz P. Fey (Poland)**: Growth rate, hatching-date distribution and otolith microstructure of larval and juvenile spring-spawning herring (*Clupea harengus* L.) from the Vistula Lagoon, Baltic Sea

- (125) **José Eduardo Rebelo, Lúcia Pombo and Anabela Ferreira (Portugal):** Age and growth of dominant fish species in the Ria de Aveiro (Portugal)
- (126) **M.T.G. Santamaria, L.J. Lopez Abellan and P. Conesa (Spain):** Age determination and growth of *Pontinus kuhlii* (Bowdich, 1825) in the Canary Islands
- (127) **Françoise Lagardère, Karine Thibaudeau, Gilles Boeuf and Jean-Yves Lafaye (France):** Sex-related variations in growth of juvenile turbot
- (128) **Gianmarco Silva David and Carmen Lucia Del Bianco Rossi (Brasil):** Age and Growth of *Cynoscion guatucupa* and *Cynoscion jamaicensis* (Teleostei, Sciaenidae) in the Continental Shelf of Ubatuba, Brazil (23°S 45°W) through Analysis of Thin Slices of Otoliths.
- (129) **Simon Robertson, David Smith and Alexander Morison (Australia):** The application of bootstrap and randomization tests to Fourier analysis of otolith shape for stock discrimination in orange roughy *Hoplostethus atlanticus*
- (130) **H. Troadec, A. Benzinou, H. de Pontual, V. Rodin, and J. Le Bihan (France):** Time-frequency representation : application to individual growth estimation
- (131) **H. Troadec, A. Benzinou, V. Rodin and J. Le Bihan (France):** Use of deformable models for otolith 2D growth ring detection by digital image processing : application to plaice (*Pleuronectes platessa*) otolith
- (132) **H. de Pontual, H. Troadec and A. Ogor (France):** Attempts to validate otolith microstructure periodicity for deep sea fish age estimation
- (133) **H. Troadec and H. de Pontual (France):** A simple otolith 3D reconstruction technique from serial sections
- (134) **Enric Massutí, Beatriz Morales-Nin and Joan Moranta (Spain):** Growth variability of rockfish, *Helicolenus dactylopterus* (Osteichthyes: Scorpaenidae), in two Western Mediterranean areas: Alboran Sea and Balearic Sea
- (135) **E. Rodríguez-Marín, E., M. Ruiz and A. Sarasúa (Spain):** Validation of roughhead grenadier (*Macrourus berglax*) otoliths reading
- (136) **M. Labropoulou, G. Petrakis and C. Papaconstantinou (Greece):** Comparison of otolith growth and somatic growth in two macrourid fishes
- (137) **Teresa Moreno and Beatriz Morales-Nin (Spain):** Growth of silversides *Atherina presbyter* of the Canary Islands determined by daily growth increments in sagitta otholiths
- (138) **Alexandra Silva (Portugal):** On the age and growth of john dory (*Zeus faber*, L.) in the Portuguese waters

- (139) **Susana Godinho and Alexandra Silva (Portugal)**: The growth of blue whiting (*Micromesistius poutassou*) off the Portuguese coast
- (140) **Jacob P. Kritzer (Australia)**: Local Variation in Growth of the Stripey Bass, *Lutjanus carponotatus* (Lutjanidae), Among the Palm Islands, Great Barrier Reef
- (141) **Frederico Werneck Kurtz and Yasunobu Matsuura (Brasil)**: Age and growth of Brazilian sardine (*Sardinella brasiliensis*) larvae along southeastern Brazilian bight
- (142) **Douglas H. Adams (USA)**: Validation of daily increment formation in saggital otoliths of juvenile anadromous alewives, *Alosa pseudoharengus*
- (143) **S. Madasamy, M. Narayanan and L. Ramalingam (India)**: Otolith measurements: A cue to age determination in *Aplocheilus lineatum* (Valenciennes) (pisces : Cyprinodontidae)
- (144) **L. Ramalingam, M. Narayanan and S. Madasamy (India)**: Otolith length weight relationship for age determination in *Pomodasys maculatus* (Bloch 179) (Pisces:Haemulidae)
- (145) **Brigid Kerrigan (Australia)**: The effects of environmental factors on larval growth dynamics in tropical reef fisheries
- (146) **R. Kishore, A. Richardson-Drakes and H. Ramsundar (West Indies)** Preliminary Age Determinations of Tropical Fish Species from the Caribbean
- (147) **Robert G. Titus (USA)**: Individual growth rates of juvenile chinook salmon in the lower american river, California, USA: Back calculation using otoliths
- (148) **Erica J. Burton, Allen H. Andrews, Kenneth H. Coale, and Gregor M. Cailliet (USA)**: Application of the radiometric ageing technique using ^{210}Pb : ^{226}Ra disequilibria in calcified structures of two long-lived fishes: Atlantic tarpon (*Megalops atlanticus*) and Atlantic sturgeon (*Acipenser oxyrinchus*)
- (149) **S.H.L. Schwamborn and B.P. Ferreira (Brazil)**: Age, growth and reproductive aspects of a small pomacentrid fish (*Stegastes fusus* Cuvier, 1830) from Tamandaré reefs, Pernambuco, Brazil
- (150) **Jasper Lament (U.S.A.)**: Growth differences between introduced populations of *Cichlasoma urophthalmus* based on otolith mass
- (151) **Suwarso and Jacques Panfili (Indonesia/ France)**: Validation of microstructure deposition rates on otoliths of the small pelagic fishes of the Java Sea, Indonesia
- (152) **R. Kishore and L. Martin (West Indies)**: Age and Growth Studies of the Spanish mackerel, *Scomberomorus brasiliensis* (Family: Scombridae) in coastal waters of Trinidad.

- (153) **Rafael Duarte and Manuela Azevedo (Portugal)**: Effects on age determination and back-calculation of total length of *Lophius spp.* based on both cut position of *Illicia* section and growth ring determination
- (154) **Peer Doering, Stellan F. Hamrin, Alexander Sasov, Michael Schatz, Dirk van Dyck, Marin van Heel, Håkan Wickström and Enrico Arneri (Sweden/Belgium/Germany/ England/Italy)**: A non destructive technique for the three dimensional reconstruction of fish otoliths
- (155) **Werner Ekau and John Blay (Germany)**: Validation of increment deposition and early development in the otoliths of the west african lagoon Tilapia, *Sarotherodon melanotheron*
- (156) **F. Colloca, P. Gentiloni, A. Belluscio, G.D. Ardizzone (Italy)**: Age and growth of Mediterranean hake (*Merluccius merluccius*) in the Central Mediterranean Sea
- (157) **M. Al-Hossaini, S. Al-Youb, A. Al-Baz, and J. Dashti (Kuwait)**: Age and Growth of Some Important Fish Species from Kuwait's Waters
- (158) **Sonia B. Arrieta, Marma Elena Maguina (Peru)**: Age determination of the peruvian anchoveta *Engraulis ringens* by means of annual rings and otolith weight
- (159) **Arne Johannessen, Geir Blom and Arild Folkvord (Norway)**: Differences in otolith and somatic growth between spring and autumn spawned herring (*Clupea harengus* L.) larvae
- (160) **George D. Jackson (Australia)**: What statolith ageing is revealing about squid growth
- (161) **Erling Kåre Stenevik and Petter Fossum (Norway)**: Age and growth from otoliths of Cape anchovy (*Engraulis capensis*) in relation to physical and biological properties of Angola-Benguela waters
- (162) **Terje van der Meeren and Erlend Moksness (Norway)**: Growth and mortality patterns evaluated from otolith microstructure in cod (*Gadus morhua* L.) larvae reared at different feeding regimes in mesocosms
- (163) **T. Ramírez, D. Cortés, and A. García (Spain)**: Otolith growth and somatic growth measured by DNA, RNA and protein content in field-collected Mediterranean sardine larvae
- (164) **Jen-chieh Shiao, Chieh-Lun Leu, Feng-Chi Chen, Chyng-shyan Tzeng (Republic of China)**: A novel means of identifying daily growth increments in otolith of fish by Proteinase K

Demo and Workshop

Session 2: Estimation of Fish Age and Growth

(165) H. Troadec and M. Vinot (France): Visilog/TNPC 3.0, a computer assisted age reading software

(166) John M. Casselman (Canada): A System (CSAIS) and Software (CSAGES) for Quantifying and Computerizing Growth and Age Interpretation of Fish from Their Otoliths

Wednesday 24 June, 0900-1315

Session 3: Otoliths in Studies of Populations

Chairman: **Audrey Geffen (UK)**

0900-0930 **(168) R. Christopher Chambers* and David A. Witting (U.S.A.):** Phenotypic reconstruction from otolith information: inferring size, growth, and history

0930-0945 **(169) P.J. Wright, I.M. Gibb, J.R.G. Hislop, F.M. Kennedy and W.M. MacDonald (Scotland, UK):** Use of birth date analysis to examine the significance of protracted spawning to reproductive success of haddock *Melanogrammus aeglefinus* in the North Sea

0945-1000 **(170) R.J. Beamish and Z. Zhang (Canada):** Biology of Ocean Age 0 Hatchery, Wild Ocean, and Wild Stream Type Chinook in the Strait of Georgia

1000-1030 Coffee

1030-1045 **(171) Peter Munk and Jan Beyer (Denmark):** The variability in daily growth rate of larvae from different environmental regimes

1045-1100 **(172) G.A. McFarlane and R.J. Beamish (Canada):** The relationship between longevity of sablefish, *Anoplomoma fimbria*, and ocean productivity regimes

1100-1115 **(173) Tomasz B. Linkowski and Dirk Nolf (Poland/Belgique):** Microstructural patterns in fossil otoliths of mesopelagic fishes (family Myctophidae) - a new tool to study Tertiary ichthyocenoses

1115-1130 **(174) Shawn P. Good and Julian J. Dodson (Canada):** Annual Variation in Size-Selective Mortality of 0+ Atlantic Salmon (*Salmo salar*) Alevins : Evidence from Otolith Microstructure

1130-1145 **(175) Charles A. Wilson and Jose Noguera (USA):** Temporal Changes in Fish Growth and Otolith Composition As Determined Using Otoliths from Indian Middens

1145-1200 **(176) Douglas J. Ferrell (Australia):** Validation of annual ageing and sources of ageing error in 5 coastal marine finfish from NSW, Australia

1200-1315 Lunch

Wednesday 24 June, 1315-1845

Session 3: Otoliths in Studies of Populations

Chairman: **Sandy McFarlane (Canada)**

1315-1345 **(177) Kevin M. Bailey*, A.L. Brown and S.J. Picquelle (USA):** Population dynamics of larval walleye pollock, *Theragra chalcogramma*, in the Gulf of Alaska

1345-1400 **(178) A.J. Fowler (Australia):** A spatial and temporal comparison of early life-history characteristics for a marine finfish species from southern Australia, based on otolith microstructure

1400-1415 **(179) C.H. Wang, W.N. Tzeng and G.R. Williamson (Republic of China/Scotland, UK):** A comparison of the larval lives of *Anguilla rostrata* and *A. anguilla* eels as revealed by examination of otoliths of glass eels collected from eleven locations around the Atlantic Ocean

1415-1430 **(180) Michael Kerstan (South Africa):** Estimation of precise ages from marginal increment widths

1430-1445 **(181) John T. Anderson and Edgar L. Dalley (Canada):** Interannual Differences in Time of Spawning and Growth Rates of Pelagic Juvenile Cod in Newfoundland Waters

1445-1500 **(182) Peter Hagen, Jim Blick, Richard Berning and Kristen Munk (USA):** Assessing the reliability of thermally-marked otolith classifications in the management of mixed stock fisheries

1500-1630 **POSTER SESSION** (Include. Coffee)

1630-1700 **(183) Eric C.Volk* (U.S.A.):** Bar codes and micro-beams: Using otolith structural and chemical attributes to monitor salmonid populations

1700-1715 **(184) Simon Hickenbotham, Peter Hagen, Richard Berning and Edwin Hancock (England/USA):** Application of computer vision and texture discrimination to identify thermal marked salmon otoliths

1715-1730 **(185) Douglas A. DeVries and Churchill B. Grimes (USA):** Using otolith shape analysis to distinguish eastern Gulf of Mexico from Atlantic Ocean stock king mackerel *Scomberomorus cavalla*

1730-1745 **(186) Dean L. Courtney, Donald G. Mortensen, and Joseph A. Orsi (USA):** Recovery of Thermally-induced Otolith Marks for Origin Identification of

Juvenile Pacific Salmon Released from Hatcheries in the Marine Waters of Southeastern Alaska

- 1745-1800 **(187) M. G. White and others (UK)**: Age determination in high-Antarctic fish
- 1800-1815 **(188) Carmen Lucia Del Bianco Rossi-Wongstchowski, Catriona Clemmesen, June Ferraz Dias and Bernd Ueberschar (Brazil/Deutschland)**: Larval growth and condition of *Sardinella brasiliensis* (Steindachner, 1879) in Brazilian waters
- 1815-1830 **(189) Peter Horn (New Zealand)**: Between-area differences in age and length at first maturity of orange roughy (*Hoplostethus atlanticus*) based on a transition zone in otoliths
- 1830-1845 **(190) M.A. Martinez-Cuapio and M.G. Hammann (Mexico)**: Age and growth of the juvenile Pacific sardine *Sardinops sagax* and its influence on the population growth rate in the northwestern zone of Baja California, Mexico, during the summer of 1994

Wednesday 24 June, 1500-1630

Posters Session

Session 3: Otoliths in Studies of Populations

- (191) **Pavel K. Gudkov (Russia)**: Otoliths of anadromous chars reflect their first smoltification
- (192) **Mortensen and Alex Wertheimer (USA)**: Detecting Stray Auke Creek Pink Salmon Using Coded-Wire Tags and Thermally Induced Otolith Marks
- (193) **P.J. Wright and F. M. Kennedy (Scotland, UK)**: Growth-dependent and size-selective mortality in 0-group haddock *Melanogrammus aeglefinus* (L.)
- (194) **Rachid Amara, Françoise Lagardère and Christophe Maryniak (France)**: Geographical and interannual growth comparison of O-group sole, *Solea solea* (L.)
- (195) **Enrico Arneri, Fortunata Donato and Gianfranco Giannetti (Italy)**: Growth of juvenile anchovy, *Engraulis encrasicolus*, in Central Adriatic Sea
- (196) **Garry Russ, Dong C. Lou and Stephanie Slade (Australia)**: The use of otolith weight to predict age structure of coral trout (*Plectropomus leopardus*) populations on the great Barrier Reef, Australia
- (197) **K.V. Drevetnyak (Russia)**: Investigations of Growth of Deep-Sea Redfish (*Sebastes mentella* Travin) From the Norwegian-Barents Sea Population
- (198) **J. Fargo and S.E. MacLellan (Canada)**: Daily growth and time of settlement in juvenile English sole (*Pleuronectes vetulus*) in Hecate Strait, British Columbia
- (199) **V. Vasilykov (Russia)**: Use of Geothermal Energy to otolith mark Chinook salmon and Sockeye salmon hatchery, Kamchatka, Russia
- (200) **Vudhichai Janekarn and Peter Munk (Thailand/Denmark)**: Growth rate variation of tropical fish larvae across frontal structures in the Andaman Sea
- (201) **J. M. Casas and C. Piñeiro (Spain)**: Growth and age estimation of Greater Fork-bear (*Phycis blennoides* Brünnich, 1768)
- (202) **N.V. Dolgova (Russia)**: Methods of Age Identification and Size-Age Structure of the Barents Sea Long Rough Dab (*Hippoglossoides platessoides*)

- (203) **Paz Jimenez, C. Piñeiro, I. Sobrino, and F. Ramos (Spain):** Study on growth and age determination of *Dicologlossa cuneata* (Moreau, 1881) in the south atlantic spanish region (gulf of Cádiz).
- (204) **A. Lopez Cazorla (Argentina):** Age structure of the population of weakfish *Cynoscion guatucupa* (Cuvier) in the Bahia Blanca waters, Argentina
- (205) **Federico Alvarez, Francisco Alemany and Paolo Merella (Spain):** Comparison of daily growth rates among winter spawned Mediterranean and winter and spring spawned Atlantic *Sardina pilchardus* (Walbaum, 1792) recruits
- (206) **A.R. Giussi, D. Hernandez and V. Abachian (Argentina):** Differences in growth of long tailed hake (*Macruronus magellanicus*) from several areas of Southwestern Atlantic Ocean
- (207) **Charles A. Wilson and Peggy B. Hebert (USA):** The Significance of Sedimentary Otoliths Around an Artificial Reef: the El' Cazador of 1784
- (208) **Chin - Wei Chang, Wann - Nian Tzeng, Ying - Chou Lee (Taiwan, R. O. C.):** Daily age, growth and the backcalculated hatching dates of juvenile grey mullets *Mugil cephalus* in the northwestern coast of Taiwan as revealed from otolith microstructure
- (209) **Brian E. Luckhurst, John Mark Dean and Marcel Reichert (Bermuda/USA):** Age and growth of lane snapper
- (210) **Henn Ojaveer (Estonia):** Discrimination of eelpout, *Zoarces viviparus* L., ecological groups by their sagittal otoliths in the Gulf of Riga (Baltic Sea)
- (211) **Tomasz P. Herra, Joel K. Elliott and W.C. Leggett (Canada):** Estimation of Hatch Periods, Growth Rates, and Subsequent Survival of Yellow Perch, *Perca flavescens*: Otolith microstructure examination
- (213) **N.B. Barros (USA):** Bottlenose dolphin population differentiation in east Florida, USA, using fish otoliths from dietary studies
- (214) **Campbell R Davies and Jacob P Kritzer (Australia):** Estimating growth of tropical reef fish: a comparison of size at age and growth increment methods for the stripey bass, *Lutjanus carponotatus*.
- (215) **Eric Graynoth (New Zealand):** Improved otolith preparation, ageing and backcalculation techniques for New Zealand freshwater eels
- (216) **Karl A. Aiken (Jamaica, W.I.):** Age, growth and reproduction of the Lane snapper, *Lutjanus synagris* (Linnaeus) in Jamaica, West Indies
- (217) **M.E. Quintero, M.T.G. Santamaría and E. Balguerías (Spain):** Age and growth of *Plectorhinchus mediterraneus* from north west Africa

- (218) **David S Peters, Lawrence R Settle and Elisabeth Laban (U.S.A.):** Growth and estimated hatch dates of juvenile Great Barracuda (*Sphyraena barracuda*) collected from adjacent but ecologically distinct habitats
- (219) **Melissa J. Neuman, David A. Witting and Kenneth W. Able (USA):** Overwinter age and growth of juvenile windowpane, *Scophthalmus aquosus*, in the Middle Atlantic Bight, USA
- (220) **V. Bühler, C. Clemmesen, G. Joakimsson and V. Kistowski (Germany):** Comparison of otolith microstructure of two stocks of larval herring (Orkney-Shetland & English Channel) in the period 1991-1997
- (221) **J.C. Potts (USA):** Comparison of Two Age and Growth Studies and the Effect on Spawning Potential Ratio Values
- (222) **Fran Saborido-Rey (Spain):** Differences in otolith weight and length among populations of genus *Sebastes* in the North Atlantic
- (223) **Yoshiro Watanabe, John L. Butler, and Motomitsu Takahashi (Japan/ USA):** Growth differences of larval and juvenile small pelagics between the Kuroshio and California current systems
- (224) **Jerzy Kuczynski and Tomasz Heese (Poland):** Age and growth of lumpfish (*Cyclopterus lumpus* L.) occurring in the southern part of the Baltic Sea, based on investigations of otoliths
- (225) **Dianne M. Tracey and Ian J. Doonan (New Zealand):** Estimate of natural mortality for New Zealand orange roughy (*Hoplostethus atlanticus*)
- (226) **Maria Nagiec, Piotr Czerkies, Eugenia Murawska and Roman Kujawa (Poland):** Mass-marking of whitefish (*Coregonus lavaretus*) larvae by thermally induced otolith banding pattern
- (227) **Scott A Holt, G. Joan Holt, and Jay R. Rooker (USA):** A comparison of growth rates of co-occurring Atlantic croaker and red drum (*Sciaenidae*) larvae in South Texas seagrass meadows
- (228) **N. Yaragina, K.H. Nedreaas, H. Mjanger, V. Koloskova and P. Ågotnes (Russia/Norway):** Differences in age determination of Northeast Arctic cod. Consequences and improvements through regular exchange of material and personell
- (229) **P. Ågotnes, H. Mjanger and K.Nedreaas (Norway):** Classification of cod from different nursery areas in the Northeast Arctic by otoliths
- (230) **Gene R. Wilde and T. H. Bonner (USA):** Use of Otoliths to Determine Spawning Periodicity and Requirements in the Arkansas River Shiner, *Notropis girardi*

- (231) **M.G. Meekan and D.A.J. Ryan (Australia)**: Does mortality select size or growth potential in young sockeye salmon (*Oncorhynchus nerka*)? A simulation based on otolith-fish size relationships
- (232) **R. Lecomte-Finiger, Budimawan (France)**: The early life history of three species of Indo-Pacific eels *Anguilla marmorata*, *A. bicolor bicolor*, *A. nebulosa nebulosa* revealed from their sagittae and lapilli
- (233) **R. Romans and R. Lecomte-Finiger (France)**: Larval duration and oceanic growth of tropical reef fishes in French Polynesia: effect of the moon phase on larval stage duration
- (234) **R.L. Allen, B.A. Thompson, and J.H. Render (USA)**: Age and Growth Rate Comparisons on a Natural and Impounded Population of Striped Mullet
- (235) **Kirsten Dau, Richard D.M. Nash and Audrey J. Geffen (Germany/UK)**: Settlement pattern of 0-group plaice, *Pleuronectes platessa*, determined by otolith microstructure
- (236) **C. Skov, P. Grønkjær and S. Berg (Denmark)**: Growth and mortality of stocked and native young-of-the-year Northern Pike (*Esox lucius* L.)
- (237) **Peter Horn and Thomas Higham (New Zealand)**: Fish otoliths as seasonal indicators in prehistory
- (238) **Chyng-Shyan Tzeng (R. O. China)**: Variable freshwater recruitment and duration at the estuary before upstream migration in the amphidromous goby *Rhinogobius gigas* in Eastern Taiwan
- (239) **A.D. Rijnsdorp, W.J. Van Neer, R.S. Millner, L.J. Bolle, P. De Smedt, P.I. van Leeuwen and D. Delbare (The Netherlands/Belgium/UK)**: Diachronic changes in growth rate of North Sea fish species in relation to anthropogenic activities
- (240) **Edward V. Farley, Jr., H. Richard Carlson, Richard E. Haight, John H. Helle, and Kristen Munk (USA)**: Incidence of Thermally Marked Pink, Chum, and Sockeye Salmon in the Coastal Waters of the North Pacific Ocean and Eastern Bering Sea
- (241) **H.Tuncay Kinacigil, Okan Akyol, Hikmet Hossucu, Gülnur Metin and Adnan Tokaç (Turkey)**: A systematic preliminary study on Sparidae (pisces) employing otolith characters in the bay of Izmir (Aegean sea)
- (242) **Chieh-Lun Leu, Jen-chieh Shiao, Chyng-shyan Tzeng (Republic of China)**: Recruiting variation and the early life history of *Anguilla marmorata*: migrating from the spawning ground to the northern boundary, Taiwan

Thursday 25 June, 0830-1315

Session 4: Otolith Composition

Chairman: **Steve Campana (Canada)**

0830-0900 **(244) John Kalish* (Australia)**: A glance at 50,000 years of otoliths

0900-0915 **(245) Norman M. Halden, Sergio R. Mejia, John A. Babaluk, James D. Reist, Allan H. Kristofferson, John L. Campbell and William J. Teesdale (Canada)**: Oscillatory Zinc distribution in Arctic char (*Salvelinus alpinus*) otoliths: the result of fish behaviour or environmental feedback?

0915-0930 **(246) Craig R. Kestelle, Daniel K. Kimura, and Shelly Jay (USA)**: Using Pb-210/Ra-226 disequilibrium age validation in rockfish (genera *Sebastes* and *Sebastolobus*)

0930-0945 **(247) Karin E. Limburg (Sweden)**: Juvenile out-migration events as recorded in adult otoliths: American shad (*Alosa sapidissima*) in the Hudson River, New York USA

0945-1000 **(248) Rudolf Kafemann, James Edward Finn, and Sara Adlerstein (Germany/USA)**: Variation in otolith strontium and calcium ratios as indicator of life-history strategies of freshwater fish species within a brackishwater system

1000-1030 Coffee

1030-1045 **(249) Christian E. Zimmerman and Gordon H. Reeves (USA)**: Utility of Otolith Microchemistry in Ecological Studies of Resident and Anadromous *Oncorhynchus mykiss*

1045-1100 **(250) Christopher R. Weidman and Richard Millner (USA/UK)**: High-Resolution Stable Isotope Records from North Atlantic Cod

1100-1115 **(251) William P. Patterson (USA)**: Life-history and paleoclimate: high-resolution records stored in otoliths

1115-1130 **(252) Gavin A. Begg (USA)**: The utility of whole otolith elemental approaches for stock identification - the need for complementary techniques

1130-1145 **(253) Michael J. Kingsford and Bronwyn M. Gillanders (Australia)**: Do microconstituents of otoliths vary with depth in which fish are collected?

1145-1200 **(254) John S. Gunn, Naomi P. Clear, John Kalish, and Jessica Farley (Australia)**: Validation of the annual formation of growth increments in the

otoliths of Southern Bluefin Tuna (*Thunnus maccoyii*) through a large-scale strontium chloride marking experiment and bomb-radiocarbon chronometry

1200-1215 **(255) H.P. Schwarcz, Y.-W. Gao, S. Campana, and U. Brand (Canada):**
Variations in stable isotope ratios of carbon and oxygen in otoliths of cod (*Gadus morhua*) from Atlantic Canada

1215-1315 Lunch

Thursday 25 June, 1315-1800

Session 4: Otolith Composition

Chairman: **Wann-Nian Tzeng (Taiwan)**

1315-1345 **(256) Steve Campana* (Canada)**: Otolith elemental fingerprints as biological tracers of fish stocks

1345-1400 **(257) Peter J. Hanson and Vincent S. Zdanowicz (USA)**: Perspective on Regulation of Trace Metal Composition in Fish Otoliths

1400-1415 **(258) H. de Pontual, F. Lagardère, H. Troadec. and Y. Désaunay (France)**: Discrimination between two nurseries of the common sole (*Solea solea*) of the Bay of Biscay (France) from otolith trace element using ICPMS and LA-ICPMS analyses

1415-1430 **(259) Simon Chenery and David Milton (UK/Australia)**: Determination of Trace Elements in Fish Otoliths by Laser Ablation MicroProbe - Inductively Coupled Plasma - Mass Spectrometry

1430-1600 POSTER SESSION (Include. Coffee)

1600-1630 **(260) Simon Thorrold* (U.S.A.)**: Can variability in coastal ocean environments be accurately reconstructed from the carbon and oxygen isotope composition of fish otoliths?

1630-1700 **(261) David Secor* (U.S.A.)**: Is otolith strontium a useful scalar of life-cycles in estuarine fishes?

1700-1740 Summing by Session Chairmens; Synthesis and future directions

1740-1800 Awards - closing remarks

1900 **Reception at Fløien Folkerestaurant. Host: Bergen Town**

2000 **Banquet (Fløien Folkerestaurant)**

Thursday 25 June, 1430-1600

Posters Session

Session 4: Otolith Composition

- (262) **D.V. Lychakov and E.A. Lavrova (Russia):** Na, K, Ca, and Mg in otoliths and otoconia of vertebrates
- (263) **David Milton, Simon Chenery, and Stephen Blaber (Australia/United Kingdom):** Comparisons of the otolith elemental fingerprints of three species of tropical shad (*Tenualosa* spp.) and their value for defining stock structure in each species
- (264) **Steven E. Campana, Cynthia M. Jones and D. Bruce Atkinson (Canada/USA):** Use of radiocarbon from nuclear testing as a dated marker in the otoliths of three North Atlantic fish species
- (265) **M. Renzi, B. Santos, A. Barral and R. Roth (Argentina):** Application of otolith microchemistry analysis in hake (*Merluccius hubbsi*)
- (266) **John A. Babaluk, James D. Reist, Eric C. Gyselman, Norman M. Halden, Sergio R. Mejia, John L. Campbell and William J. Teesdale (Canada):** Validation of the use of otolith strontium distribution for determining migratory behaviour of Arctic char (*Salvelinus alpinus*) using tag-recaptured fish
- (267) **W. N. Tzeng, K. P. Severin, H. Wickstrøm and C. H. Wang (Republic of China/ USA/Sweden):** High strontium bands in otolith of European eel *Anguilla anguilla* (L.) - An alternative method of age determination
- (268) **Christopher Wurster and William P. Patterson (USA):** Advances in computer-controlled microsampling of otoliths for stable isotope and elemental analyses
- (269) **E. S. Rutherford, S. Thorrold, S. E. Campana and David R. Swank (USA/ Canada):** Analysis of Stock Differentiation in Lake Michigan Steelhead Using Otolith Trace Element Composition
- (270) **Lee M. Paramore and Roger A. Rulifson (USA):** Investigation of the blackback-greenback phenomenon in Striped bass, *Morone saxatilis*, populations of Atlantic Canada
- (271) **Vincent S. Zdanowicz, Peter J. Hanson, and David H. Secor (USA):** Elemental Composition of Otoliths of Fish from the Northwest Atlantic and Gulf of Mexico

- (272) **G.E.Bath, S.R. Thorrold, and C.M. Jones (U.S.A.):** Age, growth, and otolith trace metal analyses of fall and winter recruiting Atlantic croaker (*Micropogonias undulatus*)
- (273) **Tanaka, Taro Ohta and David Secor (Japan/USA):** Freshwater entry of Japanese sea bass juveniles : amphidromous migration or accidental immigration
- (274) **Mohammed Rabbani and Katayoon Karimzadeh (Iran):** Molluscus of Khor-e-Musa as Oil Pollution Bio-indicator
- (275) **John M. Kalish, Reidar Nydal, Kjell Nedreaas, G. S. Burr (Australia/Norway/USA):** A Time History of Pre- and Post-Bomb Radiocarbon in the Barents Sea Derived from Arcto-Norwegian Cod Otoliths
- (276) **D.E. Hay and J. Carolsfeld (Canada):** Elemental analysis of eulachon (*Thaleichthys pacificus*) otoliths indicates partial homing fidelity to spawning grounds
- (278) **John Gunn, Craig Proctor and Naomi Clear (Australia):** Daily and seasonal cycles in the concentration of strontium and other major constituents of tuna otoliths are primarily related to growth rather than temperature
- (279) **Julian Ashford (USA):** Retroactive determination of stock structure and movement-at-age in Patagonian Toothfish through laser-based elemental analysis of otoliths

Abstracts

Session 1:

Otolith Physiology and Morphology

Invit. 1

2nd International Symposium on
Fish Otolith Research and Application
Radisson SAS Royal Bryggen Bergen
20 - 25 juni 1998

Otolith microstructure of vertically migrating vs. non-migratory mesopelagic fishes

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Abstract

Otoliths of numerous species representing two families of mesopelagic fishes (Myctophidae and Sternoptychidae) were studied to assess the impact of their habitat and behaviour on otolith microstructure. Most of the otoliths of vertically migrating species were characterised by a clear incremental structure while those of the species known as non-migrants showed a distinctive incremental pattern in the otolith central part only, deposited during the larval stage, which disappeared abruptly or gradually shortly after metamorphosis. A similar shift in the otolith microstructure was also characteristic for these vertical migratory species that temporarily do not migrate. The growth increments deposited in their otoliths during a non-migratory behaviour were very faint, narrow and hardly detectable, suggesting a slowdown of otolith and somatic growth. The simplest explanation of such an otolith microstructure would be the influence of environmental factors, i.e. a temperature shift during a diurnal vertical migration versus constant, low temperature at greater depths. However, otoliths of vertically migrating fish from the Mediterranean and Red Sea, both basins being almost homothermic, showed similar, well-defined incremental structure as had those from vertically stratified waters. This suggests a dominant role of endogenous factors on otolith growth and microstructure rather than external ones, e.g. temperature.

Contribution: 4

2nd International Symposium on
Fish Otolith Research and Application
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20 - 25 juni 1998

Evolution of the otolithic apparatus

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Abstract

The available data suggest that the otoconia appeared first in phylogenetic development of the vertebrates. Otoconia present in all groups of vertebrates with the exception of adult teleosts and coelacanth (Carlstrom,1963). However, it should be mentioned that during embryonic development a number of otoconia-like spherules are formed in the teleost otocysts. Otoconia are used for creation of the thin otoconial layer (the otoconial otolithic membrane in lamprey and tetrapods) and otoliths. There are three types of otoliths: the single amorphous otolith, the composition otolith and the single polycrystalline otolith. Initially the otolith was formed in lamprey ancestors through fusion of separate otoconia. Replacing of amorphous calcium phosphate (Petromyzones) by crystalline calcium carbonate (Gnathostomata) produced better physical properties of the otolithic apparatus, but the otoconia lost the ability to merge with each other. One of the solution of this problem was the formation of compositional otolith, which presents a conglomerate of stuck otoconia. Such otolith appears for the first time in elasmobranchs. Later on bony fish ancestors worked out a qualitatively new mechanism of formation and growth of the test mass; the mechanism is connected with the appearance of a single polycrystalline otoliths of different types (teleost and acipenser otoliths). So. the single otoliths were evolved independently no less than three times.

Contribution: 33

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Otoliths of long rough dab: Morphology and interpretation

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Abstract

Otoliths of 387 long rough dabs (*Hippoglossoides platessoides*) were analysed both through binocular and digitised pictures. Several morphometric characters were recorded. They were generally closely correlated with the length of the fish. A small, though significant, year effect was also found. However, it is not possible, with any precision, to age long rough dab directly from morphometric characters of the otoliths. For older individuals a change in the sonation pattern was observed from an age which correspond with age at maturation. However, the occurrence of these changes was not closely correlated with the maturity status of the fish. The paper includes a detailed description of the sonation patterns of the otoliths.

Age was determined two times with binoculars and two times with digitised pictures. The use of digitised pictures gave consistently higher precision of age estimates. This was shown both graphically and by use of the coefficient of variation. Age determined from digitised pictures was generally higher than the one determined by using binoculars. This was especially true for older specimens. It seems that use of digitised pictures tend to increase both accuracy and precision of age readings, and that the binocular method tend to underestimate age.

In applied fisheries research, interpretation of age from otoliths often involves considering time allotted to each otolith against the total sample size that will be available for the

assessment. With each of the above methods, otoliths were read once with and once without time limitation. Time limitation did not influence estimated age for individuals up to 10-12 years. For older fish, age tended to be underestimated when time was limited, especially when the binocular method was used.

Key words: agedetermination, digitised pictures, precision, *Hippoglossoides platessoides*.

Contribution: 43

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Characterization of Otolith Soluble-Matrix Producing Cells in the Saccular Epithelium of Rainbow Trout Inner Ear

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Abstract

Otolith soluble-matrix (OSM) was extracted from the sagitta of rainbow trout with the 10%-EDTA solution and an antiserum was raised against the OSM extract. Western blotting showed that the antiserum reacted with 43 kDa protein and smear band (>94 kDa) in the OSM. On the other hand, a single discrete band (>94 kDa) in the endolymph was also reacted with the antiserum. In immunohistochemistry, the antiserum stained three types of saccular epithelial cells; columnar cells lined at the most peripheral region of the sensory epithelium, transitional epithelial cells, and squamous epithelial cells. The squamous epithelial cells which construct the lateral wall of the sacculus showed the most intense reaction. Transmission electron microscopy revealed that the columnar cells developed a highly dilated rough endoplasmic reticulum (rER) throughout the cytoplasm. Two different cell types were distinguished in the transitional epithelial cells one had dilation of translucent vesicles from the apical surface, whereas the other had apocrine type extrusion of cytoplasm. Squamous epithelial cells were also divided into two types; the one which had extended rER throughout the cytoplasm and the one which were fairly flat. Both cell types had dilation of vesicles containing many minute globules from the apical surface.

Contribution: 162

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Organic Framework of the Otolith

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Abstract

Transmission electron microscopy (TEM) and scanning electron microscopy (SEM) of the otoliths of three higher teleost species reveal the organic framework is found 1) within the primordial region as relatively dense granular-fibrillar material 2) within individual acicular crystals that form the incremental zone 3) surrounding individual crystals in the incremental zone 4) between incremental layers and 5) surrounding individual prisms that radiate from near the center to the surface. TEM sections through the long axis of individual acicular crystals show that as a fish ages, less matrix incorporation permits progressively more crystals to grow through the "discontinuous zone." Based on these findings, a pathway for the diffusion and incorporation of elements other than calcium and strontium is proposed.

Contribution: 70

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Influence of temperature and food on otoliths of reared early life stages of sand smelt
Atherina boyeri

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Abstract

In this paper we present the first description of both embryonic and larval otoliths of reared sand smelt (*Atherina boyeri* Risso, 1810). An interpretation of growth rings, laid down under different conditions of temperature and food level, is attempted. Sand smelt larvae were reared up to an age of 16 days after hatch from eggs either naturally or artificially fertilized. Two water temperature (17 and 26 °C) and two food level (ad libitum and 1/4 of it) rearing conditions were set up (photoperiod 13L:11D, close to natural). A third set of tanks (same food levels) was exposed to natural environmental temperature and photoperiod. Both embryonic and larval sagittae showed growth rings, wider and with continuous/discontinuous units more clearly defined at the embryonic stage. Pre-hatch sagittae of embryos reared at environmental temperature showed up to seven rings, less defined at 17 °C and almost invisible at 26 °C. A hatch check was identified in post-hatch sagittae at every temperature conditions. Image analysis was employed to suggest an interpretation of other check-units. Disruption of ring deposition was observed in starved larvae reared at 17 °C.

Contribution: 71

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20 - 25 June 1998

Age validation in horse mackerel (*Trachurus trachurus*) otoliths

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Abstract

Hyaline rings resembling annuli were measured in 150 horse mackerel otoliths from the South-East Atlantic. Marginal increment widths served to estimate precise ages which ranged from 0.6 to 3.0 years. Otoliths were prepared for scanning electron microscopy. After scrutiny, 39 otolith specimens could be used to obtain ages for the various growth zones. The number of daily increments proved to be highly variable within each growth zone. In the first growth zones, daily increment counts ranged from 161 to 474. Ages exceeding 365 days in the first annual growth zone indicated that the first annuli were suppressed in some of the youngest fish at the time/event causing annulus formation. This may lead to incorrect year-class assignments. Second growth zones contained 125 - 361 daily increments. This indicated that false rings and annuli are of a similar visual appearance and that true annuli can only be identified if concurrent measurements of growth zone widths are available. Daily increment widths were also examined. Growth rates appeared to reach a maximum at around 100 days. Precise ages based on the widths of the marginal increments were, on average, overestimated by 0.2 years. The variable daily increment counts in the first and second year's growth zones are probably related to the very protracted spawning season of horse mackerel.

Contribution: 189

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First observations on otolith morphology of north-easter Italy cyprinids

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Abstract

Aim of this research is to asses the most effectual type of otolith (saccular, lagenar and utricular otoliths) for age determination within the cyprinids. The saccular otolith, usually the largest, and the most used, in the cyprinid fishes is small and with a partiucular structure that makes its use unsuitable for age determination.

Here are reported our first observations on the otolith morphology, by means of light and scanning electron microscopy, of the autochthonous cyprinid species of the north-eastern Italy (*Alburnus alburnus alborella*, *Barbus meridionalis*, *B. plebejus*, *Chondrostoma genei*, *Cyprinus carpio*, *Gobio gobio benacensis*, *Leuciscus cephalus*, *L. souffia*, *Phoxinus phoxinus*, *Rutilus erythrophthalmus*, *R. pigus*, *Scardinius erythrophthalmus* and *Tinca tinca*), and the main allochthonous cyprinid species (*Carassius auratus* and *Chondrostoma nasus nasus*).

Contribution: 15

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Fish phylogeny and systematics using otoliths. *Asterisci* and *Lapilli*, the neglected pairs

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Abstract

Since the last decades of the 19th century, many studies have shown the relevance of the use of otolith morphology in fish species identification, classification and phylogeny, specially in situations when the intact fish body is not available, e.g. stomach contents, fossil remains and archaeological findings.

While the morphology of the *sagittae* is very well known and has been widely used in ichthyology, palaeontology and archaeology, little importance has ever been attributed by the ichthyologist to the other two pair of otoliths, which have been almost completely neglected. As a consequence, no part of their morphology has been thoroughly studied and properly or consistently named.

This presentation reports some preliminary results of a larger project under course, involving the study of the three pairs of otoliths from a large variety of European fish species, and in it (1) a nomenclature for the parts and structures of the *lapilli* and *asterisci* is proposed; (2) some examples on the possibility of their use in species identification are shown, and (3) the relevance of the use of the morphology of these two pairs of otoliths in studies of phylogeny and systematics is discussed.

Contribution: 105

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Heterogeneity of endolymph chemistry in the inner ear of two teleosts (*Oncorhynchus mykiss* and *Psetta maxima*) : relation to otolith growth?

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Abstract

The chemistry ($[\text{Prot.}]$, $[\text{Na}^+]$, $[\text{Cl}^-]$, $[\text{K}^+]$, $[\text{totCa}]$, $[\text{P04}^{3-}]$, $[\text{Mg}^{2+}]$ and $[\text{totCO}_2]$) of endolymph was investigated in samples withdrawn from two different zones of the saccular endolymph in trout and turbot : a zone facing the macula (proximal zone) and a zone at the opposite side of the endolymphatic sac (distal zone). In both species, Protein, PO_4^{2-} and Mg^{2+} were significantly more concentrated (2, 4 and 2 times respectively) in proximal than in distal areas. On the contrary, K^+ and totCO_2 were more concentrated in distal than in proximal zones (respectively 4 and 2 times in trout and 0,6 and 2 times in turbot). $[\text{Na}^+]$ appeared 20% higher in proximal side than in distal side in trout while no difference was observed in turbot. In both species, totCa and Cl^- concentrations were similar whatever the zone of sampling. These results clearly demonstrate that most of the constitutive elements of the endolymph are not spatially homogeneously distributed. The origin and the physiological roles of chemical gradients along the proximo-distal axis are discussed.

Contribution: 106

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Structure and Ultrastructure of the saccular epithelium in two teleosts: *Oncorhynchus mykiss* and *Psetta maxima*

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Abstract

The function of the saccule as a sensory organ implies that the endolymph composition is compatible with sensorial activation and otolith biocalcification. The depositions on the otolith are rhythmic and can be altered by various factors. These processes depend on the functions of the different saccular epithelial cells. The location, structure and ultrastructure of the different cell types are described. Ionocytes are in two areas of the saccular epithelium. Perimacular ionocytes are large, they contain numerous mitochondria and three membranous systems (endoplasmic reticulum, tubular and vesicular systems). They exhibit pseudopods which make contacts with the pseudopods of the neighboring ionocytes to form the "meshwork". Ionocytes of "patches" are small, rich in mitochondria and characterized by infoldings of their lateral plasma membrane. The macula contains "hair cells" and "supporting cells" with their classical arrangement but a third type, that we called "granular cell", was observed. These cells are also found at the periphery of the macula and have characters of very active secreting cells. In the intermediate area, near the meshwork, some secreting cells were also observed. The location of secreting cells and of different ionocytes suggests that

endolymph may be an heterogeneous medium. Results will be discussed in relation to endolymph composition and otolith growth.

Invit. 3

2nd International Symposium on
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Understanding the black box: Otoliths as environmental monitors

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Abstract

Calcified structures such as fish otoliths and coral skeletons potentially retain important information about the temperature and metal composition of surrounding aquatic environments. Understanding how mineralisation occurs, however, is vitally important to the mission of being able to use these structures as reliable environmental indicators. The major component of these calcified structures is CaCO_3 (approx. 99%) and it has been tempting to assume that the behaviour of otoliths is driven by this component alone. This is, however, a simplistic view and available evidence points to a significant influence of other components of these structures. Otoliths also contain a small percentage (< 1%) of organic material which probably initiates, directs and inhibits the deposition of CaCO_3 . Comparison with other systems suggests that a major proportion of these components are anionic proteins which show a high affinity for cations. Although these proteins have been isolated in some systems (mainly associated with the formation of hydroxyapatite in bones and teeth), they have not been isolated or identified from predominantly aragonite structures like otoliths or coral skeletons. I will present evidence that suggests that matrix proteins are important sources of variability in metal ion signals and that there are ways of resolving their functional role. I argue that we must find out more about the otolith "black box" before we can progress in the use of otoliths as environmental monitors. I will also present results from recent studies aimed at investigating the matrix proteins of aragonite structures.

Contribution: 107

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Experimental determination of the relationships between otolith accretion, metabolism and somatic growth in three species of teleost fish

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Abstract

We investigated the possibility that there are relationships between components of metabolic rate, otolith accretion and somatic growth in individually marked demersal juvenile haddock (*Melanogrammus aeglefinus*), juvenile Atlantic salmon (*Salmo salar*) and juvenile pike (*Esox lucius*). Variation in otolith daily increment width (IW) and somatic growth were compared with experimentally induced variations in resting rate, specific dynamic action (the increase in metabolism during digestion) and activity metabolism. Salmon and haddock were subjected to acute temperature changes to vary resting metabolic rate. Haddock and pike were fed to elicit specific dynamic action. Activity levels of salmon were manipulated by varying the density of fish within a fluvial aquarium.

An experimental change in resting metabolic rate resulted in a change in IW which was uncoupled from somatic growth. Metabolic rate and IW increased simultaneously after feeding in both haddock and pike, but the magnitude of the two variables was not closely correlated in either species of fish. There was not a significant correlation between IW and activity level of salmon. The implications of these results for interpreting otoliths of wild fish will be discussed.

Contribution: 109

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Sex-related variations in growth of juvenile turbot (*Scophthalmus maximus*) under semi-controlled rearing conditions : first evidence from a short-term experiment

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Abstract

Hatchery-produced turbot were used to test the assumption of the non-existence of sex-related differences in growth of juveniles. The fishes were marked both externally and using otolith tagging. They were kept in tanks supplied with natural sea-water from March to mid-May. Fish samples were taken in order to (i) estimate growth through somatic and otolith variables, (ii) take blood samples for hormone analyses (thyroid hormones T3, T4, and growth hormone GH) and (iii) identify sexes and calculate the gonado-somatic index (GSI). At the beginning, the average GSI were already 3-fold greater in females than in males. Despite highly variable daily temperatures, the fishes doubled in size (wet weight WW \pm sd from 58.6 \pm 11.4 to 124.2 \pm 34 g). However, the mean growth rate (G) was variable. The average values for circulating hormones were not different between sexes and were in the normal range for turbot, except for T3 and, for GH, only when G variations were the greatest. Individual growth trajectories, drawn from otolith microstructures, were variable in females, buffering the initial differences between slow- and fast-growing otoliths and possibly indicating a tendency toward 'uncoupling'. In males, individual trajectories showed an increasing difference between slow- and fast-growing otoliths. From otoliths it was concluded that females exhibited higher capabilities for growth regulation; males in contrast could generate more size variation. Although preliminary, these findings should stimulate long-term studies of growth strategies in immature turbot.

Contribution: 118

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Eye size related to growth rate and nutritional status in a growth stunted population of the fresh water clupeid *Limnothrissa miodon*

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Abstract

The African fresh water sardine *Limnothrissa miodon* is naturally occurring in Lake Tanganyika and introduced into the man made Lake Kariba, where it grows to only about half its normal length. An examination of 464 individuals sampled in 1992 and 1993 showed that the diameter of the eye varies from 74% to 146% of the normal diameter. This variation is correlated with variations in otolith maximum length. An analysis of otolith microstructures showed that for fish in the same length range (58mm to 72 mm), age could vary from 126 to 396 days. Fish with large eyes (and otoliths) could be more than twice the age of fish with normal or small eyes. Growth was observed to be significantly reduced after an age of approx. 100 days. An analysis of fat content around the intestinal organs, as an indicator of present nutritional status, showed that large eyes were associated with low mesenteric fat content. Condition factor was not affected. The findings indicate that both eyes and otoliths continue to grow during reduced or arrested somatic growth, and that mesenteric fat in this situation is used for metabolism.

Contribution: 132

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Fish Otolith Research and Application
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Otoliths and onions! A new model of otolith macrostructure

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Abstract

The prevailing model of otolith structure views them like an onion whose layers are the alternating opaque and translucent zones which contain different proportions of aragonite and organic material. It is recognized that the major growth axis may change with increasing age, becoming increasingly confined to the proximal face, but within each zone identical material is assumed to be deposited in all parts of the otolith. Despite much research, there is still frequent confusion on terminology and uncertainty on the composition and timing of zone formation. For example, when otoliths are examined whole under reflected light, the often narrower translucent zones are usually counted for estimating age: when otolith sections are examined, it is usually the narrower opaque zones adjacent to the sulcal groove which are counted. Yet the literature has reported both as being formed during periods of slow growth. It can be demonstrated that this difference in appearance reflects a largely ignored complexity in otolith structure. There is evidence that the assumption of uniformity in the composition of each layer is invalid. An alternative view of otolith growth is proposed which removes some of the confusion about the nature of zones, and their appearance under different methods of preparation. The alternative model also raises important issues for studies of otolith microchemistry.

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Daily variations of saccular endolymph and plasma composition on turbot *Psetta maxima*

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Abstract

The aim of present work was to investigate the heterogeneity of the saccular endolymph during a daily cycle. Daily variations of plasma and saccular endolymph composition (Na^+ , K^+ , Cl^- , total CO_2 and total proteins) have been analyzed on turbot *Psetta maxima*. Plasma and endolymph were sampled every 3 hours. Individual endolymphatic concentrations have been measured using a sampling microtechnic on both distal and proximal sides of each sacculus. One of the main results was the simultaneous variations of plasma and endolymph total CO_2 concentrations with a maximum corresponding, in both media, to an increase of 80% of the minimal value. Total CO_2 indicated high and low level during dark and light photoperiod respectively. An increase of 5 mM in plasma was amplified to a 12 mM of total CO_2 in endolymph. The difference of 6 mM between proximal and distal total CO_2 concentrations was maintained during the cycle. Variations in proteins and monovalent ions are also observed. These results are discussed in relation to the circadian rhythm of otolith biomineralization and saccular epithelium ultrastructure.

Contribution: 146

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VARIABILITY OF THE SULCUS ACUSTICUS IN THE SAGITTA OTOLITH OF THE
GENUS *MERLUCCIUS*

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Abstract

A study was carried out on the morphology of the sulcus acusticus of the saccular otolith (sagitta) by means of image analysis on the 12 existing species of the genus *Merluccius*. The digitisation of the sulcus acusticus and the subsequent biometric analysis by means of multivariate methods and the Fourier descriptors of the perimeters obtained allowed the interspecific variability to be quantified. The results were associated with ecomorphological (functionality and environment) and phylogenetic aspects. The sulcus acusticus demonstrated a specific character and the analysis of its perimeters indicated the existence of two large groups: the american species and the euro-african species, coinciding with the phylogenetic lines. The principal difference between the two groups was found in the development of the caudal colliculum, which was larger in the american species. Within the euro-african group the deep-water species, *M. polli* and *M. paradoxus* showed different characteristics with respect to the species from surface waters. Given that a clear anatomical relationship exists between the sulcus acusticus and its adjacent sensorial epithelium, we could associate these modifications with functional specializations of the inner ear. On the other hand, the existence of genetic control in the sulcus acusticus and in the otolith indicates the importance of the shape of the sensory maculae in the determination of the shape of the whole otolith.

Invit. 4

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Structure-Function Relationships in Fish Otolith Organs

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Abstract

The saccule, lagena, and utricle each have an otolith lying close to a sensory epithelium (macula) that contains thousands of mechanoreceptive cells. These cells are very similar to the sensory hair cells found in the ears of other vertebrates and in the fish lateral line. Sensory hair cells respond to the relative motion between the otolith and the sensory epithelium, and send signals to the brain via the 8th cranial nerve.

In all fishes, the particle displacement component of a sound field directly stimulates the ear. Fishes which primarily detect sound in this manner are called hearing 'generalists' and can detect signals from below 50 Hz to 500 - 1,000 Hz. Some fishes have specializations that enable them to detect the pressure component of the sound field and transmit these signals to the inner ear indirectly. These 'hearing specialists' can often detect sounds from below 50 Hz to over 2,000 Hz, and their sensitivity is often much greater than that of hearing generalists.

This paper will discuss the general structure of the otolith organs and their sensory hair cells, basic mechanisms of hearing by fishes, peripheral morphological specialization that enhance hearing, growth of the fish ear and addition of sensory hair cells, and sound source localization.

Contribution: 161

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Ultrastructure of Otolith Formation - Secretory Activity

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Abstract

The organic framework for otolith formation is secreted by some supporting, transitional, and squamous cells of the labyrinth epithelium. Morphological and analytical studies suggest three secretory mechanisms common to all species examined. One, being vesicular activity associated with lateral plasma membranes within dilated regions of the intercellular spaces, the other being the production of two types of multivesicular secretions observed at the surface of the cells. Vesicles associated with lateral plasma membranes release granular-fibrillar into the intercellular space and the presence of secretory material was observed at the apical tight junctional complex. Multivesicular secretions originated from dilations of the distal ends of some microvilli and relatively large multivesicular bodies that were observed to form and pinch off the cell's apical surface. Observations suggest some vesicles released may contain precursor material for the formation of the subcupular zone of the otolithic membrane while other vesicles were observed to release their contents directly at the calcification front. Occasionally, vesicles were observed within mineralizing growth increments. Precursor material is concentrated at the mineralization front and crystals nucleate within micro-spaces produced by the newly formed matrix material. During early growth the discontinuous zone is formed by organic material compressed by two adjacent crystal layers growing towards each other.

Contribution: 1

2nd International Symposium on
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Otolithic apparatus in Acipenser fry

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Abstract

There are good reasons to believe that the single polycrystalline otolith developed independently in such groups as Acipenseriformes and Teleostei. By using light and scanning electron microscopy I examined the otolithic organs of *Acipenser nudiiventris* and *A. baeri*. The utricle and the lagena contain only otoconia and microotoliths forming compositional otoliths. The saccule contains one single otolith and small amounts of otoconia. The single saccular otoliths are clearly divided into two distinct structures: a sector-like blade with a structure typical of the teleost otolith, and an apex looking like an aggregate of fused concretions. The existence of the morphologically incomplete compositional otoliths in the lagena of both fishes and in the utricle of *A. baeri* and the incomplete separation of the saccular and lagenar otolith membranes are associated with the phylogenetic antiquity of the Acipensers. The existence of the single otolith indicates that the evolutionary substitution of compositional otolith for single otolith occurred in nearest ancestors of the acipensers. The dual structure and the vateritic constitution of single otoliths suggest that the single otoliths of the acipensers present a particular type of the single fish otoliths. It may point to independent origin of single otoliths in different groups of bony fishes.

Contribution: 2

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Otolithic apparatus in Black Sea elasmobranchs

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Abstract

By using light, transmission and scanning electron microscopy, and morphometry we examined the otolith organs of 25 *Raja clavata* (35 to 93 cm), 12 *Dasyatis pastinaca* (34 to 50 cm), 2 *Squalus acanthias* (100 and 145 cm). In *D. pastinaca* all three otolith membranes merge into one another, and the otolith apparatus as a whole is weakly developed. In *R. clavata* and *S. acanthias* the lagenar off the saccular otolith membrane is small. The mass (m) of the otolith membrane and the length (l) of the animal are power related. The otoconia of rays are as a rule lemon-shaped or spherical. The dogfish has large parallelepiped-shaped endogenous otoconia and exogenous otoconia and exogenous sand grains. The size of the otoconia in rays does not depend on the size of the animals. No specialized zones were found in rays either on the surface or inside the otolith membranes containing otoconia of one type or size. The data indicate that the mass of the otolith apparatus in rays increases on account of the new formation of otoconia.

Contribution: 3.

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Otolithic apparatus in the adult river lamprey.

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Abstract

By using light and scanning electron microscopy I examined the otolithic organs of *Lampetra fluviatilis* weighting from 85 to 110 g. The otolithic membrane contains a thin structurally undifferentiated layer of spherical otoconia, 2 - 25 μm in diameter, and otoliths formed as a result of otoconia fusion. The otoliths are homogeneous inside. The largest otolith is situated in the rostral part of the utricular area of otolithic membrane and weighs 12.0 - 13.5 μg , while the small otolith with the a mass ten times less occupies its caudal part. Saccular otolith is small in size; it is situated in ventrorostral corner of the vertical saccular otolithic membrane. There are no otoliths in lagenar part of otolithic membrane. The available data suggest that the otolithic apparatus of the lamprey possesses the main characteristic of the otolithic apparatus of the non-tetrapods, i.e. the ability to increase the otolith mass continually. The existence in otolithic membrane small otoliths and the layer of otoconia makes it possible to consider the otolithic membrane of the lamprey the peculiar prototype of a future, structurally differentiated otolithic membrane of tetrapods. So, the otolithic membrane of the lamprey combined features of fish and tetrapod otolithic membranes. The data prompt the conclusion that the otolithic membrane of river lamprey has a structure most close to ancestral otolithic membrane.

Contribution: 5

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Anomalous otoliths of Black Sea teleosts

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Abstract

Otoliths of 27 guppy fish, 2 European flounders and 48 Black Sea fishes of 15 species were studied using light and scanning electron microscopes. In 3 Black Sea fishes it was discovered undoubtedly anomalous otoliths. Disturbances concerned the crystalline structure of the otoliths, the structure of their surface, the overall shape, size, and mass. The analysis of the obtained and literature data shows that, in spite of the differences in systematic position of a fish and the differences in the environment, anomalous otoliths of teleosts may have a number of common features. The similarity is displayed in the existence of crystalline polymorphism, in the existence of determined, common types of habits, in conservatism of the overall shape and sizes of anomalous otoliths, and also in the fact that the disturbances may concern only one otolithic organ, whereas in nearby otolithic organs otoliths may have a normal structure. At the same time some anomalies are unique. Among such anomalies are the presence of two otoliths in one otolithic organ in stargazer and the turbot, the presence of otoliths unique in shape in lagena and sacculus of the turbot, the presence of an extraordinary otolith asymmetry in stargazer and the turbot. According to the obtained data it may be supposed that the destabilization and environmental deterioration promote the appearance of anomalies first of all in the fast growing otoliths, what is characteristic of, for example, saccular otoliths of littoral and bottom fishes. The study of anomalous otoliths and behavior of the fishes with anomalous otoliths seem to be prospective for understanding the processes of biocrystallization in the organism and solution of the problem of functional significance of otolith polymorphism. Because of the rarity of anomalies in nature it seems to be perspective to cause them by artificial means.

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The possible role of the otolith shape

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Abstract

It is well known that there is a great variety in the shape of otoliths in fishes. The functional duty of this variability is not yet quite clear. Mathematical analysis of the otolith vibrations in an acoustic field was performed on the basis of the data on otolith micro mechanics and our own morphological investigations in order to evaluate the otolith shape effect on the amplitude of its displacement relative to the macula under the acoustic influence. The amplitude of relative displacement appeared to essentially depend on the tensor of associated masses of the otolith which, in turn, was determined by the otolith shape. The amplitudes of relative shifts in various directions were found to be significantly different for the sound frequencies which were higher or equal to the natural frequency of the otolith vibrations in the otolithic organ. Thus, the otolith directional pattern revealed essential shape-dependent anisotropy. Since the otoliths have specific orientation in each otolithic organ, it can be suggested that the otolith shape variability in fishes is of adaptive significance and is caused by the need to tune the otolithic organs to the predominant recognition of specific (relative to the head) sound directions. These directions, in turn, are significant for a given species in connection with adaptation to the surrounding acoustic environment.

Contribution: 8

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Otolith regularities

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Abstract

Otolithic apparatus was studied in river lamprey, in 3 species of Black Sea elasmobranchs, in 2 species of acipensers, in 15 species of Black Sea teleosts and in guppy fish. The otoliths were weighed on Sartorius Co. scales or on VLR-200 scales and photographed. Results: 1. The main characteristic of all otoliths is that as the fish grows, the mass of the otolith continually increases. The growth of the otoliths is realized through new formation of otoconia, due to deposition of molecular layers on the otolithic surface, or, probably, due to combination of both of these two processes. 2. The ratio between masses of the different otoliths does not change with the growth of the individual fish and is stable and species-specific quantity. 3. The otolith masses, otolith growth rates, and the ratios between the masses of otoliths of the utricle, saccule, and lagena vary depending on the mode of life, this being primarily associated with differences in motor activity. The bottom and littoral fishes have the great values of ratio between masses of otoliths of saccule (M_s) and utricle (M_u) or lagena (M_l) than the pelagic fishes have. 4. Irrespective of a species of fish the ratio between the mass of the otolith and its area of the projection on the labyrinth wall is described by a power equation: $s=1.06m^{0.619}$ in utricle, $s=1.90m^{0.651}$ in saccule, $s=2.28m^{0.724}$ in lagena, where s is the area of projection (mm^2), m is the mass of the otolith (mg). 5. The ratio between otolith size and macula size did not change significantly over a wide size range in some species, but did vary between species (Gauldie, 1988).

Contribution: 17

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A digital photographic atlas of fish otoliths of the Northwest Atlantic

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Abstract

Fish, seal and seabird biologists, as well as taxonomists and archaeologists, often rely on the shape and size of preserved or undigested otoliths to reconstruct the species and size composition of the diet of fish predators. Reference collections of otoliths now exist in several locations, but none have attempted broad species coverage of the northwest Atlantic. In order to make an extensive otolith reference collection available to other scientists, a collection of about 360 sagittal otolith pairs, representing more than 200 species found in the northwest Atlantic Ocean, have been collected and archived. Lapillar and asteriscal otolith pairs have also been collected from representatives of each family. Using image analysis procedures, each otolith pair has been digitally photographed and enhanced for subsequent reproduction on both paper and CD-ROM. Gaps in species coverage still exists, and it is hoped that the scientific community will contribute material to fill those gaps. Once completed, a key will be made available to expedite species identification based on otolith shape.

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The occurrence, composition and role of otoconia in otolith formation

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Abstract

Spherules, morphologically similar to the otoconia of higher vertebrates, occur in association with the otoliths. This study used histochemical and scanning electron microscopy techniques to investigate the nature and role of otoconia and the relation of these structures to other tissues within the saccula. Otoconia were seen on the medial surface of the otolithic membrane and on the surface of the otolith. On the otolith the otoconia were enmeshed in a veil-like fibrous material which bound them together and to the otolith surface. Otoconia appeared to be transported to the surface of the otolith within the fibrous sub-cupular meshwork. Histochemical staining showed the presence of acidic mucosubstances in the sub-cupular meshwork and the core of the otoconia contained sulphated glycoprotein and glycosaminoglycans. Based on histochemical reactivity, the core material of these otoconia appeared to be secreted from specific regions of the otolithic membrane. Given the location of the otoconia layer and the need for ion concentrations to exceed the solubility product at the otolith surface it is likely that the dissolution of these structures are involved in maintaining the high ion concentrations necessary for mineralisation.

Contribution: 61

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A multi-analytical investigation into the aragonite-vaterite (CaCO_3) phase transition in otoliths from COHO salmon (*Oncorhynchus kisutch*)

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Abstract

The calcium carbonate (CaCO_3) polymorphs aragonite (orthorhombic) and vaterite (hexagonal) are thermodynamically metastable minerals at STP. Their stability as biominerals is due to their precipitation on organic substrates, the polymorph precipitated probably controlled by the type of substrate, or "template" present. X-ray photoelectron spectroscopy (XPS) on broken surfaces of vaterite and aragonite give high concentrations of organic carbon and nitrogen but only 1-2% Ca (photoelectron emission depth $\sim 40\text{\AA}$). Plasma ashed samples are free of nitrogen and organic carbon, and have 28-30% Ca. This suggests that vaterite and aragonite crystals are enclosed by a layer of organic material. Determination of 18 amino acid concentrations in bulk vaterite and aragonite samples shows that vaterite is enriched in GLX, ASX, and LYS by factors of 1.2-1.4 compared to aragonite, and is deficient in GLY, LEU, PHE, TYR, and ARG by factors of 1.3-1.5. TEM and FE-SEM imaging have not been able to resolve the morphological relationship between the organic and inorganic phases but do show that individual aragonite and vaterite crystals are idiomorphic and 50-100nm in size. The nanocrystals are organized into long needle-shaped forms that typify acid-etched otolith surfaces.

Contribution: 79

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MORPHOLOGICAL PECULIARITIES AND GROWTH OF SPOTTED CATFISH
(*ANARCHICHAS MINOR* OLAFSEN) OTOLITHS

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Abstract

Different recording structures and methods have been applied for age identification of catfish from the Anarchichadidae family. At the same time, methods of age identification of catfish by scale and bones are not sufficiently elaborated. As known, otoliths form considerably earlier than scale, therefore the use of otoliths as an age-recording structure is preferable. This fact provided the ground for research on morphological peculiarities and growth of the Barents Sea spotted catfish (*Anarchichas minor* Olafsen) otoliths, aiming at elaboration of its age identification methods.

Descriptions and measurements of catfish otoliths are, as a rule, scarce in literature and therefore give just a general notion of structure, form, size and specific peculiarities of otoliths. No data are available on age variations and peculiarities of catfish otolith growth. In the course of investigation 575 pairs of otoliths from catfish aged 0+ - 19+ have been examined under binocular, their measurements done, dependence of otolith size on length, mass and age of fish investigated.

During catfish life the form, structure and size of otoliths naturally change. Otolith length varies from 1.5 mm for fish aged 0+ to 7-8 mm for fishes aged 19+, the height varies from 1.5 to 4-5 mm, respectively. The relationship between length and height of otoliths and length, mass and age of fishes has a curvilinear character: during the first years of life the rate of otolith growth is higher than during the last ones. Therefore these relations can be best approximated by the exponential function $y=ax^b$, in this case minimum dispersions and the highest dependence on fish size were obtained for otolith height.

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On the morphometry of horse mackerel, *Trachurus trachurus*, otoliths with comments on growth and current age reading validation

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* This article is in memoriam of Blanca Landín, who passed away in 1996

Abstract

Horse mackerel, *Trachurus trachurus* (L.), specimens were collected from Galician waters (NW Spain) during the spring of 1995 to obtain otoliths for growth studies. 450 specimens were sampled, and their otoliths studied. The morphometric parameters obtained from the otoliths were the followig: maximum dorsal - ventral length, maximum distal - proximal length, antirostrum - pararostrum length and rostrum - postrostrum length. The data were analysed in relation with fish age and total length. It has been discussed the adequacy of the current methodology for age reading with the otolith growth patterns observed. The Von Bertalanffy growth function was calculated applying the current validated methodology for age reading in the ICES area, of one year per ring. This is the first attempt of this estimation for horse mackerel since the validation of one year per ring criteria was established. The results are discussed and compared with previous growth functions estimations and with those from related species.

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Morphological variation in otoliths (Sagitta) of *Pontinus kuhlii* (Bowdich), 1825) in relation to size and sex

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Abstract

The morphological variations detected “a visu” between otoliths from males and females of *Pontinus kuhlii* (Bowdich, 1825) distributed in the waters around the Canary Islands were analysed by an image processing system using the OPTIMAS software. Sagittal otoliths (n=57) of both sexes corresponding to 2 specimens at 1 cm intervals when the sample size allowed of between 17-46 cm total length were used.

Contribution: 108

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Preliminary results on the otolith morphology and microstructure of the flatfish
Lepidorhombus boscii

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Abstract

The otoliths (sagittae) of *L. boscii* are asymmetrical in shape, the left one exhibiting greater deposition towards the rostrum and the right one towards the postrostrum. To provide quantitative analysis of left-right asymmetry, two radii on each otolith were measured; one from the nucleus to the most anterior part of the rostrum and the other from the nucleus to the opposite, postrostrum edge. The relationship between otolith radial measurements and total length of the fish was determined by regression analysis. The slopes of these regressions differed significantly for both the rostrum ($F=124.4$, $p<0.001$) and the postrostrum ($F=93.1$, $p<0.001$), suggesting that left and right otolith diverged in their deposition pattern with increasing fish size. The SEM study of the otolith microstructure showed two different types of zones, light broad (incremental) and dark narrow (discontinuous) ones. Under high magnification (x3000) the crystalline structure of the incremental zones is obvious. It should be noted, however, that rings appearing to be translucent, when viewed with a stereoscope, were composed of narrower crystalline zones as compared to opaque rings, that under the SEM exhibited longer more consistently patterned crystals.

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MORPHOLOGIC PATTERNS OF THE *SAGITTA* IN FISHES ASSOCIATED TO THE
BOTTOM OF THE MARINE SHELF OF THE MAR ARGENTINO

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Abstract

Most of the fishes known to occur in the marine shelf can live in association with different kinds of substrate materials (sand or rocks). We predict that the *sagitta* of fishes associated to the same substrate, may show common basic features. Five families were considered typical from soft substrates (Group 1: *Sciaenidae*, *Bothidae*, *Paralichthyidae*, *Ariidae* and *Achiropsettidae*) and 4 families from hard substrates (Group 2: *Scorpaenidae*, *Triglidae*, *Serranidae* and *Zoarcidae*). A third group of pelagic fishes (Group 3) has been considered to compare morphologic and morphometric features with groups 1 and 2. A total of 2567 otoliths have been studied from 13 families and 22 species. Three measurements were taken on each *sagitta* of each specimen: dorso ventral width (AO), antero posterior length (LO) and antero posterior length of the *rostrum* (LR). The statistic analysis was based upon the following morphometric values $e=AO/LO$ % and $p=LR/LO$ %. These showed significant differences between groups 1, 2, and 3 ($F= 38.4742$; $\alpha= 0.05$). Particular features for each group are the following: 1= Circular shape, *rostrum* absent or poorly defined, *cisure* absent and smooth margins; 2 = elongate shape, *rostrum* of variable shapes, *cisure* present, margins without ornaments, 3 = prominent and sharp *rostrum*, deep *cisure* in V. The highest median values of p were found in the pelagic group (0.42 ± 0.11) and the lowest value was found in group 1 (0.061 ± 0.008).

Contribution: 147

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FRACTAL DIMENSION APPLIED TO THE STUDY OF THE MORPHOLOGY OF THE SAGITTA OTOLITH

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Abstract

Fractal geometry was applied in morphology studies at different levels, ranging from ultrastructural to whole organism observations. Image analysis of the perimeters of the sagitta otoliths was carried out on all the species of the genus *Merluccius*. This allowed us to obtain parameters that produced estimations of the D fractal measurement (perimeter/area) for each species. The fractal analysis detected differences in relation to the relative size and to the shape of the sagitta otolith. As a result, it separated the species with a larger relative size (and smaller perimeter/area relationship), such as *M. merluccius* and *M. albidus* from the other species. Another aspect that was involved in the arrangement of the groups was the shape of the sagitta. Thus the species with elongated otoliths or with a greater sinuosity in the perimeter had a greater perimeter/area relationship.

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IDENTIFICATION OF COD GROUPINGS BY OTOLITH STRUCTURE

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Abstract

The population of Atlantic cod (*Gadus morhua morhua* L.) inhabiting the Barents Sea and adjacent waters consists of several groupings. Three groupings of cod are commonly distinguished: the Atlantic and the coastal (Murmansk and Norwegian) ones, which are differentiated by a number of criteria. Various interpretations of these distinctions are suggested by researchers. Some scientists assume that the fjords and coastal waters off Scandinavia and Murman are inhabited by separate self-reproducing groupings of cod, others provide evidence that the Barents Sea and adjacent waters are inhabited by a single population of cod which consists of the ecological groupings stemming from the single genofond. However, both approaches to the structure of the Atlantic cod population are not supported at present by any substantial evidence. This evidence can be provided by the analysis of genetic distinctions of cod with different types of otoliths. The survey of several thousands pairs of otoliths from different areas of the Barents Sea led to the identification of the three, corresponding to the three cod groupings, otolith types, which are differentiated by the breadth and brightness of pelagic growth zones (the core), precipitation rings and annual rings as well as by a number of other criteria. The otoliths of coastal cod are thin and oblong, they are characterized by a distinct growth zone interchange; the Atlantic cod otoliths are characterized by a complicated structure of zones with complementary marks; the third group of cod otoliths is intermediate, with an inhomogenous structure of annual zones. Temporal and spatial occurrence of cod with otoliths of different types has been investigated. The presence of the intermediate type testifies to the intermixture of cod from different groupings. However, it will be possible to make a final conclusion only after the analysis of genetic distinctions of cod with different types of otoliths.

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Study of the otolith marginal daily growth ring building for the yellowtail snapper (*Ocyurus chrysurus*, Lutjanidae)

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Abstract

The juveniles of yellowtail snapper of homogeneous size were sampled along two 24 hours cycles. Sagitta were extracted, coated by a thin gold film, mechanically broken. Microstructures of the fracture surface were then revealed by acid treatment. Measures of the width of the daily growth ring in building phase were carried out on the proper areas of the fracture margin and analyzed in comparison with the previous achieved ones. Inter-individual synchronism in the daily growth ring construction was revealed. At 5 A.M. the building of the ring reaches about 70% of its definitive width and 78% at 10 A.M. The daily ring seems to be achieved at the end of the morning, with 97% of building at 11 A.M. The calcification discontinuity between two successive rings may occur at that time. Then, a new daily ring rises, reaching 46% of building at 4 P.M. and 59% at 10 P.M. The daily growth ring building rhythm is lower during the night. These results confirm the circadian periodicity of microstructure emergence on the otoliths established with other validation method like oxytetracyclin injections. That technique is an adaptation of the marginal growth analysis method at the daily scale.

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Ontogenesis of pike (*Esox lucius*) otoliths

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Abstract

Fish otoliths are acellular, mineralised structures, built mainly of aragonite variety of calcium carbonate crystals. The predecessors of Teleosts' otoliths are minute crystalline particles called otoconia (literally "ear dust") observed in the early developmental stages. Mass marking of fish otoliths by immersion in tetracycline (TC) solutions is possible within a wide range of developmental phases: from egg fertilisation till juveniles. Although the first method - marking at fertilisation - produces low quality marks, making it unusable for population studies, it is sufficient for tracing calcium compounds in developing embryo, therefore enhancing studies on ontogenesis of otoliths. Pike eggs were fertilised in TC solution (1200 ppm) in 11°C. The analysis of developing eggs were performed over two-week period, every 24 hours. The hatching took place at the 10th day of incubation. The samples were analysed in transmitted light, polarisation (crossed polarising filters ñ two nicols) and *dia*-fluorescence. Application of polarised light reveals crystalline structure of the observed objects ñ otoliths (as well as their predecessors ñ otoconia) shine in faint blue and faint pink colours. The first crystalline structures, suspected to be otoconia, were found in the earliest samples ñ unfertilised eggs. One hour after the fertilisation (just after the end of immersion in TC) these crystals, shining in polarised light, exhibited faint yellow fluorescence in UV light, typical reaction for calcium-TC chelates. The same phenomenon was observed in fully developed otoliths. The combination of transmitted light, polarisation and fluorescence enabled to follow the pike otoliths formation, which involved two parallel processes - aggregation of otoconia in primordial otolith, and migration of these aggregations to the area of the cranium formation.

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What Fish Biologists Should Know About Bivalve Shells

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Abstract

Similarities between shell and otolith growth patterns are numerous. Both have been shown to have daily increments, variations in chemical composition that can be related to environmental changes, and annual patterns. Some of the less obvious common features include the presence of subdaily increments, production of irregular microgrowth patterns at low temperature, increased transparency at high temperature, reduced increment clarity in field to laboratory transferred individuals, and decoupling between somatic growth and growth of the calcified structure. A principal difference between shells and otoliths is that while microgrowth increments are found in bivalve larvae, presence of daily increments has not been verified for any species.

Applications of shell and otolith growth patterns have also been similar. Both have been used to reconstruct the effects of environmental events after they have taken place and to obtain age data critical for estimating growth rate, recruitment, and survivorship. Recent evidence suggests that growth in these calcified structures more closely follows metabolic rate than total or somatic production. This implies that microgrowth patterns have the potential to be used in a new way, i.e., to provide information on physiological processes. Evidence is provided for bivalves that respiration rates could potentially be predicted from shell growth rates.

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Walleye Pollock (*Theragra chalcogramma*) During Transformation From the Larval To Juvenile Stage: The Relationship Between Otolith And Osteological Development

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Abstract

A Schnute growth model was formulated based on larval and juvenile age and length data for walleye pollock from the Gulf of Alaska. The model illustrates the transition points that are closely related to the length categories (life stages) that have been previously defined as first feeding, post-flexion, and transition to the juvenile stage. During these specific length categories, the sagittal otoliths show distinct changes in structure. The beginning of the transition from the larval to juvenile life stages corresponds to the development of accessory primordia in the sagittal otoliths. A completely transformed juvenile walleye pollock sagittal otolith resembles the morphology of an adult otolith. The specific changes in otolith structure at key length categories provides a better estimate of fish length when used in conjunction with otolith length and fish length. Laboratory experiments using alizarin complexone marked otoliths show that transformation from the larval to juvenile stage is length dependent and not age dependent. The juvenile stage of walleye pollock is defined as being of standard length greater than 40mm and having completely ossified vertebrae and fin rays. Squamation is not an important criterion in defining the completion of transition to the juvenile stage in walleye pollock in contrast to other fish species.

Abstracts

Session 2:

Estimation of Fish Age and Growth

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Some Methods of Analyzing Age and Growth Data

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Abstract

The past twenty years has seen many advances in the statistical treatment of age and growth data. The guiding influence in this evolution seems to be “classical” statistical theory which first provided us with regression, then likelihood methods, and now Bayesian analyses. However, perhaps an equal influence has been the omnipresence of powerful desktop computers that have encouraged the development of computational methodologies. A unique unifying factor in fisheries science is the desire to provide data and analyses useful for stock assessments. Most fisheries scientists do not wander far from this base of critical need, and the result is that some problems have been studied with a kind of obsession. Many problems in this category relate to age and growth studies: fitting von Bertalanffy growth curves, age-length key problems, and distribution mixture problems. Still, useful progress is evident in these areas of study. One possible area for future development may be the greater application of errors-in-variables models where controversy seems to have discouraged application. Traditionally, much of the analysis of age and growth data was performed outside stock assessment models, with the results incorporated into the stock assessment. The current trend is now to integrate analyses directly into an age-structured stock assessment model. This approach allows a comparison and reconciliation of all of the datasets. I examine some of these topics from a personal perspective, and do not pretend to review the now massive literature on these subjects.

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DAILY INCREMENTS IN OTOLITHS: ENDOGENOUS VERSUS EXOGENOUS GROWTH REGULATION

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Abstract

Otolith growth is a complex phenomenon integrating different factors, which can be considered either as endogenous or exogenous, although these are always regulated by the physiology of the fish. Both factors may operate upon the anabolism and catabolism of the fish, which are reflected in the rhythmic deposition of the two main constituents of the otolith: the organic matrix and the aragonite layers. Both components reflect the endogenous process in their periodicity, and the exogenous process in the amount of material laid down in the otolith, resulting in how and where the increments are formed.

At the endogenous level, several morphological and functional aspects are relevant, with the main one being the role of the otolith as a statocyst in the inner ear. Thus, the inner ear anatomy and function regulate otolith growth and morphology, through the morphology of the sacculus and sensorial area, which determine the daily growth rates. Another important internal factor is sexual development and maturity, which diverts fish growth towards the production of sexual products and causes periods of physiological stress, which are reflected in the otolith microstructure.

The otolith shape is genetically determined, by acting upon otolith growth, which is homogeneous in early development, but becomes irregular depending on the otolith area considered. However, the otolith morphology is to a certain extent plastic, reflecting environmental parameters throughout the life of the fish. Environmental conditions, transmitted through the physiology of fish, affect the otolith growth rate but increment periodicity may be disrupted only in extreme cases of physiological stress.

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Two examples of difficult-to-age fish from Florida waters: how good are the ages and how biased are the growth parameter estimates?

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Abstract

Fishery managers need data on longevity, age at maturity, and population age structure. Many economically important Florida fishes are difficult to age. Biologists are thus faced with the dilemma of ageing species whose otoliths are difficult to interpret. Two examples, black grouper (*Mycteroperca bonaci*) and tarpon (*Megalops atlanticus*), are considered here. Age estimates for young individuals (<8 years) of both species have been validated, but estimates for older fish are less precise and not validated. I used the coefficient of variation (CV) to set thresholds for the acceptable level of variation among otolith readings. Overall, growth parameter estimates were insensitive to the choice of CV threshold suggesting that age estimates were unbiased. At very low CV thresholds (<3%), age estimates for most large and old fish were rejected resulting in biased growth parameters and under estimation of longevity. Radiometric ageing of tarpon suggests that ages from otoliths are often inaccurate, but the error appears to be unbiased and thus the parameter estimates may be useful. Growth models derived from sectioned otoliths for many difficult-to-age species may be unbiased; however, the uncertainty of the ages may reduce their usefulness for assessing individual growth histories, tracking cohort abundance, or constructing age-length keys.

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Age and growth of Mediterranean horse mackerel, *Trachurus mediterraneus* (Steindachner), in the Gulf of Saronikos Gulf (Greece) - growth in early life associated with different otolith types.

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Abstract

The age and growth of Mediterranean horse mackerel, *Trachurus mediterraneus* (Steindachner), in the Gulf of Saronikos (Greece) were studied during the years 1989-92. Length frequency of a total of 4612 specimens was followed by month, while age reading was done on 1611 otoliths. The otoliths were classified in four types on the basis of differences in the structure of preannual zones. These zones and the 1st annulus were detected comparing the progression by month of the smaller modal fish length with the respective otolith appearance during the year. Successive hyaline zones were interpreted as annuli on the basis of their formation at progressively greater distances from the nucleus, while the opaque zones were not always visible. The time of annual hyaline zone completion was estimated by the study of monthly marginal increments. This time was found to be around the end of autumn and coincided with the end of spawning period. Spawning period was identified by following the seasonal changes of gonadosomatic index. Different growth rates associated with the otolith types were observed during the first three years of life due probably to the different spawning time. Mean lengths at age from otolith reading (all types combined) in the monthly samples were applied to the von Bertalanffy equation and growth parameters were estimated: $L_{inf} = 37.24$ cm, $k = 0.326$, $t_0 = -0.842$.

Keywords: *Trachurus mediterraneus* , Age, growth, otoliths

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The use of otolith weight to predict age structure of coral trout (*Plectropomus leopardus*) populations on the Great Barrier Reef, Australia

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Abstract

Knowledge of fish age structure provides the key to estimate growth, mortality and the production rates of populations. The conventional method of age determination based on examination of the sectioned otoliths has proved to be time consuming and expensive, especially in the tropics. This study assesses the use of otolith weight as a predictor of age and thus a predictor of age structure of fish populations. The otoliths of common coral trout, *Plectropomus leopardus*, collected from 24 coral reefs on the Great Barrier Reef were examined to establish a relationship between otolith weight and fish age at each individual reef. Otolith weight accounted for between 47 and 77% of the variation of age at individual reefs. There was a relatively high agreement between the observed and predicted age structures for all 24 reefs. Otolith weight was therefore a relatively effective, economic and fast method for estimating age structure of *P. leopardus* populations on a reef by reef basis. This provides a more economic method for accurately predicting age structure of coral reef fish populations.

Contribution: 30

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Age old problems in deep-water fish growth

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Abstract

It was a long held belief that the constancy of the deep-water environment would result in continuous growth and all year round reproduction. However, rings on scales and otoliths of deep-water fishes similar to those found in shallow water fish species have been reported since the beginning of the 20th century. The development of a fishery for roundnose grenadier in the 1960s led to the use of scales and otoliths for age estimation without any attempt to validate the annual nature of the growth zones. This paper reviews the literature on age estimation in macrourid fishes. New data on the validation of age estimates of juvenile macrourids are presented. The species studied are all from the eastern north Atlantic and span a depth range from about 700 to 4000 m. A common feature is the apparent delay in the onset of the growing season until the autumn and winter months. Possible linkages with food availability are discussed. On the assumption that the rings are annual the ages of five species of macrourid have been estimated and used to provide information on longevity and growth rates.

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The Use of Prey Otoliths to Check Reliability of Estimates of Commercial Fish Species Consumption by the Barents Sea Cod

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Abstract

When calculating consumption of different age groups of commercial fish species by the Barents Sea cod, length-age keys are used for each fish species. However, it is known that such method may have some errors. Besides, it is assumed that length-age composition of fish prey in the sea is identical to that in cod stomachs. Thus, it seems necessary to check the above assumption.

Results from otolith analysis of cod, haddock, deepwater redfish and long rough dab collected from cod stomachs during 1994-1997 were used to compare actual age composition of the above fish species and that calculated using age-length keys.

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Effects of Mortality and Gear Selectivity on Back-Calculation Using Simulated Otolith Data

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Abstract

The effects of mortality and gear selectivity on the otolith radius-total length relation (OR-TL) were simulated using an otolith/somatic bioenergetics model. Four gear selectivities were examined and used to produce fishery-dependent samples for statistical analysis. Samples taken with selective gears produced OR-TLs with significantly different y-intercepts than those from an unfished population; significant differences were also found between gear selectivities. The OR-TL y-intercept of a non-selectively fished population was found to be systematically influenced downward by total mortality as a result of a decrease in the number of larger fish. This influence was removed using the mean otolith radius-at-age and mean length-at-age in the OR-TL regression, which resulted in more accurate estimates of back-calculated size-at-age; the best estimates were made using only the last annulus in the calculation. These results imply that, rather than a fixed value, the y-intercept of the OR-TL is more accurately considered a dynamic parameter that changes as a cohort ages and experiences mortality. Use of the y-intercept in the back-calculation of size-at-age needs to account for the degree and selectivity of recent fishing mortality of the population under investigation.

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Growth dependent age estimation in herring (*Clupea harengus* L.) larvae

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Abstract

A controlled laboratory experiment was carried out to determine growth dependent otolith increment formation in herring larvae under constant and variable feeding regimes. Norwegian spring-spawning herring larvae were reared at 8°C for seven weeks using nominal prey densities of 40 (low) or 1200 (high) prey l⁻¹. Two groups of larvae were offered constant prey levels throughout the experiment (high and low), whereas the prey levels in two other groups were either temporarily increased or decreased. All groups were marked twice at the time of change in prey levels (day 18 and day 32 post hatching) by alizarin complexone immersion. Overall survival in the experiment ranged from 65 to 82%, and daily growth in length ranged from 0.04 to 0.4 mm day⁻¹. Average daily otolith growth in the low prey group was below 0.2 µm day⁻¹, and the apparent daily increment formation rate was significantly below one. The high prey group on the other hand had an increment deposition rate of about one after the first marking, and these increments averaged 1.1 µm. The alizarin marking confirmed that the otolith growth responded to changes in prey densities and larval growth within a few days.

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Growth and year class size variations of Pacific sardine (*Sardinops sagax caeruleus*) in Bahía Magdalena, Baja California Sur, México

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Abstract

Growth changes during the first life year of the 1981-1993 year classes, of Pacific sardine from Bahía Magdalena (Northeast Pacific), were analyzed. The average length by age was backcalculated using the functional regression among otolith radius and standard length (SL) of the fish. The von Bertalanffy growth model adequately described the Pacific sardine growth ($r^2=0.98$) during the study period (1981-1996). The results showed a selective mortality by length. The partially recruited age groups from commercial fishery, showed greater lengths (backcalculated SL at the otolith first growth band) than the completely recruited groups. There was a strong correlation between year class size and the average sea surface temperature (SST) registered during the time formation of the first opaque band on otoliths (spring-summer). A densodepend model including backcalculated SL at otolith first opaque band and the ratio of the SST to the age group-1 fish number (as survival index), explains 75 % of the variability in year class size.

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Progress in ageing juvenile Pacific swordfish via sagittal otoliths

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Abstract

Current results of otolith microincrement enumeration are based on sagittae from 27 Central Pacific swordfish specimens of 27-153 cm lower jaw fork length (LJFL). A dilute acid micro-etching technique applied to sagittae along the rostrum from core to rostrum tip is described. This technique exposes microincrements for examination via SEM and subsequent enumeration via image analysis software. Microincrement deposition rate remains unvalidated and were presumed to be produced daily throughout the lives of those fish examined. Preliminary results from power function regressions fitted to the length at age data indicate that at age 1, females have a mean length of 120 cm LJFL (95% C.I.=93-146 cm LJFL) and males 110 cm LJFL (95% C.I.=80-139 cm LJFL). Results of a similar power function fit to the rostrum length (core to anterior tip of rostrum) at age data indicates as good a relationship as that between LJFL and age. Future efforts will include the potential use of rostrum length as a cost-effective proxy for microincrement based ageing.

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PRECISION AND ACCURACY IN AGEING EURASIAN PERCH (*PERCA FLUVIATILIS* L.) AND ROACH (*RUTILUS RUTILUS* L.): DIFFERENCES BETWEEN STRUCTURES AND READERS

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Abstract

Fish ageing errors may either be related to formation of the hard structures, or be errors depending on the age determination. The first type of error can be assessed by comparative analyses of different types of hard structures from fish of known age. The second type of errors can be determined by comparing analyses made by different readers. In this study we have compared the results of age determination of two freshwater fish species common within the Nordic countries; E. perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*). In a first test we assessed the accuracy and precision when ageing E. perch using operculum bones and otoliths. In a second test we compared the age determination of roach using prints of scales, cleithra and otoliths. The results show that the deviation in age determination between age readers may be both random and systematic, and that for E. perch, operculum bones may underestimate the age of perch older than 7-8 years. The age determinations were substantially improved when several types of hard structures from the same individual were used, and when additional population characteristics, such as length, weight, date of catch, were provided. Intercalibration makes it possible to perform quality assurance tests for age determination and we suggest that this type of comparison is made within all types of ecological and environmental studies.

Key words: ageing of fish, intercalibration, operculum bones, otolith, cleithrum, scales, perch, *Perca fluviatilis* roach, *Rutilus rutilus*

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Interpretation of otolith structure: towards a reduced subjectivity

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Abstract

Although otolith composition, structure and accretion patterns are fundamentally similar among all fish, considerable variation exists in otolith growth as a result of environmental, population and individual differences. Consequently the interpretation of otolith microstructures and macrostructures is always difficult and not specifically related to any species. Such problems, often coupled with reader subjectivity and experience are the main sources of bias during otolith interpretation. The development of old otolith preparation methods concerning sectioning, staining along with other observation methods (SEM) has reduced the subjectivity of the reader. However these methods have also led to the observation of new structures which also require further interpretation. Comparison of readings (inter and/or intra-readers) has also been used to improve the accuracy and precision of the interpretation without reducing the part of subjectivity. Image analysis is the most recently employed tool in order to reduce reader subjectivity. However the result greatly depends on the quality of the primary image. To date, the interpretation of otolith structure by image analysis has been largely confined to 1 dimensional (radial) analysis. The development of 2D image analysis techniques analogous to eye vision would greatly improve the pattern recognition (i.e. ring detection). Nevertheless, ring detection using image analysis seems a more serious constraint for the interpretation of microstructures. It is also highly influenced by the subjectivity of both reader (user) and finally software developer. It is suggested that the knowledge acquired in reading otoliths by following standard procedures could be included in expert systems.

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Retention of oxytetracycline (OTC) marks up to 19 years

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Abstract

Injecting fish with OTC is a well-known method for validating age-determination methods. We started our age validation program with validating an age determination method for the long-lived marine species, Sablefish, *Anoplopoma fimbria*, in 1977. Fish tagged and injected with OTC in those early years of the program are still being recovered. After 19 years the OTC mark is clear, and confirmed that earlier interpretations of annuli formations remained valid. A reassessment of the method confirmed that careful examination of the otolith structure can produce both accurate and precise estimates of the age of sablefish.

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Use of otolith size to investigate growth rates in turbot *Scophthalmus maximus*

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Abstract

Otolith size was related to body size and growth rate in reared turbot larvae age 9-30 days, in juveniles age 400-800 days, in wild and reared, released turbot caught in the Kattegat 1991-95 and in wild turbot caught in the Baltic 1986-88. The relationships between otolith length and body length, between otolith area and body area and between otolith weight and body weight could all be described by linear regression models. Otolith size was observed to be affected by growth rate and slow growing fish tended to develop relatively larger otoliths. The effect of growth rate on otolith size was, however, small compared to the observed variations in otolith size. This limits the use of relative otoliths size as a measure of growth rate to comparisons of groups of fish with relatively large differences in growth rate. No difference could be observed in otolith size at length between sampling years or between Kattegat and Baltic turbot. Released turbot had significantly larger otoliths than wild turbot and male turbot showed a tendency for larger otoliths than female turbot. The observed differences are in accordance with expected differences in growth rate.

Contribution: 133

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Fish Otolith Research and Application
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The Application of Artificial Neural Networks to Automatic Fish Ageing

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Abstract

Current methods for estimating the age of fish are time consuming, rely on the ability of experienced readers and do not provide explicit information on errors associated with individual age estimates. Several attempts at fully automating this process have been tried in the past with little success. The Central Ageing Facility have been trialing Artificial Neural Networks (ANN's) as a means of classifying otolith images to estimate age. Artificial neural networks are numerical models which are capable of finding solutions to complex problems. A three layer feedforward back propagation ANN was trained to correctly identify the age classes of samples from transects of luminescence values from sectioned otoliths. The network was then presented with unseen transects and achieved results comparable to that of an expert reader for two of the three species trialed. In addition to the predicted age, the distribution of ANN outputs quantifies the level of confidence in each assigned age, a measure which has not been previously possible to obtain. The outputs can therefore be used to discriminate samples which are not adequately described by the model, to further reduce the error between the observed and predicted age. ANN's provide a means to minimise differences between readers and laboratories combined with the rapid processing of samples for production ageing. Artificial neural networks can replicate the interpretation of an expert reader to provide a reliable system for automatic age estimation.

Contribution: 139

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Age estimation by digital image processing : some fundamentals

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Abstract

Age estimation with calcified structures is mainly based on visual perception and thus digital image processing has been widely used for data collection assistance and reader objectivity improvement. Despite research efforts undertaken since the 70's, most of today computer assisted age reading software still proposes rough interactive tools, except for few specific cases. It is suggested that this situation is due to the fact that some fundamentals are neglected in those tools. Through the analysis of application studies, we describe the constraints introduced both by signal processing and by biological features. From this, we present and discuss some basic requirements for conducting age reading automation.

Invit. 8

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Recent otolith growth in relation to condition indices in pelagic juvenile fish - is faster growth better?

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Abstract

Indices of condition, or health in larval and pelagic juvenile fish reveal the integrated effect of rearing techniques or oceanographic conditions over a variable and unknown time period. In this paper, condition indices are classified as either growth, starvation, feeding, storage and/or morphometric measures. Recent changes in length or weight, is back-calculated from recent otolith growth (ROG) over the previous 2-14 days precapture, using the biological intercept method. ROG is used to calibrate some storage and morphometric indices in terms of growth in length or weight, and used to determine the temperature dependent time period over which each index operates. Issues associated with the laboratory calibration of any growth and condition index are investigated and compared with ROG determined in the laboratory and field. The 1-2 day temporal fidelity of ROG to starvation events is examined in some reared pelagic juvenile gadiform and perciform fish, which is compared to an index of protein synthesis (relative RNA concentration), and to the problem of temporal lags between otolith and somatic growth. The relationship of ROG to condition indices, to the environment and to survival is reviewed, and illustrated in the relative survival of six cohorts of juvenile tropical reef fish.

Contribution: 152

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State of knowledge of the growth pattern of the European hake (*Merluccius merluccius* L.)

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Abstract

The study of the population dynamics of exploited fish relies on knowledge of the growth pattern of the population concerned to determine its demographic structure and to assess its status and exploitation pattern. The growth of the European hake (*Merluccius merluccius* L.) has been the subject of a large number of studies. Research has largely focused on age determination studies based on the interpretation of the otoliths' pattern of rings and to a lesser extent on length composition modal analyses. In spite of many efforts, as yet there is no agreement among authors so as to the growth pattern of this species which is an important target of groundfish fisheries in the Northeast Atlantic.

This review examines the age determination and growth studies of European hake conducted until present. Traditional and alternative methods are examined for both age and growth estimation with particular emphasis given to the main sources of discrepancy such as location of the first annual ring, discrimination of checks and interpretation of the edge. In view of the wide range of estimations obtained by different authors and methods, the implications for the assessment of European Northeast Atlantic hake stocks are considered.

Contribution: 155

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How are growth rate and nutritional condition reflected in the otolith structure and RNA/DNA ratio- coupled analysis on herring larvae from the mesocosm

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Abstract

Spring-spawned North Sea herring eggs from Norway and the Scottish River Clyde were artificially fertilized, incubated in the laboratory and released into a mesocosm and Flodevigen Marine research station. Herring eggs were tagged with Alizarin complexion 1-2 days before hatching for later separation of the two stocks. Herring larvae were sampled every three days from day 1 until 8 weeks after hatching. Length, dryweight, protein content, RNA/DNA ratio and otolith microstructure analysis was performed simultaneously on the same larvae. After four weeks of feeding a group of larvae was transferred to a bag floating in the mesocosm and deprived of food for a period of 18 days. Samples of starving and feeding larvae were taken twice a week during that period. A reduction in somatic growth (measured as dryweight, length and protein content) and otolith increment width in the starving group was seen. The link between somatic growth, nutritional condition and otolith structure will be shown and discussed.

Contribution: 179

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Backcalculating size at age: use and misuse in estimating growth

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Abstract

Retrospective estimation of size at age from otoliths provides valuable data for use in estimating growth. Estimates of the individual's previous growth history greatly increases information beyond that of size and age at capture. However, the proper use of these data has proven problematic. A review of the published literature reveals discussion of proper algorithms for ratios of otolith to fish size and the effect of regression intercepts on predicted growth. The more fundamental constraint -- lack of independence in retrospective measures of size at age-- has been largely overlooked. When independence is mistakenly assumed, growth parameters are estimated incorrectly. Improper use of these data results in incorrect estimates of precision due to the inflation of degrees of freedom, among other problems. Using data from Atlantic menhaden, *Brevoortia tyrannus*, I demonstrate the effects of ignoring the autocorrelation of growth within an individual when fitting growth functions and demonstrate the appropriate use of repeated-measures, mixed-model, nonlinear regressions.

Contribution: 188

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Pattern recognition applied to morphological analysis of daily and annual bands on otoliths:
estimation of fish age and growth

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Abstract

At present, there exist some computer-aided systems to analyse periodic bands of fish otoliths and other structures for age estimation. But, in general, these systems are semi-automatic. In this paper we address problems related to age estimation or code bars marking using pattern recognition techniques. The first subproblem deals with the morphological analysis of induced rings in the otoliths of juvenile fish introduced by temperature variation. Our purpose is the extraction of lines from digitalized images and their biological interpretation in the context of growth evaluation and quality control in fish breeding. The second sub-problem concerns the line reconstruction process in adult otolith images. We propose a two step method to age estimation. The first step consists of the extraction of dark lines based on a filiformity topological measure. The output of the procedure is a set of binary segments lying on annual rings. In a second step, we analyse each segment (length and mean curvature) with a skeleton detection algorithm to extract highly significant segments using morphological constraints. Finally, we reconstruct annual rings with a snake algorithm (adaptive curves).

We present preliminary results of this fully automatic approach for morphological analysis of fish otolith images.

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Otolith microstructure examination and growth patterns of *Vinciguerria nimbaria* (Photichthyidae) in the tropical Atlantic Ocean

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Abstract

Otolith microstructures of *Vinciguerria nimbaria* from the tropical Atlantic Ocean were examined in order to explain the peculiar behavior of this small mesopelagic fish species. One part of the population forms schools near the surface during the day while the other part keeps undertaking diel migrations between the surface (night) and the bottom (day). Thin transverse sections of the otolith (10 to 40 μm thickness) showed an extremely clear succession of daily-like microincrements along the dorsal and ventral axis. So far no validation of the microincrement deposition could be undertaken on this fragile species. Five distinct growth zones were observed along the otolith of all individuals representing some common life history events during larval stages, metamorphosis, juvenile and adult stages. The lifespan is probably very short (120 to 150 microincrements counted, with a maximum of 240), probably less than one year. Nevertheless differences in growth patterns were not recorded between migrating and non-migrating individuals during the day. Several experimental designs are proposed for the future validation.

Contribution: 200

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Age and growth of the Pacific grenadier (Family *Macrouridae*, *Coryphaenoides acrolepis*)
with age estimate validation using an improved radiometric ageing technique

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Abstract

Longevity estimates for the Pacific grenadier, *Coryphaenoides acrolepis*, range from 6 to greater than 60 years. Age estimates in this study, using the quantification of growth increments in otolith sections, indicate the Pacific grenadier is long-lived and may approach 75 years. Prior to this study, traditional ageing of this fish was not validated. To validate this trend, the radioactive disequilibria of ^{210}Pb and ^{226}Ra in otolith cores was used to determine age using an improved radiometric ageing technique. This technique isolates ^{226}Ra using ion-exchange chromatography and measures ^{226}Ra using thermal ionization mass spectrometry (TIMS). Because TIMS measures radium directly by counting ionized atoms, the accuracy and precision of the technique is superior to conventional alpha-spectrometric methods. Samples in this study were more than two times smaller than attempted in other studies, and had increased accuracy and decreased processing time. Radiometric ages for the Pacific grenadier closely agree with traditional age estimates. This confirms the annual periodicity of the growth increments. Radiometric results indicate the Pacific grenadier can live at least 56 years and growth increments indicate longevity can be at least 73 years. Because the Pacific grenadier is long-lived and matures late in life, it may be vulnerable to fishing pressure.

Contribution: 9

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Age and growth of *Clarias batrachus* (Linn.) as determined by otolith

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Abstract

The age and growth of *Clarias batrachus* (Linn.) was determined with the help of formation of periodic translucent alternating opaque zonation on otolith and length-frequency studies. A straight relationship between the total length and the otolith length of the fish was found. The annual growth rates for 1st and 2nd age groups, 2nd and 3rd age groups and 3rd and 4th age groups were found to be 4.3, 3.8 and 3.7 cm respectively, leading to the conclusion that the growth rate of fishes was rather fast during their first year than during the successive years. Seasonal variations in length-frequencies revealed that four peaks (15.0, 20.0, 25.0 and 30.0 cm) can be considered as age groups I, II, III and IV, respectively, which was directly correlated with the mean length representing the I, II, III, IV translucent alternating opaque zonation on the otoliths. Present observations attributed the periodic formation of the translucent and opaque zonation on the otolith to the reduction in feeding activity of the fish, which occurs simultaneously with the maturation of gonads.

Contribution: 14

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Use of the back-calculation in studies of growth: Case study of the Chilean horse mackerel
Trachurus murphyi (Caragnidae)

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Abstract

The proportional back-calculation (PBC) is a technique that has been used in studies of growth in fish when the youngest individuals of the population are not had. Their use is frequently confused with a mere analysis of regression.

The PBC has been used normally in order to determine the growth of exploited populations, only using the sample obtained of the stock without evaluating the possible deviation of the results with individual that represent the range of the population ages.

Information of the horse mackerel of the north zone of Chile is used, in order to compare the differences between the results of the PBC and regression techniques and also the curves of growth obtained are compared with the PBC and a sample that will represent the complete range of the population ages.

The PBC and the regression techniques give results without significant differences. These results when being compared with a sample that contains the complete range of ages of the population, present av wide deviation in the growth parameters.

According to the results, it is suggested that in studies of fish growth the use of the back-calculations must be validated.

Contribution: 27

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A comparison of age determination from scales and otoliths for Kamchatkan stocks of walleye pollock (*Theragra chalcogramma*)

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Russia

Abstract

Age determination from scales and otoliths have been compared for different stocks of walleye pollock inhabiting Kamchatkan coastal waters, as namely: east part of the Sea of Okhotsk, Pacific waters off southeast Kamchatka, west part of the Bering Sea and the part to the eastward from 178° 00' E (cape Navarin area). More, than 5000 samples of scales and otoliths were collected together through 1996-97. Comparative data analysis for the stocks of walleye pollock from the west and north parts of the Bering Sea indicates of small difference in age composition, estimated by using two methods. Reliable difference ($P < 0.001$) between age readings on scales and otoliths has been found in fishes of 56 cm in length and upwards, i. e. in older age groups. Similar tendency has been noted for the stock of walleye pollock from adjoining to southeast Kamchatka waters of Pacific Ocean (sampling for 1997). Comparison of age estimations on scales and otoliths for the stock of walleye pollock from the east part of the Sea of Okhotsk indicates of occurring reliable difference ($P < 0.001$) for individuals over 38 cm in length. An average divergence between age estimations for dominant generation in 1996-97 is one year, it being the age estimation on the otoliths older. Some biological parameters of walleye pollock have been compared in a respect to the age composition estimated on scales and otoliths. The correlation between length, width and mass of the otolith and body-length of fishes have been calculated. The correlation between otolith mass and body-length of fish is much obvious ($R = 0.94$).

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Ageing squid using statoliths: Noise and some data

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Abstract

Squid statoliths are characteristically small and have complicated external morphologies. Sectioned statoliths reveal complex internal microstructure (morphological and elemental) which changes according to the sectional plane and which varies according to the techniques of preparation employed. Squids are now routinely aged using statolith increment counts (usually from transverse sections). The "wide" (=second order) increments are counted and are generally treated as daily increments. All other structures (particularly ring patterns) are considered as "noise". This interpretation has been justified by various validation attempts, limited so far by low numbers of individuals analysed, incomplete size ranges, high rejection rates, frequent errors encountered, etc. The conclusions, emerging from this research to date, are as follows:

1. There are certainly some increments in squid statoliths which are deposited daily;
2. There is evidence that, sometimes, daily increment(s) may not be deposited at all;
3. Whether "wide" (second order) patterns may always be regarded as daily increments, is open to debate;
4. There are many varied ring patterns, visible on various statolith sections, which cannot be defined as increments;
5. Therefore, there are large, compound errors involved in ageing squid using statoliths, and the knowledge as to the nature of these errors is poor.

Contribution: 40

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An Evaluation of Back-Calculation Methods with Simulated Otolith Data

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Abstract

I simulated somatic growth and accompanying otolith growth using an individual-based bioenergetics model in order to examine the performance of several back-calculation methods. Otolith growth was modeled as a function of brain weight and temperature, and four shapes of otolith radius-total length relations (OR-TL) were simulated. Ten different back-calculation equations, two different regression models of radius-length, and two schemes of annulus selection were examined for a total of twenty different methods to estimate size at age from simulated data sets of length and annulus measurements. Each method was evaluated by comparing each of the estimates of size-at-age to known (true) size at age. The best back-calculation technique was directly related to how well the OR-TL model fit. An individually corrected Weibull cumulative distribution function is presented and, although not always resulting in the best outcome, proved to be very flexible in fitting different shaped OR-TL.

Contribution: 47

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Validation of daily increments in the otoliths of *Anguilla anguilla* (L.)

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Abstract

Eel larvae were caught over the continental slope of the Southern Bay of Biscay in November 1995. Twenty four just transformed eel leptocephali (stage IV) were kept alive and dyed in Alizarine Complexon (0.1 g.l⁻¹) twice, with an interval of 18 days. They were kept in constant conditions in 60 l. dark containers immersed in the 15 m³ ship tank. Then they were sacrificed 13 days after the second marking. Their otolith reading was successful for 16 individuals and revealed that, in addition to the Alizarine impregnation, deep stress checks due to handling allowed to use the SEM photographs. Increments deposited in the between-mark time were very faint, but of the same width than the previous increments. The width of this between-mark zone was equivalent to the width of the 18 increments just preceding the experiment, thus proving that increments are formed daily. This validation provided an estimate of the age of eel leptocephali at the onset of their metamorphosis, which is about 6-7 months. Hence, the total age of glass eels entering the French estuaries can be confirmed and is less than one year. The effect of diurnal variation of depth, light and temperature on the increment deposition is discussed, in regard with the constant conditions experienced in this study.

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Potential use of otolith weight for the determination of the age-structure of cod (*Gadus morhua*) and plaice (*Pleuronectes platessa*)

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Abstract

An estimate of the age structure of a fish population is essential for most of the forms of stock assessment and this is often derived by ageing a sample of individuals and calculating the relative abundance of each age-class. Unfortunately, while traditional methods to determine the age of fish (such as annuli in sectioned otoliths) provide relatively precise estimates of age, they are normally expensive and time-consuming, which usually restrict the size of the sample used. As showed by several authors, the weight of otoliths may provide an objective and economic method of ageing fish since otoliths increase in weight throughout the life of a fish. Otoliths of cod and plaice, collected from 1991 to 1997 were used to estimate the relationship between otolith weight and age in different years and areas. The differences between the estimated age-structures using otoliths weight and the true age structure determined from annuli in sectioned otoliths were statistically tested. The potential use of otolith weight as an estimator of age structure was discussed.

Contribution: 51

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AUTOMATION AGING OF SEA MARKETIBAL FISH

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Abstract

We are developing whole informative technologie for sea marcetibal fish. This one includes: 1. The usage imaging and automation of calcified structure diagnostic system 2. The standartisation of specimens preparation and of conditions images capturing 3. The usage of diagnostic characteristics to raise aging validation 4. The bank of standard patterns and the algorithms of which provides reproduction of age estimation. Compared with similar systems, Imaging and automation of calcified structure diagnostic system (IM) is developed specifically for application that use scales, otoliths, bones, etc. The technique was developed for Sebastes, Cod, Pollock, Halibut and others species from various Pacific and Atlantic ocean areas. It has the peculiarities for different objects. The usage of diagnostic characteristics includes: back-calculation of fish lenghts increments, allocation of falling brightness in luminance diagram, and the analysis of periodicity by spectral function of profile. It allows to decrease errors while recognising of annual rings. Several algorithms were employed for different version: when increments are considerably varying by sex or areas and age decreases. Computer estimation of rings is fast and reductions age errors and makes it more objective and reproductive. For algorithm of age validation similar human productiviti can be 1600 otoliths per day (Pentium processor) and age validation more then human can be 540 otoliths per day. High age validation needs more power resourOes.

Contribution: 52

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Age and growth of the southern blue whiting *Micromesistius australis* in the Argentine Sea.

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Abstract

Sagitta otoliths were used for age determination in 3500 specimens of *Micromesistius australis*, from some research surveys and commercial catches within the South West Atlantic during 1994 and 1995. The size of fishes ranged 17 cm to 60 cm of total length,; the mean weight -at -age, mean, length -at -age , and Z were estimated. The species has a fast growth before reaching the first maturity (about 59% of the asymptotic length in males and 61% in females). The ages 3 to 9 were the most frequent in the catches. . A significant difference in growth between sexes was found. Estimation of growth parameters (von Bertalanffy growth equation) was done by a maximum likelihood method,as follows: $L_t = 53.85 \text{ cm} [1 - e^{-0.2368 (t + 0.9524)}]$ in males, and $L_t = 59.66 \text{ cm} [1 - e^{-0.2088 (t + 1.1990)}]$ in females , for the year 1994. For estimations these parameters age groups 0 to 19 (in males) and 0 to 20 (in females) were taken into account. The maximum age was 23 years. According to the overlapping of the confidence intervals built around each growth parameter, the differences among males and females are due to the asymptotic length.

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Otolith daily increments and growth of 0 year-old of *Macruronus magellanicus*, and first annuli formation, in Argentine waters.

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Abstract

Daily increments in otoliths of 0 year-old of *Macruronus magellanicus* collected in May 1993 and February, May and August 1997 around Argentine waters were studied. Otolith daily increments were generally observed clearly under a light microscope (x200-400). Number of increments were counted as 94 for 50 mm TL specimen collected in February, and as 160-228 for 140-205 mm TL specimens in May, showing that they hatched mainly in November. The growth pattern of 1997 specimens was shown in a following formula; $L=1.27D-62.70$ ($r=0.96$, $n=8$) where L and D were TL and the age in days each. Mean TL of 1997 May specimens (198.14 ± 7.73 mm) was larger than 1993 May specimens (162.22 ± 12.02 mm) regardless of their hatching period being close, suggesting that 1997 specimens grew faster than 1993 specimens. In otoliths collected in August, the translucent zones, consequently being observed as the 1st annulus, were observed at otolith edge, showing that the annulus was formed during winter.

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Backcalculation of fish length and planktonic larval duration from marks on otoliths:
validation of methods for three *Diplodus* species in the Mediterranean sea

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Abstract

The validity of backcalculation techniques used to estimate fish length and age at settlement from marks on otoliths was tested for three species of sparid fishes in the Mediterranean sea. The relationship between fish length (L) and otolith radius (R) was best described by the non-linear model of Fry ($L = a + b.R^c$) and the resulting backcalculated growth curves were not significantly different from the observed ones. Length estimation both by otolithometry and visual censuses was thus validated for the three species studied. Absolute growth rate in terms of otolith radius (dR/dt) increased until settlement and decreased afterwards for *Diplodus putazzo* and *D. vulgaris*, which settled in cold waters (late autumn to winter), but did not decrease after benthic installation of *D. sargus* which settled in warm waters (late spring to early summer). Nevertheless, relative growth rate in terms of fish length ($dL/(L.dt)$) reached a maximum at settlement in all species. This peak in fish growth was thus validated to be a reliable mark of settlement and will permit accurate backcalculation of planktonic larval duration in these three sparid species.

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Age and growth of black seabream *Spondyliosoma cantharus* off the Canary Islands, Central-east Atlantic

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Abstract

Age and growth of the black seabream *Spondyliosoma cantharus* off the Canary Islands were determined by interpreting growth rings on the cross section of the otoliths. The alternative pattern of translucent and opaque zones was easily distinguishable on the otoliths. Of the 1276 otoliths examined, 81.1% were readable. Individuals aged 0 to 10 years old were present in the samples. The von Bertalanffy growth parameters obtained for the whole population were: $L_{\infty} = 43.35$ cm, $k = 0.24$ yr⁻¹, and $t_0 = -0.11$ yr. Significant differences in the growth parameters were found between males and females. The growth of the black seabream off the Canary archipelago was similar to that reported for the same species in other regions.

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Growth of axillary seabream *Pagellus acarne* off the Canary Islands, Central-east Atlantic

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Abstract

Growth of axillary seabream *Pagellus acarne* off the Canary Islands between January 1991 and December 1994 was determined by means of otoliths interpretation and length frequency analysis. Both methods provided very similar results for the whole population. The growth parameters obtained by reading otoliths were $L_{\infty} = 32,98\text{cm}$, $k = 0,225 \text{ yr}^{-1}$, and $t_0 = -0870 \text{ yr}$. The values of the parameters of the seasonally oscillating von Bertalanffy growth equation, determined by the method of Pauly and David (1981), were: $L_{\infty} = 35.02 \text{ cm}$, $k = 0.208 \text{ yr}^{-1}$, $C = 0.610$, and $WP = 0.950$.

Contribution: 57

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On the uncertainty of herring otolith ages

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Abstract

A set of otoliths from 196 Baltic herrings (*Clupea harengus* L.) from commercial trap-net catches was aged by the authors. All three readers agreed on 70% of the fish and agreed pairwise on 72-85%. Age estimates for individual fish differed by as much as 5 years. The three age distributions obtained were similar, but bias was present between all three pairs of readers. Variability was highest in the older fish, and the deviation between ages assigned correlated with fish size. Between readers, the calculated mean length at age differed for age-group 7 only, and the estimated mortality for ages 4-10 varied from 0.4 to 0.5.

The validity of herring otolith ages and the effects of age determination variation on the use of age-structured data are discussed.

Contribution: 59

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The influence of light period and feeding frequency on the distinctness of daily otolith increments in larval coregonids (*Coregonus* spp.)

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Abstract

In larval and juvenile whitefish (*Coregonus lavaretus*) from Lake Constance, Germany, otolith increments are deposited daily, whereas daily deposition could not be confirmed in larval whitefish from Lake Pyhäselkä, Finland. While Lake Constance whitefish experienced 12 to 14 hours light per day, light intensity in Finnish lakes was under 100 lux for about two hours only and complete darkness was never observed. Therefore, we tested the hypothesis that lack of a clear zeitgeber leads to an irregular formation of otolith increments so that daily increments cannot be counted unequivocally. The alternative hypothesis is that continuous feeding throughout 24 hours provokes the formation of subdaily increments. This hypothesis is based on the concept that otolith growth is induced by specific dynamic action (SDA), which includes biochemical and physiological processes that are associated with feeding. Under continuous light, SDA will stay at elevated levels throughout the day which could lead to the deposition of multiple increments per day. Whitefish larvae were reared under continuous illumination, and they were either fed during 24 hours or during 12 hours only. Control groups were reared under 12 to 14 hours light and were fed during 12 hours. After four weeks, otoliths were removed and increments analysed. Control fish had clearly defined daily increments. Fish from the continuous light/12 hours feeding groups had some subdaily increments but still could be aged reliably. Fish from the continuous light/24 hours feeding groups had many narrow increments and could not be aged. These results lend support to the second hypothesis that elevated levels of SDA lead to the formation of multiple increments per day, while the first hypothesis was rejected.

Contribution: 60

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Fluorochrome marking of embryo otoliths with Alizarin Red S

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Abstract

Fluorochrome marking of fish otoliths is becoming increasingly important for mass marking of fish at the embryo and larval stage. When hatchery capacities are sufficient for handling large amounts of larvae, these can be marked by immersion in Alizarin Red S (ARS) solutions. Low pH values, however, should be avoided. Whitefish (*Coregonus lavaretus* L.) larvae which were immersed for three hours in 300 mg/l ARS had 100% mortality at pH 7 and lower, while in control groups mortality was 50% at pH 6 and 10% at pH 7. When hatchery practices do not permit the marking of larvae, eyed eggs must be marked. This is the case at Lake Constance, e.g., where up to 500 million of whitefish eggs are incubated annually, and most larvae are immediately released into the lake at the time of hatching. We developed a method for mass marking whitefish eggs in ARS solutions of 5000 mg/l, where incorporation of the fluorochrome into the egg is facilitated by osmotic shock (5 % NaCl).

Contribution: 64

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Age and Growth of Flathead *Platycephalus* sp. from the Coastal Waters of West Kyushu, Japan

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Abstract

Age and growth of flathead *Platycephalus* sp. (Japanese name: Magochi) were estimated from transverse sections of otoliths for 545 specimens collected from the coastal waters of west Kyushu, Japan. Marginal increments showed that one annulus formed during summer months. Gonadosomatic indices indicated that the fish spawned from spring to summer. Assuming a birth date of June 1, ages were assigned to every individual according to the number of annuli and the value of marginal increments. The von Bertalanffy growth equation for males was $L_t = 430.3 (1 - \exp(-0.667 (t+0.093)))$, and for females was $L_t = 551.5 (1 - \exp(-0.478 (t+0.125)))$, where t is age (year) and L_t is total length (mm) at age t . Maximum age observed was 16 years for males and 11 years for females, and the lengths of females calculated from the equation were larger than those of males at any age.

Contribution: 66

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The temporal and spatial dynamics of spawning, settlement and growth of the gray snapper (*Lutjanus griseus*) determined using otolith microstructure

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Abstract

Juvenile gray snapper (*Lutjanus griseus*) were collected over two consecutive years from seagrass meadows off the West Florida shelf using a benthic scrape and otter trawl. Three main sampling regions were compared to determine patterns in the temporal and spatial variation of spawning, settlement and growth. Pre-settlement processes were inferred using the otolith microstructure of post-settlement survivors. Histological samples of gonads from adults collected near the juvenile sampling areas were used for an independent estimate of spawning dates. Daily growth increments were visible in the lapillus of snapper 11 to 150 mm standard length. These daily growth increments were used to calculate growth rates and to back-calculate spawning and settlement dates. Ages ranged from 35 to 226 days. Growth estimated as the slope of the regression of SL on age ranged from 0.62-1.06 mm/d. No significant difference was noted for growth rates among the three sampling regions or across sampling years. Birth dates for 1996 occurred mainly during summer, while 1997 birth dates occurred both winter and summer. Back-calculated settlement dates occurred during the summer both years and also in the winter of 1997. Settlement dates did appear to be correlated with moon phase, however birth dates did not.

Contribution: 67

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A new ageing technique for Birdbeak dogfish (*Deania calcea* Lowe, 1839) dorsal spines

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Abstract

The commercial fleet, due to its recent tendency to explore newer and deeper areas, commonly catches deep-water species. This led to an increase on the research of their biology and population dynamics.

Birdbeak dogfish is a squaloid shark captured in research surveys held by the Portuguese Marine Research Institute - IPIMAR, along the Portuguese continental slope at depths between 500 m and 900 m.

At IPIMAR, growth studies on this species based on the analysis of different calcified structures began in 1996. The satisfactory results obtained using the second dorsal spine, as ageing material is a good indication for its future use on age assignment.

The present paper describes the technique developed for enhancing growth bands on *Deania calcea* dorsal spine. The technique includes decalcification and staining of fine transversal spine sections. Applying this technique to several specimens a clear growth pattern became evident on the sections analysed.

Key words: *Deania calcea*, dorsal spines, ageing technique

Contribution: 72

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First observations on otoliths of grass goby populations in Venice Lagoon

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Abstract

The grass goby *Zosterisessor ophiocephalus* (Pallas, 1811) is one of the most typical species of ichthyofauna in Northern Adriatic coastal lagoons. Its linkage to the seagrass prairies environment makes this benthic species suitable for ecological and ethological studies, and it is considered to be, together with sand smelt (*Atherina boyeri*), the most important target species of small scale fisheries in Venice Lagoon. In this paper we report first data on otoliths of grass goby for the area considered, with respect to dimensions of sagittae, lapilli and asteriscii, described with the aid of an image analysis system. Furthermore, a comparison of growth of populations living in different areas of the Venice lagoon is proposed, based on annuli/fine increments readings and regressions of fish size vs. otolith size. Preliminary observations carried out on sagittal sections of embedded otoliths showed the nucleus of grass goby sagittae to be composed by several primordia.

Contribution: 76

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Otolith daily increments and first annuli formation of *Micromesistius australis* in the Argentine sea

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Abstract

Otolith daily increments were observed in juveniles of *Micromesistius australis*, ranging from 130 mm to 250 mm in total length, collected in the Argentine Sea in february 1995 and September 1996. Daily increments were clearly observed with a transmitted light microscope (x 200-400). The number of increments in juveniles of 130 to 150 mm ranged between 150 to 200 showing that they were 0 year old and the hatching took place between September to November. Besides increments of juvenile between 190 and 240 mm in total length collected in September, wich were considered to be about 1 year-old showed a clear daily increments until beginning of winter in all specimens. Results of daily increment indicate that in *M. australis* the first annulus formation occurred at 19 to 23 cm in total length.

Contribution: 80

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Validation of annual growth rings in the otoliths of the lutjanids *Pristipomoides filamentosus* and *Aprion virescens*, and the lethrinid *Lethrinus mahsena*, from sites in the tropical Indian Ocean

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Abstract

The study investigated the growth of the lutjanids *Pristipomoides filamentosus* and *Aprion virescens*, and the lethrinid *Lethrinus mahsena*, commercially important demersal reef species from the central Indian Ocean. Due to their relatively long-lived, slow growing nature, length frequency analyses are unsuitable, although these methods are still commonly applied. To obtain more reliable estimates of growth, otolithometry was used. Successful validation of annual, and in some cases daily, marks has been reported in these species from a number of locations, but not for the target areas of this study; Seychelles, Mauritius and the British Indian Ocean Territory (Chagos Archipelago).

This paper describes the utility of otolithometry for ageing the target species. Otoliths were collected from the study fisheries over an extended period. A range of methodologies were used in an attempt to validate the otoliths. These included back calculation, marginal increment analysis and Scanning Electron Microscopy relating the number of daily rings to annual rings.

The results of validation are presented, along with a description of the problems encountered, and a critique of the suitability of the methodologies used. Conclusions are drawn regarding the assumption of annual or daily rings based on validation achieved in other locations.

Contribution: 83

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Evidence of the relationship weight of otolith - age for the Chilean horse mackerel *Trachurus murphyi* (Carangidae)

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Abstract

The difficult interpretation and reading of horse mackerel otolith forces search of new methodological procedures in order to estimate the age. The objective of the present study is to present evidences of the otolith weight (OW) and age relationship of horse mackerel. The evidences come according to the persistence and temporary progression of the OW, finding the displacement of 10 modes, carrying out the analysis with MULTIFAN. The relation of the OW and the age, which was estimated by means of the method of integration of the density of daily growth increments, was significantly and of lineal form. The numbers of modes present in the distribution of OW upon relating them with a sequence of ages was that the first mode had a mean weight of 15.88 mg, that according to the age-OW relationship corresponds to individuals of 2.5 years old. Also, the existent relationship between the mean length was analyzed, estimated with the OW and the mean length for age groups obtained with an independent analysis, revealing the analysis of 9 age groups and the mean length belong together directly with the mean weight. The results are discussed in function of the potential use of OW for the monitoring of the fishery and elaboration of size-age keys and how to improve the estimates of age using OW.

Contribution: 84

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Growth of the Chilean hake (*Macruronus magellanicus* L.) of the Center-South Chile using otolith weight-age relationship

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Abstract

The otolith weight (OW) - age relationship is in this moment a tool of great potential to estimate the age of fish. In this study, the growth of the Chilean hoki is analyzed using the OW. A linear relationship between OW and age was fitted by regression, the age was determined using the traditional method of reading otoliths. The monthly OW-frequency distribution was analyzed in order to determine the number of year classes present and the average OW increment between age-classes was compared using the OW-age relationship. Annual growth was also estimated by analyzing a length-frequency data set through the MULTIFAN method. The OW-age relationship is highly significant ($r^2=0.918$, $n=1228$, $p<0.05$). In the OW-frequency data was estimated 13 modal groups, having the first group a mean OW of 87.9 mg. The age estimate for the mean weight of the first age group is 3 year-old, increasing every 1 year until complete 15 years. The von Bertalanffy growth parameters estimated using the OW are $L_{inf}= 85.1$ cm, $K= 0.142$ yr⁻¹, and $t_0= -0.902$ yr, while the growth parameters from length frequency analysis were $L_{inf}= 90.2$ and $K= 0.136$ yr⁻¹. The growth estimated using MULTIFAN is in agreement to the growth predicted from OW. The advantages of the use of the OW in terms of obtaining a better description of the growth in length are discussed.

Contribution: 92

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Growth rate, hatching-date distribution and otolith microstructure of larval and juvenile spring-spawning herring (*Clupea harengus* L.) from the Vistula Lagoon, Baltic Sea

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Abstract

Larval and juvenile spring-spawned herring (*Clupea harengus*) were collected in the Vistula Lagoon of the Baltic Sea. The otolith microstructure in the sagittae was examined, and the age and growth rates of fish collected at different periods in May-August 1997 were estimated. The hatching dates were back-calculated from otoliths as well and the results were compared with those obtained from the fish size-frequency analysis. The effect of temperature on the width of daily increments was investigated. In addition, the relationship between otolith growth and somatic growth were analyzed with regard to the assumption of proportionality between otolith growth and fish growth.

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Age and growth of dominant fish species in the Ria de Aveiro (Portugal)

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Abstract

The community dynamics and the growth/age relationship of the fish fauna were investigated in the Ria de Aveiro, an estuarine coastal lagoon system (43 Km²), which has both marine and fluvial influences. The fishes were sampled in nine strategic stations during twelve months. They were taxonomically identified, measured, weighted, and age estimated by otolith reading. The *Atherinidae*, *Mugilidae*, *Moronidae* and *Gobiidae* families were the most representatives in terms of density. The ecological guilds sedentary species and marine juvenile migrant species presented the higher species richness. The oldest specimens are included in these guilds. The specimens frequency was inversely proportional to the age. The growth in length is substantial all along the age. The condition factor of the oldest fishes is, in almost cases, higher than in the young ones.

Contribution: 101

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Age determination and growth of *Pontinus kuhlii* (Bowdich, 1825) in the Canary Islands

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Abstract

Sagittal otoliths (n=421) and scales from specimens of *Pontinus kuhlii* (Bowdich, 1825) of between 16 and 46 cm total length collected around the Canary Islands were examined in order to determine their age and growth parameters. Age was estimated by direct reading of annual rings using a profile projector (scales) and stereo microscope (otoliths). The first of January was considered as a birthdate for age class attribution. The growth parameters were estimated by least squares method using SPSS program ($K=0.096$, $t_0=1.0058$, $L_{\infty}=52.22$). Both structures showed many false rings that made their interpretation much more difficult, and a greater distance between the 4^o and 5^o rings in relation to the previous zone was detected. Ages were estimated between 6 and 18 years and thus the relation between the size and the age was established by means of the corresponding key.

Contribution: 109

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Sex-related variations in growth of juvenile turbot (*Scophthalmus maximus*) under semi-controlled rearing conditions : first evidence from a short-term experiment

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Abstract

Hatchery-produced turbot were used to test the assumption of the non-existence of sex-related differences in growth of juveniles. The fishes were marked both externally and using otolith tagging. They were kept in tanks supplied with natural sea-water from March to mid-May. Fish samples were taken in order to (i) estimate growth through somatic and otolith variables, (ii) take blood samples for hormone analyses (thyroid hormones T3, T4, and growth hormone GH) and (iii) identify sexes and calculate the gonado-somatic index (GSI). At the beginning, the average GSI were already 3-fold greater in females than in males. Despite highly variable daily temperatures, the fishes doubled in size (wet weight WW \pm sd from 58.6 \pm 11.4 to 124.2 \pm 34 g). However, the mean growth rate (G) was variable. The average values for circulating hormones were not different between sexes and were in the normal range for turbot, except for T3 and, for GH, only when G variations were the greatest. Individual growth trajectories, drawn from otolith microstructures, were variable in females, buffering the initial differences between slow- and fast-growing otoliths and possibly indicating a tendency toward 'uncoupling'. In males, individual trajectories showed an increasing difference between slow- and fast-growing otoliths. From otoliths it was concluded that females exhibited higher capabilities for growth regulation; males in contrast could generate more size variation. Although preliminary, these findings should stimulate long-term studies of growth strategies in immature turbot.

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Age and Growth of *Cynoscion guatucupa* and *Cynoscion jamaicensis* (Teleostei, Sciaenidae) in the Continental Shelf of Ubatuba, Brazil (23°S 45°W) through Analysis of Thin Slices of Otoliths.

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Abstract

In order to confirm relative ages and growth parameters estimation based on length frequencies analysis (ELEFAN), thin slices of the Sagitta otoliths from *Cynoscion guatucupa* and *Cynoscion jamaicensis* were prepared. The margin of each otolith was classified as opaque or translucent, the seasonal rings were counted and the marginal increment was measured. It was verified that for both species opaque rings are formed in spring/summer, when the South Atlantic Central Water mass, cold and rich in nutrients, reaches the area and causes a seasonal enhancement of production. *Cynoscion guatucupa*, which is associated to cold and relatively deep waters, presents well formed rings, while in *Cynoscion jamaicensis*, a species that prefers warmer and coastal waters, the ring's pattern is not so clear and uniform. For both species the rings are formed yearly and individuals with 0 to 3 years old predominates in the area, most of them juveniles. The von Bertalanffy growth equations for the populations present in the area were: *Cynoscion guatucupa* $TL=457,48*(1-e(-0,205(t(-1,23))))$ *Cynoscion jamaicensis* $TL=329,47*(1-e(-0,366(t(-0,084))))$ These results are very similar to that obtained in the length frequencies analysis, confirming as absolute the relative ages found by the ELEFAN program.

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The application of bootstrap and randomization tests to Fourier analysis of otolith shape for stock discrimination in orange roughy *Hoplostethus atlanticus*

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Abstract

Most orange roughy *Hoplostethus atlanticus* taken in Australia's South East Fishery are caught off eastern Tasmania from a winter spawning aggregation, or off southern Tasmania in summer. Evidence from mitochondrial DNA, estimation of age and growth, a previous analysis of otolith shape, and analysis of parasites, suggested some stock structuring but did not resolve the question of whether a single or separate stocks are exploited in the two components of the fishery. This question is a major source of uncertainty in biomass and yield estimates for the fishery. Otolith shape was analysed using Fourier analysis for samples from both the fishing and non-fishing seasons from both areas and the difference between arrays of Fourier descriptors was reduced to a single scalar value. The bootstrap technique was used to calculate confidence intervals for within and between sample comparisons and randomization tests estimated the probability of obtaining the observed differences by chance. The analysis suggested the presence of two distinct stocks. The most likely distribution pattern for these stocks is one numerically dominant stock, which moves from eastern Tasmania in winter to more southerly latitudes in summer, and a second stock which occurs in lower numbers in both areas at all times of the year.

Contribution: 140

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Time-frequency representation : application to individual growth estimation

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Abstract

Time and frequency are dual representation commonly used in signal processing. Individual growth estimation from otoliths is usually made through a "discrete" inter-ring distance measurement. Another way to estimate growth is to analyse signal modulation. Actually, the alternate translucent and opaque growth bands on calcified structures generate a waveform signal on digital images. Growth induces a band width variation which corresponds to a frequency modulation in the signal. Classical spectral analysis tools, such as Fast Fourier Transform (FFT), only allow to switch from a time representation to a frequency representation. New signal processing tools, such as wavelets, provide a time-frequency representation, i.e, to locate frequency variation in time. From this, we can expect to globally estimate an individual growth trajectory. Precision and accuracy linked to this approach are presented, compared to the classical one, and discussed.

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Use of deformable models for otolith 2D growth ring detection by digital image processing :
application to plaice (*Pleuronectes platessa*) otolith

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Abstract

Most of today computer assisted age reading software are limited to 1D processing. Two dimensionnal ring detection is closely linked to the ability of image processing algorithms to perceive structure continuity. The recourse to deformable models, based on closed B-splines, allows to fit locally a shape to the image by some maximisation or minimisation criteria according to translucent or opaque ring nature. The algorithm takes into account otolith shape information on edge contour and *a priori* "fuzzy" biological information such as ring size decrease, in order to adapt the detection to the local scale. The number of growth rings is estimated and the contour of each ring is provided allowing perimeter, area or shape descriptors computation. A reference test image set (N= 120) of plaice otolith, previously age by a reader, were processed. The whole processing requires a mean of 5 mn per otolith, 52% of the rings are correctly detected (does not require a manual correction), 37% require a manual correction and 11% are missing. 71% of otolith are correctly aged. Source of variation are described and discussed.

Contribution: 142

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Attempts to validate otolith microstructure periodicity for deep sea fish age estimation

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Abstract

Because of its specific adaptative strategy, Orange Roughy (*Hoplostethus atlanticus*) has been chosen as a target species in a national project focused on marine biodiversity. This species is supposed to live more than a hundred year though this point has never been clearly established. There is thus a need for age validation studies on such a species. Fluorochrom tagging of otoliths have been seldom tried on deep-sea fish because catch stress and pressure variation are often lethal. During the PROSPEC cruise on R/V Thalassa three ways to attempt to validate the microstructure periodicity have been developed : (1) *in situ* chemical tagging using baited traps, (2) tagging on board and recompression in an hyperbaric tank and (3) tagging on board and maintenance at atmospheric pressure in a cold room. The first experiment failed partly due to technical problems. One Orange Roughy and two Portuguese dogfish survived in the hyperbaric tank more than 48 hours. The best results were obtained with the third approach, though survival times (2 to 9 days depending on the species) were too short to validate microstructure periodicity.

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A simple otolith 3D reconstruction technique from serial sections

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Abstract

3D structure representation is essential to otolith morphogenesis understanding as well as to sectional plan searching. Today, digital image processing allows to visualise and manipulate 3D object on microcomputers. A simple 3D otolith reconstruction technique based on automatic registration of serial sections is presented. Otolith are embedded in black resin with a plastic box which provides landmarks for the registration. Then, serial cuts are registered by computing a translation-rotation matrix, on the base of 3 fiducial points. Translation correction is then applied with a microscope motorized stage and the image is digitally rotated. Registered cuts are digitized with a 1024x1024 high resolution camera and viewed with a 3D image render allowing 3D measurements. During the whole process, the operator intervention is limited to the acquisition of fiducial point coordinates. Precision of registration is estimated for 4 different magnification (x2.5, x5, x10, x20) and ranges from 2.6 to 4 pixels translation error and from .27 to .58 degrees rotation error. Because otolith are digitised without any grinding or polishing, resolution is directly linked to the ability of the saw to make thin otolith slice. Application to deep-sea fish otolith are presented.

Contribution: 145

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Growth variability of rockfish, *Helicolenus dactylopterus* (Osteichthyes: Scorpaenidae), in two Western Mediterranean areas: Alboran Sea and Balearic Sea

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Abstract

Helicolenus dactylopterus (Osteichthyes: Scorpaenidae) is a common fish of the Western Mediterranean bottom fauna. Data and sampling from 15 bottom trawl surveys carried out from 1991 to 1997 along the Iberian Mediterranean coast were analysed. Age and growth of this species were determined for two different areas: Alboran Sea and Balearic Sea, characterized by different oceanographic conditions.

Length, weight and sex of 3092 individuals, 2114 from Alboran Sea and 978 from Balearic Sea, were determined. Sagittal otoliths were collected in random subsamples, selected to cover the size distribution of both sexes in each area. The otoliths were measured, weighed and read following standard techniques. Otolith and fish morphology were analysed by means of regression equations, and the von Bertalanffy growth equation was fitted to the age-length relationship obtained.

The fish length range was comprised between 3 and 36 cm in the Alboran Sea and between 2 and 33 cm in the Balearic Sea, corresponding to individuals from 0 to 30 and from 0 to 24 years old, respectively. In both areas, around 70% of the population were 0-3 years old specimens. The age determination was validated using otolith microincrements, to determine the first annual ring from fish between 3 and 9 cm length, and by the evolution of the marginal structure of the otolith with time, from fish between 1 and 4 years old. The different observed age composition between sexes and areas was related to the fish length range studied, and the growth differences between both areas are discussed in relation to the different oceanographic conditions.

Contribution: 148

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Validation of roughhead grenadier (*Macrourus berglax*) otoliths reading

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Abstract

Fractal geometry was applied in morphology studies at different levels, ranging from ultrastructural to whole organism observations. Image analysis of the perimeters of the sagitta otoliths was carried out on all the species of the genus *Merluccius*. This allowed us to obtain parameters that produced estimations of the D fractal measurement (perimeter/area) for each species. The fractal analysis detected differences in relation to the relative size and to the shape of the sagitta otolith. As a result, it separated the species with a larger relative size (and smaller perimeter/area relationship), such as *M. merluccius* and *M. albidus* from the other species. Another aspect that was involved in the arrangement of the groups was the shape of the sagitta. Thus the species with elongated otoliths or with a greater sinuosity in the perimeter had a greater perimeter/area relationship.

Contribution: 149

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Comparison of otolith growth and somatic growth in two macrourid fishes

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Abstract

Otoliths from a wide size range of two Macrouridae species (*Nezumia sclerorhynchus* and *Coelorhynchus coelorhynchus*) were collected on a monthly basis (December 1996-November 1997) from experimental bottom trawls in the Ionian Sea, Greece, between 400 and 1000 m. All otoliths showed the ring pattern common to teleost fish, opaque and hyaline rings laid down around an opaque nucleus. To assess the annual nature of otolith rings, the evolution over time of the percentage of opaque rings in the otolith margin was determined. The growth parameters and the growth curves obtained from the interpretation of the growth rings showed a low growth rate for both species. However, *Coelorhynchus coelorhynchus* grow comparatively faster and attain greater asymptotic sizes than *Nezumia sclerorhynchus*. Since a considerable variation in size at age was found for both species, the otolith weight and length-fish length relationships were estimated for each age group. This analysis permits a much greater proportion of fish to be assigned ages than is possible with otolith reading alone. The results suggest that since the otolith growth is not synchronous with the growth of fish, otolith weight can be useful in confirming age distribution of the examined fish species.

Contribution: 151

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GROWTH OF SILVERSIDES *Atherina presbyter* OFF THE CANARY ISLANDS
DETERMINED BY DAILY GROWTH INCREMENTS IN SAGITTA OTOLITHS

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Abstract

Growth parameters and age-length keys were estimated from daily growth increments (DGI) on sagitta otoliths of *Atherina presbyter* Cuvier, 1829. Samples were taken monthly from landings on Gran Canary Island from June 1990 until December 1991. In total 225 otoliths were examined with each otolith subjected to two counts. Using 5% as the maximum error difference for age interpretation, 201 otoliths were considered valid. Fish total length (TL) ranged from 23 to 102 mm, which corresponded from 50 to 478 DGI. Validation of the daily increment deposition rate was determined in juvenile fish by marking otoliths with SrCl in fish from 20 to 60 mm TL held in tanks for 45 days. Age validation in adults (between 70 and 90 mm TL) was made by modal length progression analysis. The DGI widths were widest in individuals smaller than 70 mm, suggesting a faster growth rate than the one found in sexually mature fish, which divert energy for reproduction. Von Bertalanffy growth parameters were determined for both sexes, due to the sexual dimorphism of the species. The maximum length and life cycle duration found in fish from Gran Canary Island were shorter than those obtained for this species in the North Atlantic.

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On the age and growth of john dory (*Zeus faber*, L.) in the Portuguese waters

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Abstract

Length frequency distributions of male and female john dory are analysed to describe the age structure and the growth of this fish off the Portuguese continental coast. The samples were collected on six groundfish surveys carried out in February/March (winter), June/July (summer) and October/December (autumn) 1992 and 1993. Length frequency analysis is used to estimate growth parameters and these are, in turn, applied to length data in order to build theoretical age distributions.

Contribution: 156

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The growth of blue whiting (*Micromesistius poutassou*) off the Portuguese coast

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Abstract

The growth of blue whiting off the Portuguese coast is studied based on the analysis of data from six groundfish surveys carried out between 1991 and 1993, in February/March (winter), June/July (summer) and October/November (autumn). Ring counts and measurements are done on whole otoliths immersed in microscopy oil. The Von-Bertalanffy growth parameters for males and females are estimated based on direct length at age data and on back-calculated length-at-age data. Comparisons of the growth pattern between different areas of the Portuguese coast and both between and within the different seasons of the year will be presented.

Contribution: 158

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Local Variation in Growth of the Stripey Bass, *Lutjanus carponotatus* (Lutjanidae), Among the Palm Islands, Great Barrier Reef

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Abstract

The stripey bass, *Lutjanus carponotatus*, is a small snapper that is common in the catch of line fishers on the Great Barrier Reef (GBR). Annuli in sagittal otoliths were used to analyze differences in growth between four locations spanning 15 km along a north-south gradient (one in the north to four in the south) at the Palm Island group on the central GBR. The von Bertalanffy growth function (VBGF) was used to describe growth at each location and for all locations combined. VBGF parameter estimates ranged from $k=0.075/\text{year}$ and $L_{\text{inf}}=365$ mm FL at location one to $k=0.75/\text{year}$ and $L_{\text{inf}}=237$ mm FL at location three. Analysis indicated that there were significant differences in growth trajectories between locations (ARSS: $df=9,281$ $F=3.106$ $p=0.0014$). The two southernmost locations exhibited very similar model parameters, while the northernmost location was the most drastically different. While it is possible that sampling artefacts are partially responsible for the large observed differences, it is equally likely that the differences are driven by location-specific environmental conditions and levels of fishing pressure. Such differences on a local scale cautions against assuming one set of demographic parameters estimated from one location to be representative of a larger region.

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Age and growth of Brazilian sardine (*Sardinella brasiliensis*) larvae along southeastern Brazilian bight

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Abstract

The Brazilian sardine *Sardinella brasiliensis* is one of the most important economic fishes from southeastern Brazilian coast. Since the 228,000 tons peak landings in 1973, the harvesting had declined to around 90,000 tons per year. This work is part of a wide program concerning the variability of recruitment in this species. Samples were obtained from R/V Victor Hensen (MAR-1 Project/1990-91) and R/V Prof. W. Besnard (SARDINHA-1 Project/1991 SARDINHA-2 Project/1993) during three summer cruises along southeastern Brazilian bight between Cabo Frio (23°S) and Cabo de Santa Marta Grande (29°S). Oblique tows were performed using bongo nets, and the samples were preserved in 80% ethanol buffered with Sigma 7-9. A total amount of 550 larvae, ranging from 4.0 to 37.0 mm SL were analyzed. The larvae were aged using sagittal otoliths increments viewed under a light microscope at 400x or 1000x magnifications. Maximum otolith diameters were measured to the nearest micron. The Gompertz growth model was fitted to each cruise data set. The relationship between growth patterns and environmental conditions is discussed.

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Validation of daily increment formation in saggital otoliths of juvenile anadromous alewives,
Alosa pseudoharengus

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Abstract

The saggital otoliths of anadromous juvenile alewives, *Alosa pseudoharengus*, collected from the Lamprey River in coastal New Hampshire, USA, were marked by immersion of fish in oxytetracycline (250-350 mg/L) for 6-11 hr. Marked juveniles (n = 101) were held in the laboratory and in the field for up to 20 days. The number of increments formed after the oxytetracycline mark were then compared to the number of days fish were held after marking. The frequency with which increments were deposited was consistent with the hypothesis that juvenile alewives form one growth increment per day. There was no significant difference between increment counts made by either light microscopy or scanning electron microscopy. Results of this study indicate daily otolith increments are useful for estimating age and growth of juvenile anadromous alewives in freshwater nursery habitats prior to seaward migration.

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OTOLITH MEASUREMENTS: A CUE TO AGE DETERMINATION IN *APLOCHEILUS LINEATUM* (VALENCIENNES) (PISCES: CYPRINODONTIDAE)

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Abstract

Otolith from thirty female specimens of freshwater fish *Aplocheilus lineatum* ranging from 37 to 66 mm were subjected to age and growth determination. There is a strong linear relationship between total fish length and otolith. The regression equation is $Y = 0.1287 + 0.0237 X$ ($r = 0.899$) and signifies that the increase in length of the fish is an exponent function of its otolith length. The calculation of age determination from this relationship and the link between the somatic and otolith growth will be discussed.

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Otolith length weight relationship for age determination in *Pomodasys maculatus* (Bloch 1797) (Pisces:Haemulidae)

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Abstract

Samples of otolith from thirty three samples ranging from 143 to 185mm total length of marine fish, *Pomodasys maculatus* were subjected to age determination. The relationship between otolith length and total length of fish recorded a significant positive correlation ($r=0.8395$). The regression equation is $Y = -1.509 + 1.88 \log X$. The length and weight of otolith also showed a linear relationship $Y = -3.66 + 2.88 \log X$ ($r=0.924$). Both the relationship showed an exponential function of otolith length.

The regression equation for both male and female have been worked out separately and showed positive correlation. The slope values of both sexes have also been compared with student's 't' test and found insignificant at 0.05 level ($p > 0.05$).

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The effects of environmental factors on larval growth dynamics in tropical reef fisheries

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Abstract

The early life history phase of reef fishes is undoubtedly important in determining the dynamics of recruitment to reef populations. Processes during oogenesis and the early larval phase have the potential to structure mortality and growth schedules of individuals within a cohort. The purpose of this study was to quantify the effect of variable environmental and maternal influences on offspring growth and survivorship in the field. This research has focused on the planktivorous brooding damselfish *Acanthochromis polyacanthus* (Pomacentridae). *Acanthochromis* is one of the few reef fishes that has a non-dispersive larval phase. Brood size (number of offspring produced per breeding pair) and growth dynamics of larvae were compared between exposed high energy reefs and enclosed sheltered lagoons. Brood size and individual larval growth were significantly greater on the exposed reefs. A manipulative field experiment was then established to quantify the specific effects of food availability and temperature on survival and growth dynamics of larvae. Replicate spawning pairs were monitored within each habitat. The diets of 50% were supplemented till broods appeared, feeding was continued until 3 weeks post-hatching. Mortality occurred in all broods irrespective of food availability, however, individuals on exposed reefs whose diets were supplemented had significantly higher growth rates. Growth trajectories for individuals were developed from otolith increment width analysis. The trajectories of survivors ((3 weeks old) were contrasted with those 1 week post-hatching. Results are discussed in relation to selection for or against faster growing individuals.

To validate the linkage between somatic and otolith newly hatched larvae were raised under controlled experimental conditions of low, medium, and high food levels for 3 weeks. Growth trajectories of individual larvae were developed from morphometric measurements taken through time and contrasted with those derived from the analysis of increment widths at the completion of the experiment. In general, there was a proven link between somatic and otolith growth during the first 3 weeks of larval life.

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Preliminary Age Determinations of Tropical Fish Species from the Caribbean

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Abstract

The CARICOM Fisheries Resource Assessment and Management Programme (CFRAMP) is geared towards promoting the management and conservation of the fisheries resources of Caribbean countries. It has provided funding for enhancing the fish age and growth capabilities of the Institute of Marine Affairs (IMA). The Age and Growth Laboratory is currently working on twenty-seven (27) species of tropical fish including both teleosts and sharks submitted from 13 Caribbean countries. Hard parts of species from different habitats e.g. deep-slope, reef and pelagic, are collected by the various Caribbean countries and sent to the Laboratory for ageing.

Hard-parts (otoliths, vertebrae and spines) used, varied depending on the species. Annuli interpretations are provided for *Acanthurus chirurgus*, *Balistes vetula*, *Epinephelus guttatus*, *Holocentrus adscensionis*, *Lutjanus synagris*, *L. vivanus* and *Scomberomorus cavalla*. Preliminary growth parameter estimates have been derived for *A. chirurgus*, *B. vetula*, *H. adscensionis* and *S. cavalla*.

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INDIVIDUAL GROWTH RATES OF JUVENILE CHINOOK SALMON IN THE LOWER
AMERICAN RIVER, CALIFORNIA, USA: BACK CALCULATION USING OTOLITHS

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Abstract

The objective of this study was to develop a backcalculation method to estimate individual growth rates of juvenile chinook salmon (*Oncorhynchus tshawytscha*) in a Central Valley, California river, an application for which no praxis exists. Salmon were sampled throughout the egg and yolk-sac stages to bracket hatching and first feeding (emergence), and then at least bi-weekly during the in-river rearing period. Analysis of microstructures in sagittal otoliths, in conjunction with data on yolk dry weight:total dry weight ratios and presence/absence of food in the gut, was used to validate the formation of check marks formed at hatching and emergence, important microstructure benchmarks. A regression model was developed relating fork length to otolith size for post-emergence stage salmon. The model was used to backcalculate individual fork lengths at emergence. The change in fork length, along with counts of daily increments, was used to estimate the average daily growth rate of individual salmon over specified periods. The results are discussed relative to the challenges of developing a generalized backcalculation model for juvenile chinook salmon due to (i) their protracted spawning, embryonic, and emergence periods, and (ii) the effects of size-selective emigration of smolting fish.

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Application of the radiometric ageing technique using ^{210}Pb : ^{226}Ra disequilibria in calcified structures of two long-lived fishes: Atlantic tarpon (*Megalops atlanticus*) and Atlantic sturgeon (*Acipenser oxyrinchus*)

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Abstract

Radiometric ageing is a recently developed technique using the disequilibria of ^{210}Pb : ^{226}Ra in calcified structures to determine age in long-lived fishes. It has been successfully applied to several fish species, but limitations of existing techniques made improvements desirable. A new ion-exchange separation technique was used to isolate small quantities of radium from calcified structures for subsequent radium quantification using isotope-dilution thermal ionization mass spectrometry. We applied this technique to calcified structures of two fish species: otolith cores of Atlantic tarpon (*Megalops atlanticus*), and pectoral fin ray cores of Atlantic sturgeon (*Acipenser oxyrinchus*). Radiochemistry confirmed that Atlantic tarpon are long-lived and may have a longevity that approaches 82 years. Growth increment counts, however, did not closely agree with radiometric ages. This study sets a precedent in radiometric age determination, because individual otolith cores were used to age individual fish. Radiometric age of Atlantic sturgeon, however, could not be determined using pectoral fin ray cores. This result was attributed to a closed system violation where nuclides migrate in and out of the core, or incorporation of exogenous ^{210}Pb during fin ray formation, or both. Application and limitations of this technique are discussed

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Age, growth and reproductive aspects of a small pomacentrid fish (*Stegastes fuscus* Cuvier, 1830) from Tamandaré reefs, Pernambuco, Brazil

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Abstract

Growth, age structure and reproductive aspects of *Stegastes fuscus* (Pisces: Pomacentridae) were investigated during the present study. Individuals were collected monthly by divers using nets or spears at Tamandaré reefs, Pernambuco, Brazil. Otoliths were sectioned transversally to determine the age. Otolith sections showed a clear pattern of opaque and translucent bands. Opaque bands were counted and initially attributed to the age of the individual fish. To determine the periodicity of the formation of the bands, individuals were injected with tetracycline (50-mg tetracycline/kg fish) and held in the laboratory for periods between three months and one year. Spawning season was determined by histological examination of the gonads and by analysis of the gonadosomatic index variation. Results of the validation experiment showed that opaque bands are deposited on an annual basis. The ages obtained from otoliths collected monthly ranged between zero and fifteen years. Analysis of margins of monthly collected individuals suggested that opaque bands are deposited between September and March, during the dry season. Readings of tetracycline-marked otoliths corroborated this results. The length-at-age curve yielded a K of 0.19. The high variability of the length-at-age data indicated individual growth variability. Highest abundance of mature and spawned individuals was found between September and March. Highest GSI values also occurred during this period, coinciding with dry season. In contrast, females and males in resting stage predominated between April and August (rainy season), period of lowest GSI. Assynchronous gonadal development indicated that *S. fuscus* is probably a partial spawner. In spite of the synchronicity between the spawning season and the deposition period of opaque bands in otoliths, it was concluded that the reproduction activity was not the factor inducing otolith ring deposition since annual bands were observed also in juveniles. Length-frequency data were also used to obtain growth parameters. Growth

constant (K) determined with this data varied between 0.5 and 0.6 and differed markedly of the K values determined from length-at-age data indicating that length-frequency data are not suitable to determine growth of this species. The present study showed that otoliths were a reliable structure for ageing *S. fuscus*, which is a relative long-lived and slow-growing species.

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Growth differences between introduced populations of *Cichlasoma urophthalmus* based on otolith mass

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Abstract

I collected Mayan Cichlids, *Cichlasoma urophthalmus*, monthly from three recently introduced populations occupying different habitats in southern Florida between May 1996 and June 1997. Populations were sampled in freshwater sawgrass wetland, flooded cypress forest, and brackish mangrove habitats. Minimum adult size was estimated as 125 mm TL on the basis of the size at 1st maturity. Sagittal otolith mass (OM) was regressed on TL for all fish >125mm TL. A cube root transformation of OM was used to homogenize residuals. The regression coefficients differed significantly among all three populations ($p=0.01$ $n=894$). The cypress population the slope of the OM-TL regression ($n=375$) differed significantly ($p<0.01$) from that of both the mangrove ($n=146$) and sawgrass ($n=373$) populations. The regression coefficients of mangrove and sawgrass populations did not differ significantly ($p=0.24$). Thus, cypress forest fish exhibited faster growth.

Abiotic and biotic factors were evaluated as potential explanations for the observed differences in growth rate. The population-level differences in growth could not be explained by geographic proximity, hydrologic similarity, water temperature, salinity, length-frequency distributions, or age composition. The possibility of dietary differences could not be excluded. Higher growth rates in the cypress forest population could be explained by either a life history strategy of reduced gonad investment, or a new population effect of intra-specific competitive release.

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Validation of microstructure deposition rates on otoliths of the small pelagic fishes of the Java Sea, Indonesia

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Abstract

Validation experiments were carried out using both tetracycline injections (50 mg kg^{-1}) and immersion ($500 \text{ mg l}^{-1} \cdot 24\text{h}^{-1}$) in two experimental design locations: an artificial environment using tanks with closed water circulation system at Ancol (Jakarta, West Java) and a semi-natural environment using cages in the open sea near Bojongara coast (Serang, West Java). Target species were *Rastrelliger brachysoma*, *Sardinella gibbosa*, *Selaroides leptolepis* in the first experiment during 2 months and *Decapterus sp.*, *Rastrelliger kanagurta*, *Selar crumenophthalmus* and *Selaroides leptolepis* in the second one during one month. Mortalities were more important after immersion than after injection, while one species *Sardinella gibbosa* could not be reared. All otoliths were prepared using the same standardized technique with thin transverse section through the nucleus. Intense tetracycline marks have been observed on every otolith sections. The number of microstructures interpreted under high magnification microscope ($\times 1250$) and UV light do not correspond to the number of days of growth after marking. The two alternative explanative hypotheses, biological reality or experimental bias, are discussed.

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Age and Growth Studies of the Spanish mackerel, *Scomberomorus brasiliensis* (Family: Scombridae) in coastal waters of Trinidad.

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Abstract

Scomberomorus brasiliensis is commercially important throughout its range from Brazil to Trinidad. Several papers exist on age and growth studies of this species, however, this is the first time annuli were interpreted using sectioned otoliths (sagitta). Growth parameter estimates based on the von Bertalanffy Growth Model for females were $L_{\infty} = 89.01$ cm, $K = 0.318 \text{ year}^{-1}$ and $t_0 = -1.34$ years and for males $L_{\infty} = 62.59$ cm, $K = 0.329 \text{ year}^{-1}$ and $t_0 = -3.13$ years. Significant differences were found when compared to other growth curves of this species, particularly mean length-at-age of 1 year olds. In this study, *S. brasiliensis* grows rapidly in the first year reaching a mean size of about 49 cm. Age/length key shows that the commercial catch of *S. brasiliensis* comprises mainly young of the year (YOY) fish and I and II year olds.

Translucent zone formation appears to be seasonal, from August to November, with a peak from September to October. Presumed daily rings are present on the lapilli, and are currently being used to validate the position of the first annulus which is difficult to interpret in this species.

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Effects on age determination and back-calculation of total length of *Lophius spp.* based on both cut position of *Illicia* section and growth ring determination

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Abstract

The age determination of *Lophius spp.* is based on transversal sections of the first dorsal ray (*Illicium*). The position of the cut to obtain the *illicia* sections is very important to consider in the counting and in the measure of the growth rings. Different cut positions are considered and the number and measure of the growth rings are compared between them. Another problem in the age determination using *illicia* sections is the ring nature. In the otoliths of the majority of the fish species the translucent rings are deposited during the slow growth period (usually during the winter) and the opaque rings are growth zones formed during the faster growing season (usually the summer). This type of deposition is not observed in the dorsal ray sections of *Lophius spp.*. This study makes a general review of this problem with emphasis on the chemical composition of the growth zones.

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A non destructive technique for the three dimensional reconstruction of fish otoliths

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Abstract

The three dimensional (3D) reconstruction of an otolith was calculated using a newly developed micro X-ray tomography device. The device has a resolution of 8 μ m, which means that a 1 cm long otolith may be imaged within a volume of 512x512x512 voxels. The technique, compared to a reconstruction from serial sections, is relatively fast since no special treatment of the otolith is required. From the 3D reconstructed volumes, 2D contours may be extracted, which are directly comparable to the 2D shapes derived from the maximum projection area of an otolith. These shapes have been used successfully for fish stock discrimination. As a next step we expect to be able to follow the zones of isodensity within the 3D X-ray density distribution of the otolith. The advantage of the micro-tomographic approach is that all growth shells the otolith contains are collected at once and may be compared to each other directly without physical destruction. 3D analysis may yield new insights into the allometric growth history. The complete description of the 3D structure of an otolith is expected to reflect the life history of the fish.

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VALIDATION OF INCREMENT DEPOSITION AND EARLY DEVELOPMENT IN THE
OTOLITHS OF THE WEST AFRICAN LAGOON TILAPIA, *SAROTHERODON*
MELANOTHERON

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Abstract

Selanotherodon melanotheron is a common tilapia species in the coastal lagoons of Ghana. The aim of this work was the validation of growth increments in otoliths to enable comparative growth and ecological studies on a number of populations in different lagoons and estuaries along the Ghanesian coast. A total of 231 otoliths of reared larvae and 87 from wild catches were examined on their morphometric growth, daily increments and structural patterns. A one to one relationship was found between days of incubation and counted increment rings in the otoliths certifying, that increment deposition is daily. A marked hatching ring was found in all otoliths, both from reared fish and wild specimen, including a varying number of first, prolarval rings, the periodicity of which cannot as yet be explained properly. A range of 3 to 7 rings is built between hatching and yolk sac resorption before regular deposition of 1 ring per day.

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Age and growth of Mediterranean hake (*Merluccius merluccius*) in the Central Mediterranean Sea

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Abstract

Mediterranean hake (*Merluccius merluccius*) was studied in order to obtain information on its growth patterns in the Central Tyrrhenian Sea. Age determination of *M. merluccius* has been discussed by several authors and ICES working groups. In the Mediterranean Sea further studies are required to standardise interpretations and develop a model of growth for this species. In the 1997 the E.C. commissioned a research program aimed at analysing the biology and population dynamics of the hake in the Central Tyrrhenian Sea. Since January 1997 more than 2000 fish between 4 and 80 cm were collected from commercial catch samples. Both whole and sectioned otoliths were used for this study. The back-calculated average lengths together with the marginal increment analysis were used to confirm age determination. Measurement of otoliths indicate a linear and highly significant relationship ($r^2 > 0.95$) between fish length and various otolith dimensions (total and half length, radius, height). The von Bertalanffy curves obtained from mean lengths-at-age and back-calculated lengths adequately describe the growth of Mediterranean hake over the first ten years, and these are comparable with other estimates of growth.

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Age and Growth of Some Important Fish Species from Kuwait's Waters

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Abstract

Age and growth of some important fish species in Kuwait's fishery were studied for the first time in the region by examining the annual marks in the transverse sections of sagittal otoliths. The von Bertalanffy growth parameters were estimated from length-at-age data using least square and bootstrapping methods. The studied species and their estimated parameters (L° , k , t_{max}) respectively were; nagroor (*Pomadasys kaakan*, Family: Haemulidae, 63.2, 0.25, 18), zobaidy (*Pumpus argenteus*, Family: Stromateidae, 38.56, 0.25, 6), chanaed (*Scomberomorus commerson*, Family: Scombridae, 171.5, 0.224, 14), khobat (*Scomberomorus guttatus*, Family: Scombridae, 55.03, 1.16, 8), maid (*Liza carinata*, Family: Mugilidae, 20.0, 0.554, 5), and beyah (*Liza macrolepis*, Family: Mugilidae, 28.13, 0.295, 4). The results of the study indicated that these species live longer than previously estimated from length-based methods. These results will be used to assess these stocks in Kuwait's fishery using age-based methods."

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Age determination of the Peruvian anchoveta *Engraulis ringens* by means of annual rings and otolith weight

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Abstract

The Peruvian anchovy *Engraulis ringens* was aged by means of growth rings in the sagittal otoliths. The ring periodicity was determined by means of a monthly analysis of the outer edge of the otoliths. The results showed one hyaline ring per year. The task of ageing the Peruvian anchovy is very difficult due to the otoliths being heavily calcified structures, which obscure the presence of rings. In addition, many false rings are found. The possibility of using otolith weight for ageing was also investigated. Analysis of covariance using fish total length, age and otolith weight as dependent variables showed that the relationship between length and age was significant. It is found that otolith weight is insufficient for predicting age. However, the frequency distribution of otolith weight displayed three or four modes, which is consistent with the finding of four groups from otolith reading. Growth parameters were determined using both methods.

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Differences in otolith and somatic growth between spring and autumn spawned herring (*Clupea harengus* L.) larvae

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Abstract

Laboratory experiments were conducted on herring (*Clupea harengus* L.) larvae in 500 liter tanks during autumn 1995 and spring 1996. Natural photoperiod for the time of year was simulated in both trials. The larvae were kept at 8 °C, and were fed wild zooplankton; 2 tanks with low prey densities (20 and 40 preys l⁻¹) and another 2 tanks with high prey densities (1200 and 2000 preys l⁻¹). Monitoring of temperature, prey density and mortality was conducted every day, and larval sampling was performed at least once a week. The durations of the experiments were 35 days. Daily mortality rates were 2.4 (autumn) and 1.5 % (spring) in the low density groups, and 0.4 (spring) and 0.2 % (autumn) in the high density groups. The mean growth rates in length were 0.06 and 0.07 mm d⁻¹ in autumn and spring spawned larvae at low prey densities, and 0.24 and 0.35 mm d⁻¹ in corresponding high density groups, respectively. Average specific growth rates in weight were 2.0 and 1.2 % d⁻¹ in autumn and spring spawned larvae at low prey densities, respectively, and 6.1 and 7.1 % d⁻¹ in corresponding high density groups. The growth strategy of early autumn spawned larvae differed from that of spring spawned larvae. In autumn, the larvae had relatively high initial growth rates, reaching a maximum about 2 and 3-4 weeks post hatching for those fed at high and low rations respectively, after which the rates decreased. In spring, the larvae grew at approximately constant rates during the first three to four weeks, with increasing growth rates thereafter. Mean otolith growth rates were 0.04 and 0.05 µm d⁻¹ in autumn and spring spawned larvae at low prey densities, respectively, and 0.45 and 0.98 µm d⁻¹ in corresponding high density groups. Otolith growth rates in the control (starving) groups were not significantly different from the larval groups fed at low prey densities. Otolith radii were similar at corresponding lengths in both autumn and spring spawned larvae. We conclude that body length and otolith growth rates were higher for spring spawned larvae than autumn

spawned ones, and the primary difference between the two experiments is suggested to be the seasonal day length.

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What statolith ageing is revealing about squid growth

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Abstract

Research into squid growth and population dynamics has increased substantially in recent years. In many ways daily statolith increments are analogous to daily increments in larval fish. Many techniques in the analysis of daily increments in fish otoliths can be applied to squid statoliths. However, squid ageing research has revealed a form of growth that differs from most teleost fish. Growth appears to generally be exponential or linear in form. Life spans are short, generally less than 6 months in tropical species and many temperate species have life spans of about a year. Ageing research has revealed that squid growth is very plastic and closely related to ambient temperature, with a considerable lengthening of the life span at cooler temperatures. Squid statolith increment widths also appear to be closely related to individual daily growth rates. Statoliths may therefore act as barometers of daily growth rates in individuals.

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Age and growth from otoliths of Cape anchovy (*Engraulis capensis*) in relation to physical and biological properties of Angola-Benguela waters

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Abstract

Cape anchovy (*Engraulis capensis*) larvae were sampled during a BENIFIT survey of the Angola Benguela front and the Angola Dome 4 April-23 April, 1997. Otoliths microstructure analysis were used to back calculate hatching and to estimate growth of the larvae. The microstructure of the otoliths were relative distinct and wide increments were observed. However there was high variation in the increment width, which indicates variation in growth. Age and growth of larvae from water masses with different physical and biological watermasses were compared to explain some of the variation in growth. A portion of the otoliths were read by a second reader to estimate the precision of the readings.

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Growth and mortality patterns evaluated from otolith microstructure in cod (*Gadus morhua* L.) larvae reared at different feeding regimes in mesocosms

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Abstract

In a situation where predators are excluded, growth and mortality rates of cod larvae should be independent. This was evaluated from distributions of otolith increments in larvae sampled at different times during development. A mesocosm experiment was carried out in four 5.2m³ plastic bag enclosures placed along a raft system in a 20.000m³ seawater pond used for zooplankton production. Two different food regimes (low- and high-ration, each in two enclosures) were set up on the basis of a fixed specific growth rate (SGR) applied in a bioenergetic model. Larval length, weight, and otolith increments were analysed from samples on day 10 and 20, and at termination on day 31 post-hatch. Overall survival to day 31 was 52.3% ± 4.4, and somatic growth was initially higher than expected from the bioenergetic model. Increase of prey size after day 20 had profound effects on otolith growth which also responded rapidly to availability of suitable prey. Mortality was not clearly dependent on otolith growth, but slow growth during early larval stages promoted survival in cases when significant differences were detected. Feeding conditions seemed to act directionally on the selective processes, causing selection for larvae with bigger increments in the high-ration group compared to the low-ration group. The relation between otolith radius and larval length was not linear. Furthermore, in the low-ration group otolith growth persisted at a higher rate than expected from somatic growth after day 20 during the alterations of the feeding conditions. In conclusion, otolith increments in cod larvae showed a very dynamic relationship between food availability and larval growth.

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Otolith growth and somatic growth measured by DNA, RNA and protein content in field-collected Mediterranean sardine larvae

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Abstract

Field-collected sardine larvae (*Sardina pilchardus*) were analyzed by otolith microstructure, DNA, RNA, protein content and wet-weight. All the analyses were carried out in the same larva. Daily length increments ($\text{mm}\cdot\text{d}^{-1}$) decreased with larval age, while daily growth rates expressed as DNA ($\mu\text{g}\cdot\text{d}^{-1}$), RNA ($\mu\text{g}\cdot\text{d}^{-1}$), protein ($\mu\text{g}\cdot\text{d}^{-1}$) and wet-weight ($\text{mg}\cdot\text{d}^{-1}$) increased with larval age. These results indicate that in the size range studied, sardine larvae grew in mass more than in length. The relationships between otolith growth rates ($\mu\text{m}\cdot\text{d}^{-1}$) and somatic growth rates (expressed as gain in mass) were significant. The best fits were observed for daily DNA and daily wet-weight increase and these parameters respectively explained 67% and 64% of the variation in long-term otolith growth rate. Moreover, the residual analyses showed that these relations were age-independent. Recent otolith growth (μm), expressed as the average width of the last six increments, was closely related to otolith radius, long-term otolith growth rate ($\mu\text{m}\cdot\text{d}^{-1}$), and somatic growth rates. The residual analyses showed that these relationships were age-independent. These finds suggest that recent fast-growing larvae had faster somatic and otolith growth, throughout their early life stages.

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A novel means of identifying daily growth increments in otolith of fish by Proteinase K

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Abstract

Daily rings and annual checks in otoliths play a critical role in determining the age of fish. Conventional methods are still limited in terms of etching the sectional otoliths. Therefore, this study presents a novel means of improving the daily growth increments. Otoliths of *amphidromous gobies*, *Stiphodon elegans* and *Sicyopterus japonicus*, and marine eel, *Strophidon sathete*, are digested by Proteinase K. In addition, Proteinase K removes the minor organic matrix, discontinuous zone, and retains the major incremental zone to create conspicuous daily rings. Compared with etching by EDTA, Proteinase K reveals daily rings with high contrast and accuracy. Furthermore, daily rings and annual checks can be simultaneously displayed by the enzymatic method. Results presented herein demonstrate the feasibility and powerful digestive ability of Proteinase K, ultimately providing another effective means to reveal otolith microstructure while examining daily growth increment.

KEY WORDS: otoliths, daily growth increment, Proteinase K

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Visilog/TNPC 3.0, a computer assisted age reading software

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Abstract

TNPC (*Traitement Numérique de Pièces Calcifiées*) is a software developed by the LASAA/IFREMER (Laboratoire de Sclérochronologie des Animaux Aquatiques) for digital image processing of calcified structures. This software is based on the dual principle of image radial profile process (simple and synthetic) and of inserting biological knowledge in the process, and is composed of two sets:

- automatic radial processing tools (smoothing, detrend, ring detection, FFT, demodulation),
- a full on line interactive module made up for automatic detection correction.

Data are stored in ASCII files (CSV format) and can be loaded onto any spreadsheet (Excel, ...). Most software available today is only designed to process simple profile. TNPC proposes on one hand, the possibility of integrating the signal between several profiles in order to build a synthetic profile over an area of interest and on the other hand, the possibility of taking into account an *a priori* growth pattern (Von Bertalanffy, Gompertz, exponential) in the profile processing by signal demodulation. In addition TNPC proposes real time distance measurements and a configurable fish length back-calculation based on different models (Dahl-Lea, SPH, BPH, Carlander). It can be used interactively with a keyboard or a mouse, and also automatically or semi-automatically by the means of the recording of processing sequences in a macro file.

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A System (CSAIS) and Software (CSAGES) for Quantifying and Computerizing Growth and Age Interpretation of Fish from Their Otoliths

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Abstract

If advances are to be made in otolith growth and age interpretation technology and science, the process must be standardized and quantified. An objective and precise growth interpretation system, based on specific criteria, is required to meet the needs of modern science and technology. Such a Calcified Structure Age Interpretation System (CSAIS), has been developed, which can be applied to any species and otolith preparation. It involves locating discontinuities in the growth pattern (translucent zones and lamellae); ranking their extent (in proportional ninths); and classifying the growth on the edge of the otolith on the basis of the seasonal growth cycle, commencing with the alpha growth phase '*' (annulus formation) and ending with the omega growth phase 'o' (translucent zone formation). A DOS-based Calcified Structure Age Growth data Extraction Software (CSAGES) has been developed that allows these quantitative data to be collected and stored electronically through a digitizer integrated with a CSAIS or user-defined keypad. The Calcified Structure Age (CSA), composed of the Number of Complete Annuli (NCA) and a symbol describing the edge, is determined, and if the alpha growth period is defined, calendar age and annual growth can be automatically assigned. The data and files can be examined, analyzed, edited, and exported. Utilities permit interpretations to be automatically re-presented, annual increment and year-class assigned, von Bertalanffy growth curves calculated and illustrated, variance analyzed, interpretations compared and contrasted, body size reconstructed, growth chronologies calculated, and age-growth data summarized.

Abbreviated Title: Otolith Growth-Age Interpretation System and Software

Abstracts

Session 3:

Otoliths in Studies of Populations

Invit: 11

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Phenotypic reconstruction from otolith information: inferring size, growth, and history

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Abstract

The information contained in fish otoliths may allow us to draw inferences about the age, past sizes, and experiences of fish. Although such information necessarily originates as observations made on individual fish, these data are often aggregated or averaged and then analyzed at that level. This practice is appropriate in some but not all instances. Indeed, one of the most useful characteristics of otolith data is that they can provide multiple, individual-level observations about the fish from which the otolith was extracted. These types of data are difficult or impossible to obtain in any other way, especially for the early life history stages of marine fishes. There exist several important analyses that are compromised when individual-level data are aggregated before further analyses. First, aggregation of data precludes analysis of within-individual covariances between sequential measures (e.g., size-at-age). Second, the assumption that parameter estimates relating two variables (e.g., size vs. age) based on aggregate data are appropriate (unbiased) predictors of individual-level patterns is often incorrect. We consider these and other consequences of failure to maintain the distinction between individual phenotypes and population statistics, and how these affect our ability to infer the history of individual fish.

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Use of birth date analysis to examine the significance of protracted spawning to reproductive success of haddock *Melanogrammus aeglefinus* in the North Sea

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Abstract

The risk of reproductive failure due to short-term variations in egg and larval mortality is expected to favour protracted spawning. Haddock exhibit such a trait as a result of individuals spawning repeatedly and age and size specific differences in the times and durations of spawning. In areas of the North Sea where the age and size diversity of the spawning stock is relatively low the spawning season of this species is relatively short. This investigation considers whether a reduction in the duration of the spawning season is likely to increase the likelihood of recruitment failure by examining the scope for mis-match between spawning and the optimal conditions for early survival. Data on the temporal pattern of spawning and the birthdate distribution of progeny surviving to the demersal phase were collected during a three year study. Particle tracking and sea circulation models were used to predict the transport of progeny away from the surveyed spawning areas. If survivors originate from different sub-sets of the annual production in different years this would demonstrate the advantage conferred by protracted spawning. Results from the study indicated that this was the case as survivors arose from all parts of the spawning season and there was no regular recurring period that was favourable to survival. Birthdate analysis gave some insight into the dispersal of early life-history stages whilst the birthdate distributions of pelagic phase juveniles reflected the seasonal spawning pattern of the area where they were captured, no such regional differences were evident at the demersal phase.

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Biology of Ocean Age 0 Hatchery, Wild Ocean, and Wild Stream Type Chinook in the Strait of Georgia

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Abstract

The pattern of otolith daily growth increments was used to study the first year of ocean residence of hatchery-reared, wild ocean- and wild stream-type chinook in the Strait of Georgia. Several checks of the accuracy of the otolith estimates of life history and rearing types indicate that the determinations appeared reliable. The percentage of hatchery-reared fish is higher than that of wild fish in samples collected in March-July. However, there are more wild fish in September, probably due to entry of numerous wild chinook in August and September, the three rearing and life history types were distributed throughout the strait and to depths ranging from 40-60 m. The mean size difference that existed in the early samples, persisted throughout the year, but the mean sizes of the three types were equal by the spring of the next year. Wild stream-type juveniles remained in the strait and were more abundant relative to wild ocean type juveniles than in the past. This is the first comparison of the biology of the three life history types of chinook salmon in their first year in the ocean.

Contribution: 75

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The variability in daily growth rate of larvae from different environmental regimes

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Abstract

The daily growth rate variation of sprat larvae was examined by otolith microstructure analysis of larvae sampled in an area of the North Sea covering water masses of stratified, mixed and frontal characteristics. The variability of otolith ring formation differed significantly between the hydrographical regimes, being highest in the stratified region. Further, both time (of year) and larval size influenced the observed variability in otolith growth. The findings illustrate how the heterogeneity of the marine environment influence the growth trajectories of larval fish, and led to improved understanding of larval growth pattern in the field.

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The relationship between longevity of sablefish, *Anoplomoma fimbria*, and ocean productivity regimes

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Abstract

Sablefish, *Anoplomoma fimbria*, have been reported to live to ages greater than 100 years. Growth is rapid to age 5 at which time the most fish mature. Growth slows after maturity and is greatly reduced after age 10. Both males and females continue to live for long periods during which little growth occurs. We propose that the longevity and pattern of growth is an adaptation to occupying a deep spawning habitat which is suitable for reproduction provided the appropriate environmental and biological conditions exist. The length of life of sablefish may correspond to the maximum period (over evolutionary time) that unsuitable conditions have occurred. In an unfished population long life would ensure that the habitat is occupied. Fishing reduces the number of occupants of the habitat but in a favourable environment (and under appropriate management strategies) the occupants are replaced through recruitment. However, fishing strategies that consider longevity only in relation to mortality have a tendency to reduce the number of older fish in a population. In an unproductive regime recruitment may be very low and the fishery needs to be regulated to that suitable adult spawning and rearing habitat is occupied for the duration of the unfavourable regime. This requires an understanding of the impacts of fishing and changes in the longevity and growth of the population.

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Microstructural patterns in fossil otoliths of mesopelagic fishes (family Myctophidae) - a new tool to study Tertiary ichthyocenoses

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Abstract

The fossil otolith microstructure is rarely preserved due to diagenesis. Although rare, fossil otoliths bearing internal microstructure might constitute a significant source of paleoecological information. Recent myctophids are characterised by an abundant and extensive geographical distribution. A frequent and abundant occurrence of myctophid otoliths in Tertiary sediments as well as long species duration in terms of geological time give a unique opportunity to compare the otolith microstructure of the same species among paleontological sites and/or between fossil and recent forms. The microstructure and otolith growth of three myctophid species from the southern European Miocene (Tortonian and Messinian), Pliocene (Zanclian and Piacenzian) and Pleistocene deposits, namely, *Scopelopsis pliocenicus* (Anfossi & Mosna 1976), *Ceratoscopelus maderensis* (Lowe 1839) and *Hygophum hygomi* (Lütken 1829) were studied and compared with those of the North Atlantic recent species of *C.maderensis* and *H.hygomi*, and South Atlantic *S.multipunctatus* Brauer 1906. Preliminary conclusions referring to paleoceanography were derived on the basis of the otolith microstructure.

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Annual Variation in Size-Selective Mortality of 0+ Atlantic Salmon (*Salmo salar*) Alevins :
Evidence from Otolith Microstructure

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Abstract

We sampled 20 Atlantic salmon (*Salmo salar*) fry at emergence and at the end of August during two environmentally diverse summers in the Ste-Marguerite R., Quebec, to detect differences in size-selective mortality. The summer of 1995 was hot and dry whereas that of 1996 was characterized by the largest flood ever to occur in Quebec's recorded history. Through otolith microstructural examination, fry body size-at-hatching was back-calculated using the biological intercept method. Size-selective mortality was observed in both summers; however, the direction of mortality differed. In 1995, back-calculated standard lengths at hatching of fry collected in August were significantly larger than for those collected in June, indicating a higher summer mortality rate of smaller alevins. However, comparisons of back-calculated body size between the 2 sampling periods in 1996 indicated that the largest alevins at hatching suffered higher mortality. This inter-annual variability in size-selective mortality led to significant differences in the mean size of fry at the end of their first summer of life. Current theory holds that social dominance and competitive advantages early in life influence size-at-age and age-at-maturity of salmon. However, size-selective mortality, influenced by meteorological and hydrological events, may amplify or negate advantages gained through social dominance.

Contribution: 99

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Fish Otolith Research and Application
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Temporal Changes in Fish Growth and Otolith Composition As Determined Using Otoliths from Indian Middens

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Abstract

Sagittal otoliths excavated from four American Indian midden sites were used to compare the age structure and growth characteristics of prehistoric and contemporary freshwater drum, *Aplodinotus grunniens*, in Louisiana and to gain insight into the chemical stability of otoliths. Based on marginal increment analysis of 307 sectioned sagittae from fresh water drum collected in 1987-1988, one distinct opaque zone formed each year in individuals ranging from 2 to 11 years. Using this annulus validation, prehistoric freshwater drum ranged in age from 2 to 15 years with the majority ranging from 2 to 6 years old. Comparison of otolith annulus widths, observed in transverse sections of prehistoric and contemporary freshwater drum sagittae, provided evidence that growth rates of freshwater drum in Louisiana have changed over the past 2500 years. Freshwater drum grew slower from 800- 200 B.C. and faster from 700 to 1710 than did contemporary fish (1987-88), based on otolith annulus width at age. It is possible that such change in growth is due to changes in habitat quality, fish life history, or population size. The chemical composition of otoliths collected during this project was compared using wave length dynamics to describe diagenesis over the 2500 year time period.

Contribution: 100

2nd International Symposium on
Fish Otolith Research and Application
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Validation of annual ageing and sources of ageing error in 5 coastal marine finfish from NSW, Australia

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Abstract

A two year program to externally tag and mark estuarine fish with tetracycline was completed the southern coast of NSW. To date, a total of 695 tetracycline-marked individuals of *Pagrus auratus*, *Acanthopagrus australis*, *A.butcheri* (Sparidae), *Sillago ciliata* (Sillaginidae), and *Argyrosomus hololepidotus* (Scienidae) have been recaptured and examined for ageing validation. Although for each species the macrostructure of otoliths conforms to an annual periodicity, the accuracy of the age estimates varies among species. Two important sources of ageing error are described in this study. There is within-species variation in when the opaque zones are formed, and the magnitude of this variation differs amongst the five species. This causes errors in age estimation because it influences the readers ability to correctly interpret the edge of the otolith, with respect to month of capture of the fish. The second influence on ageing accuracy arises from the degree of individual variation in the rate of growth of the otolith. Fish with either fast or slow growing otoliths are more likely to be incorrectly aged, also because they can present the reader with the same difficulty interpreting the edge of the otolith relative to the month of capture.

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Population dynamics of larval walleye pollock in the Gulf of Alaska

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Abstract

Otolith aging plays a key role in studies of the population dynamics of walleye pollock in the Gulf of Alaska. This population has some life history characteristics that make it particularly suitable for studies of mortality and transport. Surveys to estimate age-specific abundances of larval pollock are designed to accommodate these life history characteristics and their interaction with oceanographic features. Mortality rates of early feeding stage larvae vary interannually by over an order of magnitude, and decline with increasing age. Coefficients of variation of the mortality estimates are on the order of 10%. Mean seasonal mortality estimates are compared to seasonal means of environmental conditions for 12 years of data over the period 1981-95. Finer scale within-season resolution is made from comparisons of daily hatch date distributions to daily environmental conditions. Length-at-age analysis is conducted to examine interannual variability in larval growth rates, and to examine factors related to this variability. Finally, critical periods in the life history of pollock are examined from life tables. Various problem areas in otolith-population studies are discussed.

Contribution: 103

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A spatial and temporal comparison of early life-history characteristics for a marine finfish species from southern Australia, based on otolith microstructure

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Abstract

Early life-history characteristics of marine finfish vary with exogenous influences, which contributes to substantial inter-annual and amongst-site variation in recruitment rates. The microstructure of otoliths of young fish can retrospectively reveal some extraordinary detail of the earlier experiences of such fish. It was previously shown that for King George whiting (*Sillaginodes punctata*) of southern Australia, the pre-settlement growth and duration for post-larvae collected from one site through one settlement season, varied considerably. Here, the spatial scale of comparison of such characteristics has been increased to include four nursery areas up to 500 kms apart. Each was sampled for post-larvae three times through the settlement season of 1994. At each nursery area the average growth rate decreased whilst size-at-age and likely pre-settlement duration increased systematically throughout the long settlement season, possibly in response to seasonal variation in water temperature. Alternatively, the differences amongst areas were relatively minor and related to lower pre-settlement durations at two coastal embayments. These results determined that temporal variation at the small spatial scale was more significant than spatial variation over a distance of 500 kms. They warn that meaningful comparative studies on the early life-history of finfish at different spatial scales, must be based on a thorough understanding of local variation in early life-history characteristics through time.

Contribution: 111

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A comparison of the larval lives of *Anguilla rostrata* and *A. anguilla* eels as revealed by examination of otoliths of glass eels collected from eleven locations around the Atlantic Ocean

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Abstract

Glass eels of the American eel *Anguilla rostrata* (Le Sueur) and of the European eel *A. anguilla* Linnaeus were collected from six estuaries on the American coast and five estuaries on the European coast. The point of metamorphosis of leptocephalus to glass eel on the otolith is declared to be the place where there is a sudden decline in the Sr/Ca ratio. The mean ages of the larvae at different stages in their lives were estimated to be:

| Stage | Age in days (month) | |
|--|---------------------|--------------------|
| | <i>A. rostrata</i> | <i>A. anguilla</i> |
| (1) at arrival in estuary | 255 (8.5) | 448 (14.9) |
| (2) from hatching to metamorphosis | 200 (6.6) | 350 (11.6) |
| (3) from metamorphosis to arrival in estuary | 55 (1.8) | 98 (3.3) |

The growth rate of American eel larvae was estimated to be 0.21 mm d⁻¹, and growth rate of European eels 0.15 mm d⁻¹. The spawning season of American eels was estimated to be April-September and that of European eels November - March. These results suggest that slower growth rate and longer pre-metamorphic life in European eels are the principal methods by which European and American eel leptocephali become separated.

Contribution: 115

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Estimation of precise ages from marginal increment widths

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Abstract

More than 15000 sardine (*Sardinops sagax*) otoliths originating from the South African west and south coasts were examined. Otolith ages were determined from whole otoliths. Annual Growth Zones (AGZ) and Marginal Increment Widths (MIW) were measured in all otoliths. Precise ages were then assigned to the MIWs, judging their widths in relation to the previous complete AGZ and relative to the expected width derived from AGZ-frequency distributions. A discriminant analysis was subsequently employed to separate groups of otoliths with common growth characteristics and of common age, using year, date, landing site and fish length as additional identifiers. Landing site and year allowed a separation of South and West Coast specimens. For both groups, General Linear Models (GLM) including interaction terms were fitted, using otolith measurements, fish lengths and landing dates. The GLMs predicted that in young sardines fish length is a significant predictor variable of precise age. For sardines older than 2 years, the last two AGZ widths determined the precise age at a particular date. Predicted precise ages deviated between 0.1 and 0.2 years from initially estimated ages. Imprecision of estimated precise ages increased with increasing age. This was attributed to the effect of the increased measurement imprecision on the smaller AGZs and MIWs. The improved precise age estimation will improve year-class assignment in sardine, a species with a year-round spawning season.

Contribution: 127

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Interannual Differences in Time of Spawning and Growth Rates of Pelagic Juvenile Cod in Newfoundland Waters

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Abstract

Age (d) and growth rates (mm d⁻¹) were determined from micro-otoliths of pelagic juvenile cod (*Gadus morhua*) captured during pelagic juvenile fish surveys, 1992-1996. Significant differences occurred among years in the hatching dates of cod. Spawning and hatching occurred primarily in August of 1992 and 1993, whereas in 1994-1996 it occurred primarily in June and July. The late spawning period in 1992 and 1993 coincided with years of extensive ice cover, which persisted much later than usual, and below normal water temperatures. In 1994-1996 both seasonal ice cover and surface water temperatures returned to near normal conditions. We hypothesize that significant differences in seasonal ice cover affected the spawning time of the northern Newfoundland cod. Mean growth rates were higher in 1992 and 1993 when hatching occurred later in the season, averaging 0.641 and 0.643 mm d⁻¹, respectively. In 1994 and 1996, growth rates were lower, averaging 0.565 and 0.548 mm d⁻¹, respectively. However, 1995 growth rates were the highest observed during these five years, averaging 0.670 mm d⁻¹. These differences in growth rates are not directly explained by differences in water temperatures.

Contribution: 130

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Assessing the reliability of thermally-marked otolith classifications in the management of mixed stock fisheries

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Abstract

Otolith thermal marking is an efficient method of mass marking hatchery reared salmon and with careful sampling the marks are routinely used to determine the proportion of hatchery fish captured in over 100 fishery openings in Alaska each year. However the ability to classify thermal patterns is ultimately a subjective determination which is dependent upon a number of factors including the training and experience level of personnel. Under such conditions, estimating accuracy is problematic. An agreement index such as Kappa, is a tractable measure of reliability that can be applied when two readers make independent determinations. However the magnitude of Kappa is influenced by the true proportion of marked fish. As an alternative, latent class models (LCM) when applied to three or more independent readings or multiple groups of paired readings, allow estimation on the rates of false positive and false negative calls by each reader. LCM provides a means to incorporate the variance due to reader error directly into the contribution estimates. The use of Kappa and LCM are illustrated by data generated from quality control procedures applied to the detection of thermal marks as an aid in the management of several pink, chum and sockeye salmon fisheries.

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Bar Codes and Micro-Beams: Using Otolith Structural and Chemical Attributes to Monitor Salmonid Populations

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Abstract

Pacific salmon species are comprised of many populations with specific spatial and temporal associations to spawning rivers. These populations, or stocks, lie at the heart of salmon fisheries management since a host of conservation and allocation decisions are dependent upon recent trends in abundance for each. The desire to harvest surplus fish from healthy stocks while protecting those in decline places a premium on methods to identify the origins of juvenile and adult fish. Distinguishing between hatchery origin versus naturally-spawned fish is a particular concern, where the magnitude of hatchery salmon production dictates the need for practical mass-marking methods. Otolith thermal marking is a widely employed technique which uses short-term temperature fluctuations to place distinctive structural marks on the otoliths of incubating hatchery salmonids, *en masse*. We review the biological basis for otolith marking, using experimental studies to demonstrate how duration and magnitude of planned temperature changes impacts salmonid otoliths, how thermal manipulations interact with ambient regimes to determine the efficacy of induced marks, and strategies to create recognizable patterns of thermal events. Case studies illustrate the utility of thermal marking in diverse scenarios.

Just as natural incubation environments with divergent thermal regimes produce effective thermal marks, we employed natural chemical variability in salmonid otoliths to distinguish anadromous origin steelhead or sockeye salmon juveniles from sympatric, fresh water resident rainbow trout and kokanee in Washington State. Chemical analyses of juvenile and adult otoliths supports the idea that maternal associations with fresh and sea water can often be determined through strontium abundance in the primordial region of progeny otoliths. Planned crosses with three species of pacific salmon reveal that progeny of sea water origin females are unequivocally distinguishable from their fresh water resident counterparts.

Results from an experimental spawning channel show that strontium signatures in otolith primordial regions can function as a natural marker for the progeny of females sequestered in fresh water captive brood stock programs. Variability among species and populations of pacific salmon reveals a trend, suggesting that the timing of spawning migrations with respect to egg development plays a major role in determining strontium abundance in the primordial otolith, providing some discrimination between spring/summer and fall/winter races of chinook salmon and steelhead. Several examples show the power and pitfalls of using otolith core chemistry to distinguish anadromous from fresh water origin salmonid progeny

Contribution: 160

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Application of computer vision and texture discrimination to identify thermal marked salmon otoliths

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Abstract

We adopt a novel approach to detecting thermal marks using techniques that are being developed for texture discrimination in computer vision. This provides a more natural framework for thermal mark detection than the line detector schemes that are commonly proposed because the detection and inter-mark distance measurement are combined in a single filtering step. We decompose the image into a multi-channel representation using a bank of Gabor filters that has been previously tuned to discriminate thermal marks. We learn the pattern of filter responses by using the Expectation - Maximization algorithm of Dempster, Laird and Rubin to fit a mixture-of-Gaussian model to the data. We arrive at a hard classification of the data by assigning different components of the model to foreground or background classes. The approach is evaluated by examining test samples containing a mixture of known otoliths from thermally marked hatchery and wild pink salmon fry from Prince William Sound, Alaska. The accuracy of the classifications are compared to those from human readers which examined the same test samples. The advantages and disadvantages of computer vision in this application are considered.

Contribution: 68

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Using otolith shape analysis to distinguish eastern Gulf of Mexico from Atlantic Ocean stock
king mackerel *Scomberomorus cavalla*

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Abstract

During the winter, king mackerel from the eastern Gulf of Mexico and Atlantic stocks mix off southeast Florida, where they support a large fishery. Because neither tagging nor genetic studies have yielded a satisfactory way to accurately estimate mixing rates, for management purposes, these fish have been considered to be all Gulf stock. Our objective was to develop a technique to distinguish the two stocks using discriminant analysis of otolith shape data, including standardized Fourier amplitude, area, and perimeter. Shape data were collected, using image analysis, from the sagittae of 363 females 80-96 cm FL from northwest Florida and the Atlantic coast north of Cape Canaveral obtained during the spawning season (summer). Using backward elimination variable selection on our training set of 240 fish, we developed a quadratic discriminant function using perimeter, area, and 10 harmonics of Fourier amplitude data which correctly classified 77.1% of Atlantic and 85.0% of eastern Gulf fish in an independent test data set (n=123). When applied to shape data from 463 females 80-96 cm FL collected from the mixing area the following winter, the discriminant rule classified 88% as Atlantic stock and only 12% as eastern Gulf.

Contribution: 172

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Recovery of Thermally-induced Otolith Marks for Origin Identification of Juvenile Pacific Salmon Released from Hatcheries in the Marine Waters of Southeastern Alaska

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Abstract

Samples of juvenile Pacific salmon were examined for origin identification from over 25 thousand juveniles recovered during the summer of their first ocean year in the marine waters of southeastern Alaska in 1993-96. All juveniles were electronically scanned for internal coded-wire tags and only 0.1% (30) contained coded-wire tags. Conversely, a small fraction of the juvenile pink (1,724), chum (805), and sockeye (5) were examined for thermally-induced otolith marks and a relatively large proportion were detected for each species: 2.6%, 24.0%, and 40.0%; respectively. All otolith marks detected from these samples were cross checked by two readers and questionable marks (~5%) were sent to a third reader for further validation. Banding patterns of thermal marks in the left and right sagittal otoliths were used to identify the hatchery of origin and release locality of the juveniles. Most marked juveniles recovered had migrated 100-150 km over a 60-90 d period. This relatively high recovery rate of otolith marked juveniles has broad implications for the study of Pacific salmon life histories. In particular, systematic sampling of juveniles for otolith marks during their early marine life history will give insight on the temporal and spatial occurrence, growth, mortality of hatchery stocks and will give an unprecedented opportunity to study wild and hatchery stock interactions in marine ecosystems.

Contribution: 184

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Age determination in high-Antarctic fish

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Abstract

The polar marine environment is characterised by highly stable temperatures but a marked seasonal primary production and light environment. Such an environment exerts a highly seasonal influence on the growth and development processes among Antarctic fish. Polar fish, in general, are slow growing, have delayed maturation, low relative fecundity, spawn annually and are naturally long-lived. A small number of species achieve large size. Annual and daily increments have been described in the otoliths and other structures of *low-Antarctic' species although few have been properly validated. Some species, particularly among the channichthyids, remain difficult to age using conventional methods despite the highly seasonal environment. This account extends information about polar species to those groups found on the continental shelf of Antarctic and indicates why age estimates can be misinterpreted unless the life-history and niche requirements are well understood.

Contribution: 187

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Larval growth and condition of *Sardinella brasiliensis* (Steindachner, 1879) in Brazilian waters*

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Abstract

Over the last two decades, Brazilian sardine the most important resource in the south-eastern Brazilian coast, presented a great variation and decline in its stocks. The main factors contributing to this seem to be: changes in the oceanographic structure causing displacement of the spawning schools, recruitment failures, excessive catches of juveniles, growth of fishery effort. In spite of this, no alterations in the density dependent parameters (individual batch fecundity, gonado-somatic ratio, condition factor and length at first maturation) were detected. So, methods analysing physiological condition of the larvae (RNA/DNA ratios and tryptic enzyme activity) coupled with methods determining growth using sagittae otolith increment width started to be performed to evaluate growth, under different experimental conditions. The results of the readings on the sagittae were compared with the known age of the laboratory-reared sardine larvae and confirmed that increments are formed on a daily basis. Under poor feeding conditions, sardine larvae showed a low growth expressed by length, dry weight, RNA/DNA and tryptic enzyme activity and on the narrow and low contrasting increments in the otoliths. The increment width showed an unexpected decline between increments number 8 and 10 in fed larvae, coupled with a decrease in the biochemical indices in the feeding group occurring 2 days earlier. It can suggest that some factor other than food availability was affecting the condition of the larvae and might be indicative of some physiological changes occurring in sardine larvae (calcium metabolism/deposition, neuroprotein secretion, metabolism/somatic growth), since food in sufficient amount was available to the larvae.

The authors contributed equally to the paper

Contribution: 240

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Between-area differences in age and length at first maturity of orange roughy (*Hoplostethus atlanticus*) based on a transition zone in otoliths

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Abstract

A transition zone in otoliths of orange roughy (*Hoplostethus atlanticus*), where annulus width decreases markedly, is shown to mark the time of first sexual maturity. Assuming that otolith annuli are formed annually (which has been directly validated for only the first four translucent zones), mean age and length at onset of maturity were calculated for orange roughy populations off New Zealand, Namibia, and Great Britain. Significant between-area differences were apparent in both these parameters. The implications of the between-area differences on stock structure of orange roughy in New Zealand waters are discussed. A directly proportional relationship between age at onset of maturity and the modal size of fish in the mature population is demonstrated. This is consistent with later-maturing fish experiencing a longer period of growth at the pre-maturity growth rate, which is relatively faster than the rate of somatic growth after maturity.

Contribution: 195

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Age and growth of the juvenile Pacific sardine *Sardinops sagax* and its influence on the population growth rate in the northwestern zone of Baja California, Mexico, during the summer of 1994

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Abstract

Juvenile Pacific sardine *Sardinops sagax* (50-175 mm SL), were collected by the sportfishing fleet off Ensenada (NW zone of Baja California, Mexico) between July and September 1994. The ages of 72 juveniles were determined by means of counts of daily growth rings in saggitae otoliths. The back-calculated hatching period was determined. Gompertz model fitted the data between SL and absolute age, and the somatic growth rate was 0.61 mm/d. A total of 13,541 increments were measured and showed different widths. Using the relationship otolith radius-SL, the lengths (mm) were back-calculated from each increment width (μm), with the objective to obtain the daily growth rate (mm/d) and evaluate a possible relation with the oceanographic conditions. The individual growth trajectories were gathered. The growth variability of the juveniles as explained by the daily growth rates were grouped by stage of development. A simple ANOVA model showed significant differences in the mean growth rate by stage ($p < 0.05$). With the average growth rate by stage it was possible to calculate the duration (days) of the stage. The effect of variable growth rates by stage on the dynamics of the species was examined using a Lefkovich matrix. A change in the duration of the juvenile I stage (60-85 mm SL) from 39 to 24 days and a change in the duration of the juvenile II stage (86-110 mm SL) from 38 to 27 days results in an increase of 8.9 % and 6.5 % by year in the population growth rate ($\lambda = 1.089$ and $\lambda = 1.065$) in both scenarios. The influence of the juvenile growth on the population dynamics of the Pacific sardine is discussed.

Thematic area: estimation of growth rate.

Contribution: 10

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Otoliths of anadromous chars reflect their first smoltification

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Abstract

Otoliths of four char species (genus *Salvelinus*, *Salmonidae*) have been studied from various regions of North-East of Russia. Chars of this region are characterized by number of anadromous populations, when fish during few months are feeding in sea and receive at this time main energy for their life. For this reason chars grow very slowly during first 2-5 years before smoltification, but later with regular shifts of fresh and saltwater dwelling their growth becomes much faster. This life history feature of chars is precisely reflected by their otoliths. The form of otoliths is getting significantly modified since first smoltification of chars. This happens because of slowing down of its growth in downward and acceleration in backward and, especially, forward directions. As a result of marine life the external surface of otoliths sharply changes as well. Radial folds raised high over the surface appear on some parts of an otolith. It is true for various species of chars and for some other salmons. Study of these structures by scanning has revealed some feature for different species. The first "marine" annual ring of an otolith has, as a rule, maximal optical density. Long-term experience shows, that the age of the first smoltification of chars can be rather reliably determined by otoliths in reflected light. The age of smoltification has been determined in 60-70 % of specimens from the sample size in populations of Taranetzi char, and in 95-100 % - in malma. This percent adequately reflects their differences in marine spending.

Contribution: 11

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Detecting Stray Auke Creek Pink Salmon Using Coded-Wire Tags and Thermally Induced Otolith Marks

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Abstract

Our study examined the relative survival and straying rates of coded-wire tagged and otolith marked pink salmon from Auke Creek, Alaska. Generally the pink salmon survivals in streams in the Auke Bay and Juneau vicinity were very poor. Accordingly the survival of coded-wire tagged (cwt'd) Auke Creek pink salmon was also very poor (0.18%) as was the survival of otolith marked pinks (0.40%). However the otolith marked pinks survived significantly ($p=0.05$) better than those which were coded-wire tagged. Additionally we found much higher survival (1.65%) of unmarked pinks in relation to both cwt'd and otolith marked which may be attributed in part to straying of unmarked fish from other stream systems. Only 2.7% of the returning Auke Creek pink salmon strayed to other streams. The straying rate of early and late run components of the Auke Creek production were not significantly different. Interestingly the straying rate of Auke Creek pinks based on recovery of cwt's was significantly ($p=0.05$) less than the straying rate of otolith marked fish. As most of the cwt'd pinks were also otolith marked the difference can be attributed to a combination of low survival of the cwts and poor detection of adipose clipped fish. Straying was also influenced by stream type with significantly ($p=0.05$) more strays being found in larger streams with larger populations and higher water flows.

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Growth-dependent and size-selective mortality in 0-group haddock *Melanogrammus aeglefinus* (L.)

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Abstract

The stage and size selective nature of many mortality processes, and in particular predation, has led to considerable interest in the role of growth rate in influencing year-class strength. As part of an investigation into the factors controlling recruitment in haddock in the North Sea, we tested for evidence of growth and size related differences in mortality during the late larval and juvenile phase using otolith microstructure. The methodology employed was first verified experimentally by rearing 0-group haddock to a year old and investigating the fish size-otolith size relationships of individual fish. Field samples of larvae, pelagic and demersal juveniles were collected in surveys during 1994 and 1996. These investigations demonstrated that juveniles surviving to settlement in August were subject to selective mortality on the basis of size, but not age. Indeed only the largest size fraction of the pelagic juveniles appeared to survive to settlement. Following settlement there appeared to be relatively little further size selection. The apparent importance of size selective mortality between the pelagic and demersal phase may explain why earlier indices of pelagic 0-group gadoid abundance were not good predictors of year-class strength. The work also highlights the need to consider the pelagic-demersal juvenile transition for our understanding of recruitment variability.

Contribution: 31

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Geographical and interannual growth comparison of 0-group sole, *Solea solea* (L.)

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Abstract

0-group sole, *Solea solea* (L.) were sampled in late spring-early summer by a small beam trawl (1m and 2m beam trawl) in the Vilaine estuary (Northern Bay of Biscay) in 1992 and 1993 and, in the Eastern English Channel, along the French coast in 1997. In the Northern Bay of Biscay, spawning and nursery areas are spatially separated (about 70 km), whereas spawning areas are located either offshore or overlapping coastal nurseries in the Eastern Channel. Left lapillar otoliths were used to estimate age and growth. Daily formation of lapillar increments was validated using hatchery-produced juveniles, marked by immersion in an alizarin-complexone sea-water solution, at a concentration of 100 mg/l for 4 hours. Late larvae and early juveniles settled on the nursery later in the Eastern Channel (late May-early June) than in the Vilaine estuary (early and late April). Analyses of growth rates indicated no interannual variations in the Vilaine estuary and small, but no significant variations within areas (Bay of Biscay and Eastern Channel). In the Vilaine estuary, 0-group growth rates were estimated to be 0.472 mm/d (range of total length of individuals analysed, TL: 20-66 mm; n=71) in 1992, 0.473 mm/d (TL: 21-82 mm; n=84) in 1993 and 0.46 mm/d (TL: 19-65 mm; n=80) in the Eastern Channel in 1997. The duration of the spawning and larval immigration period, the distance between spawning and nursery areas and the influence of environmental factors on growth and population dynamics of 0-group sole are discussed.

Contribution: 32

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Growth of juvenile anchovy, *Engraulis encrasicolus*, in Central Adriatic Sea

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Abstract

Engraulis encrasicolus post larvae and juveniles were collected monthly during 1996-97, in the coastal area of Ortona (Central-Western Adriatic Sea), using a commercial bottom trawl net for fish fry. Individuals up to 60 mm in total length were aged by means of daily otolith (sagitta) increments observed at light microscope. Growth rates were calculated for different seasons and values obtained ranged from 0.55 to 0.72 mm/day for juveniles from 30 to 60 mm in total length. Young anchovies reached the size of 60 mm in less than three months and during this period they tended to concentrate in shallow (less than 30 m depth) waters. Distribution of back calculated birth dates showed that the spawning period of anchovy in the Adriatic could be longer than previously reported. An indirect validation of daily periodicity of increment deposition was inferred comparing the change in mean increment count (in modal classes) and the time elapsed between successive sample dates.

Contribution: 35

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The use of otolith weight to predict age structure of coral trout (*Plectropomus leopardus*) populations on the great Barrier Reef, Australia

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Abstract

Knowledge of fish age structure provides the key to estimate growth, mortality and the production rates of populations. The conventional method of age determination based on examination of the sectioned otoliths has proved to be time consuming and expensive, especially in the tropics. This study assesses the use of otolith weight as a predictor of age and thus a predictor of age structure of fish populations. The otoliths of common coral trout, *Plectropomus leopardus*, collected from 24 coral reefs on the Great Barrier Reef were examined to establish a relationship between otolith weight and fish age at each individual reefs. There was a relatively high agreement between the observed and predicted age structures for all 24 reefs. Otolith weight was therefore relatively effective, economic and fast method for estimating age structure of *P. leopardus* populations on a reef by reef basis. This provides a more economic method for accurately predicting age structure of coral reef fish populations.

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Contribution: 36

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Investigations of Growth of Deep-Sea Redfish (*Sebastes mentella* Travin) From the Norwegian-Barents Sea Population

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Abstract

On the basis of otolith analysis for 1992-1997 results from investigations of linear and weight growth of deep-sea redfish from the Norwegian-Barents Sea population are presented.

Linear and weight growth of the deep-sea redfish of the study population follow the patterns typical of many fishes, that is linear growth is intensive in young fish but maximum weight increments are observed in older individuals.

The most intensive linear growth of males and females is observed in the young age. Maximum absolute and relative linear increments were registered in young, immature fish constituting 1.4 - 4.2 cm and 5.0 - 22.7%, respectively. The decrease of linear growth rate when maturation is reached is typical of many fishes. Slowing down of linear growth in the deep-sea redfish occurs at age 10-15, i.e. absolute and relative increments reduces down to 0.9-1.5 cm and 2.9-5.0 % (males), 1.1-1.4 cm and 3.3-4.7% (females).

Weight increments are minimum in young, immature individuals and reach their maximum at maturation, i.e. according to our data the mean absolute weight increment in the deep-sea redfish at age 4-13 constituted 42.2 g and in fish at age 14-19 it was 64.7 g.

Thus, reasonable exploitation of the deep-sea redfish from the Norwegian and Barents Sea population should be based on catch of fish older than age 12-13. Removal of younger deepwater redfish will not permit them to reach the period of intensive weight growth and, therefore will reduce the annual increment of biomass of the population subjected to fishery.

Contribution: 39

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Daily growth and time of settlement in juvenile English sole (*Pleuronectes vetulus*) in Hecate Strait, British Columbia

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Abstract

We examined daily growth rings on otoliths collected from juvenile English sole (*Pleuronectes vetulus*). Counts of daily growth rings were used to determine the time of settlement. The otoliths examined exhibited three characteristic growth patterns during the first year of life. These patterns corresponded to the time of settlement of English sole larvae to the benthic habitat from October through the following April. The variation in growth among age one fish was significantly greater than that for juveniles of age 2 and 3 suggesting that survival for this species may be promoted by growth that occurs during the first year of life. Growth during the first year of life is critically affected by the time of settlement of larvae. Growth during the early life stages may play a role in characterizing the maturation schedule as well as somatic growth in adults.

Contribution: 69

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Use of Geothermal Energy to otolith mark Chinook salmon and Sockeye salmon hatchery,
Kamchatka, Russia

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Abstract

In 1995 at Malkiís geothermal factory there was first thermomarking of sockeye salmonís and chinookís fry with the use of geothermal energy. The Island boiler system was used for water temperature regulating. There was the thermomarking plan on which, for having a higher reliability, double W-marks were induced on otoliths. Except the planned thermomarks on otoliths of factory fry the spontaneous thermomarks are laid. Microstructure of factory fry otoliths from Malkiís factory differs by having more intensive and wider rings along the otolith thickness (up to the first food ring) than wild fry. The presence of rings next to primordia and up to the ring of hatching is typical for wild fry. The formation of these rings is connected with autumn ñ winter temperature fluctuations in spawning hillocks.

It is possible to discover the signs which are characteristic for microstructure of hatchery fish with a more reliability by mathematic spectrum analysis of brightness profile and algorithms of improving image otoliths quality. The computer image analyser IM of IMADA Firm (Russia) was used for solution this tasks. This one based on using ourself worked special algorithms and means for analysis otoliths and scale of fish. The more detailed information is mention in (1).

Contribution: 74

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Growth rate variation of tropical fish larvae across frontal structures in the Andaman Sea

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Abstract

The growth rate was analysed for fish larvae of the families *Carangidae*, *Gonostomatidae*, *Lutjanidae* and *Myctophidae*. Larvae were sampled across frontal structures at the shelf slope of the Andaman Sea, and their otolith microstructure was analysed. The growth rate varied markedly along the sampling transects, the rate being highest in regions of frontal characteristics. However, growth patterns differed between families, the rate increased towards distributional centres of the different families. The characteristics of larval fish growth in tropical waters are compared to findings in temperate areas.

Contribution: 77

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Growth and age estimation of Greater Fork-bear (*Phycis blennoides* Brünnich, 1768)

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Abstract

Phycis blennoides (Brünnich, 1768) is a gadoid fish, distributed along the continental shelf and slope on bottoms between 90 m and 1250 m. This species is object of a deep-water fishery by small long-liners in Cantabrian Sea (ICES Division VIIIc). Also this species is caught, jointly with hake and blue ling as by-catch in the bottom trawl fishery on continental shelf. In 1996 and 1997, a wide size range of the otoliths were collected and aged from Experimental and Research surveys, on board of trawlers and from long-liners landings. In general way, the sectioned otoliths shown a group of bands constituted with numerous and weakly marked rings. The modal analysis from catches length distribution of the youngest specimens permits to establish the age one to individuals with mean length around 17 cm. In the central part of the otolith, close to the nucleus appears frequently a check ring strongly marked. After this, annual rings laid down forming a band of several rings clustered which hinder the interpretation of growth pattern corresponding to the older ages. The Von Bertalanffy growth curve shows differences by sex: The females growth faster, reaching 11 years with 81 cm, while the males did not reach more than 5 years with 46 cm.

Contribution: 78

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Methods of Age Identification and Size-Age Structure of the Barents Sea Long Rough Dab
(*Hippoglossoides platessoides*)

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Abstract

Long rough dab is an abundant species that is common at a wide range of depths, temperatures and salinity. Research on the age of this species dates from 1967. The age of the Barents Sea long rough dab is identified by whole otoliths which have been soaked in a special solution and after that examined in the incident light at 32x magnification. The results of size-age structure analysis of long rough dab in 1987-1997 have proved that the school of long rough dab retained its multi-age structure. However, in comparison with 1970s, rejuvenation of the population has been observed on account of the increase in the number of juveniles. In the same period the average length and age of both males and females considerably decreased. Differences in the length of the specimens of the same age group have been remained, females are larger than males because their growth rate is higher. Long rough dab grows faster (3-5 cm yearly) till it reaches maturity, then the growth decreases to 1- 3 cm that characterizes the Barents Sea long rough dab as a slow-growing species.

Contribution: 81

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STUDY ON GROWTH AND AGE DETERMINATION OF *DICOLOGLOSSA CUNEATA* (Moreau, 1881) IN THE SOUTH ATLANTIC SPANISH REGION (GULF OF CÁDIZ).

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Abstract

The *Dicologlossa cuneata* (Moreau, 1881) is a demersal sole species, typically from the coast, and it is considered one of the most important species of the demersal fisheries of South Atlantic Spanish Region (ICES IXA). The growth pattern of wedge sole of the Gulf of Cádiz is studied. The determination of age by means of observation of whole otoliths is done, obtaining the mean lengths at age for males and females for 1993. Parameters of the von Bertalanffy growth function for both sexes were also estimated, and they were compared with those obtained by other authors in other areas of its range of distribution. By means of the interpretation of otoliths and their edge, an alternate sequence of bands of growth is observed and these coincide with fast and slow growths, presenting the highest percentages of opaque edge (fast growth) in the period of May to October. Mean diameters for every age estimated are obtained and the relationship between size of the fish and diameter of the otolith is calculated.

Contribution: 90

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Age structure of the population of weakfish *Cynoscion guatucupa* (Cuvier) in the Bahia Blanca waters, Argentina

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Abstract

The age of *Cynoscion guatucupa* from the Bahia Blanca estuary (39°LS), south-western Atlantic waters, was studied by means of sagittae otoliths. A total of 1018 fish, caught by the fishing fleets operating in the Bahia Blanca area, were collected between April 1991 and May 1993. The annual periodicity in the growth marks was validated by examining the monthly proportions of opaque and hyaline growth band in the margin of the sliced (edge) otoliths. Annulus formation occurred in June-August. The age for juveniles, ranging from 50 to 150 mm TL, was 0. For adults, the ages ranged from 5 to 23 years (400-520 mm TL) for females and 7 to 22 years (400-510 mm TL) for males. Length-weight relationships were $W(g)=0.0067 L(mm) \exp. 3.8$ for juveniles, $W(g)=0.299 L(mm) \exp. 2.06$ for female and $W(g)=0.269 L(mm) \exp. 2.08$ for males. At the same age, females were longer and heavier than males. Like other sciaenids, *C. guatucupa* is a typical inhabitant of estuaries and coastal regions. In the study area, the juveniles stay there during their first year of life and adults come into the estuary after the spawning period, for feeding and recovering.

Key words: *Cynoscion guatucupa*, Sciaenidae, age, Argentina.

Contribution: 91

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Comparison of daily growth rates among winter spawned Mediterranean and winter and spring spawned Atlantic *Sardina pilchardus* (Walbaum, 1792) recruits

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Abstract

Sagitta otoliths of 267 and 126 *Sardina pilchardus* juveniles from Atlantic and Mediterranean spanish coasts respectively were used to determine birthdate distributions and daily growth rates, estimated from calculated relationships between somatic and otolith growth. Samples were collected in periods comprised between April and October in three years: 1988, 1991 and 1992. In order to compare the results among areas and years mean values were used, because individual growth patterns were similar within each studied group. Significant differences in the evolution of daily growth rates between winter and spring spawned recruits were observed. Maximum daily growth rates were detected in spring spawned individuals. Spring spawned recruits maintained higher growth rates than winter spawned ones during the three first months of life, but from that age winter spawned recruits grew faster. These results were used to identify different stages during larval and juvenile periods and to compare the mean growth rates at each stage among both areas and years.

Contribution: 96

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Differences in growth of long tailed hake (*Macruronus magellanicus*) from several areas of Southwestern Atlantic Ocean

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Abstract

The presence of juveniles of *Macruronus magellanicus* at the same time in three different locations of Argentine shelf (36°-55°S) conducted to inquire into whether they belong to a single stock. Samples were taken from southeast Tierra del Fuego Island, San Matias Gulf and Grande Bay, during May 1993, and April and May 1994, respectively. In an attempt to distinguish differences in those geographical groups, radius of sagittae otoliths and the total length of long tailed hake were measured. The measurements were made in whole otoliths after 48 hours water immersion in order to clarify the rings. The relationship between them resulted to be linear in the complete range of total length analyzed, which included small juveniles (8-35 cm TL, 0 and 1 year old), and preadults and adults (36-95 cm TL, older than 2 years old). Comparisons between the geographical groups showed that the individuals caught in San Matias Gulf had highly significant differences, with smaller length at age than those which were distributed on the Patagonian shelf. Growth parameters of von Bertalanffy equation were estimated by radius-age method and by least square of length at age, both by ageing otoliths.

Contribution: 98

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The Significance of Sedimentary Otoliths Around an Artificial Reef: the El' Cazador of 1784

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Abstract

On 2 August 1993 the wrecksite of the El' Cazador was discovered by the fishing vessel "Mistake", at a depth of 200 m, about 80 km off the Louisiana coast. The El' Cazador was a Spanish brigantine of war en route from Vera Cruz, Mexico to New Orleans in 1784. Excavation of the site has produced 800,000 pieces of mint condition silver coins and thousands of fish otoliths. The shape of the sagitta was used to identify fish to genus and sometimes species levels. Sectioned sagitti were used to estimate age and to determine season of death. We identified five species of fish from the site. Transverse otolith sections of the two most abundant species, seatrout, *Cynoscion sp.* (45%) and Atlantic croaker *Micropogonias undulatus* (40%), were analyzed. Ages ranged from 0 to 7 years and 1 to 6 years for seatrout and croaker. Age structure from the collection was consistent with modern populations. The otolith margins showed that fish death did not result from a single catastrophic event, but that mortality occurred year-round across multiple year classes. Community structure at this site, based on otoliths has changed from coastal, estuarine dependent species, to a reef fish dominated community today.

Contribution: 113

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Daily age, growth and the backcalculated hatching dates of juvenile grey mullets *Mugil cephalus* in the northwestern coast of Taiwan as revealed from otolith microstructure

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Abstract

Age and growth of juvenile grey mullets *Mugil cephalus* collected from the estuary in the northwest of Taiwan during the period from November 1995 through March 1997 were determined by daily growth increments in otoliths. The daily periodicity of the growth increments in otoliths was validated by using tetracycline immersion of the juveniles. It was found that the juveniles of grey mullet recruited into the estuary at the mean size of 20.6 mm TL and approximately 32 days after hatching. They left the estuary at 34.0 mm (62 days). The duration of estuarine staying was about a month, growth rate was 0.452 mm d⁻¹ during this period. Backcalculated hatching dates lasted approximately five months from October through the following February.

Key words: grey mullet, otolith, daily age, growth, hatching date

Contribution: 114

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Age and growth of lane snapper

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Abstract

The sagittal otoliths of 300 lane snapper (*Lutjanus synagris*) with a size range of 18-36 cm fork length were analysed to estimate their age. Transverse sections of embedded sagittae were prepared for microstructural analysis. All specimens presented clear annular increments which were readily counted by three independent readers. Marginal increment analysis and OTC (oxytetracycline) injected specimens held in captivity validated that one annular increment was formed annually. The results enabled the estimation of von Bertalanffy growth parameters ($K=0.362$, $L_{\infty}=33.0$, $t_0=-2.51$). Ninety percent of L_{∞} is reached in four years and first sexual maturity is attained in the 1+ year class. There was no significant difference in the parameter estimates between males and females. The maximum age of 19 years determined in this study is the oldest age recorded for this species in the western Atlantic Ocean. Implications of the size-age structure of the population will be discussed as they relate to fisheries resource management.

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Discrimination of eelpout, *Zoarces viviparus* L., ecological groups by their sagittal otoliths in the Gulf of Riga (Baltic Sea)

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Abstract

Eelpout were caught from the shallowest (Pärnu Bay, depth ≤ 6 m) to the deepest regions (Ruhnu Deep, depth up to 54 m) in the Gulf of Riga during April-May, 1996. Their sagittal otoliths were visually inspected for shape and measured for length and width. Also, the diameter of the birth ring and width of yearly increments were determined. These investigations allowed to perform discrimination of the species into the two ecological groups that occupy the following regions within the survey area: 1 - shallow Pärnu River estuary. This area is characterised by enhanced biological production at remarkably higher water temperatures during the growth period as compared to the deep area, and permanent estuarine hydrological front that separates it from other areas of the Gulf of Riga, , and. 2 - deeper parts (≥ 25 m) of the basin that situate below the seasonal thermocline, including the Ruhnu Deep. Eelpout that inhabit the transitional zone between the main distribution centres of these two spatially separated stocks display intermediate pattern of the parameters measured. Existence of such eelpout groups was also supported by other studies of the species - vertebral counts, somatic growth rate, feeding habits and reproduction pattern. The mechanism for formation of the above-given structure of eelpout, originally a stenotherm cold-water species, is proposed. It is concluded that regional intraspecific units of sedentary

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Estimation of Hatch Periods, Growth Rates, and Subsequent Survival of Yellow Perch, *Perca flavescens*: Otolith microstructure examination

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Abstract

Growth rates of yellow perch were investigated in 1996 spawning season in Lake Opinicon, Ontario. The aging technique for yellow perch larvae was validated. The daily rings provided a reliable means for back-calculating growth and estimating hatching dates. The duration of estimated hatch periods for yellow perch eggs ranged from as early as May 1 to as late as June 7. Estimated initial growth rates of different cohorts of larvae ranged from 0.23 mm.d⁻¹ in the beginning of May to 0.37 mm.d⁻¹ a month later. Measuring of initial daily increments of otolith from juveniles provided an estimation of back-calculated hatching dates. Most of the survivals were drawn from the second half of the spawning season, at the time of higher water temperature and initial growth. Examination of juveniles from fall of 1996 and spring of 1997 provide some evidence of size-selective mortality.

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Should we make ageing of the lumpsucker (*Cyclopterus lumpus*) a part of its stock assessment?

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Abstract

Lumpsucker has been aged by a few researchers in the past (Cox 1920 Sæmundsson 1926 Bage 1964, 1967 Schopka 1974 Torsteinsson 1983 after Davenport 1985). This poster describes the efforts of a group from Iceland and Norway, which has taken up the work again, and, specifically, used the method of Torsteinsson (1983) of reading the sagittal otoliths in glycerol under transmitted light. This gave good agreement with previous results for juveniles, but reading otoliths from adults proved more difficult. Otoliths from adult lumpsuckers were also mounted on slides and ground until the year rings were clearer. This new method shows promise, but is rather time consuming and failed for some otoliths. The conclusion from our studies, at the moment, is that age reading is useful for clarifying the age structure of the oceanic stock of juveniles. On the other hand, ageing adult lumpsuckers will always be difficult but further work could lead to better results. Alternatives such as reading lapillar otoliths might improve the precision but that particular otolith is even more difficult to find than the sagitta. For stock assessment it might be advisable to develop length-based methods.

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BOTTLENOSE DOLPHIN POPULATION DIFFERENTIATION IN EAST FLORIDA,
USA, USING FISH OTOLITHS FROM DIETARY STUDIES

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Abstract

Different populations of bottlenose dolphins (*Tursiops truncatus*) occur off the east coast of Florida. Stomach content data derived from stranded animals were used in this study to compare the feeding ecology of two parapatric populations. Examination of 119 stomachs from dolphins inhabiting a protected estuary (the Indian River Lagoon system), and 127 stomachs from a population occupying exposed, inshore adjacent waters revealed overlapping diets. Important fish prey families were Sciaenidae, Mugilidae, Sparidae, Batrachoididae, Clupeidae and Engraulidae. However, estuarine dolphins were nearly exclusively piscivorous, whereas dolphins from exposed inshore waters had a mixed diet of fish and cephalopods. Additionally, key fish prey species occurred only in each particular area therefore, their otoliths were diagnostic of the dolphin population in question. Future studies on the elemental composition of otoliths from species commonly taken by both dolphin populations may shed light into the exposed inshore and protected estuarine habitat utilization of these animals.

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Estimating growth of tropical reef fish: a comparison of size at age and growth increment methods for the stripey bass, *Lutjanus carponotatus*.

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Abstract

Estimates of growth form a central element of most stock assessments. Such data is commonly lacking for many species exploited by tropical reef fisheries. In this study, estimates of von Bertalanffy growth equation (VBGE) parameters for the stripey bass, *Lutjanus carponotatus*, were derived from growth increment data and size at age data for a population from Lizard Island lagoon, northern Great Barrier Reef. Age determination was performed using increments in sagittal otoliths validated as annuli. Analysis of growth increment data from a tagging study produced VBGE parameter estimates of $L_{\infty}=357$ mm length to caudal fork (LCF) and $k=0.13$ year⁻¹, while size at age data produced estimates of $L_{\infty}=312$ mm LCF and $k=0.31$ year⁻¹. The pattern of growth described by the size at age analysis indicated that 84% of L_{∞} was attained in the first 4 years and that growth was greatly reduced thereafter. The size at age estimate is considered more accurate. The probable negative effects of tagging on growth, lack of small individuals in the growth increment sample, and the protracted period of negligible growth by species suggest that parameter estimates derived from growth increment methods will be biased. These results highlight the utility and importance of age-based parameter estimates in tropical fisheries population dynamics.

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Improved otolith preparation, ageing and backcalculation techniques for New Zealand freshwater eels

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Abstract

We improved the quality and readability of eel otoliths by cutting them through the nucleus using a scalpel blade before burning. The percentage of readable half otoliths increased from 56 % using the conventional break and burn technique to 99% using this technique. The level surface and consistent cut helped us identify supernumerary growth checks and backcalculate growth rates and lengths at previous ages. Supernumerary growth checks were identified by pattern recognition software measurements of radii width, check width and colour intensity and by examining thin otolith sections stained with toluidine blue. Growth rates and lengths at previous ages were backcalculated using a logarithmic relationship between otolith radius (R) and fish length (L mm). $R = 0.17024 + 0.01364 * (L - 60)^{0.72538}$, $r^2 = 0.992$, $n = 1210$. This relationship assumes copunctual individual growth trajectories and accommodates the tendency for fast growing eels to have relatively small otoliths. We developed seasonal growth curves and validated age and growth rates using tag recapture data, modal age group analysis and experiments on cultured eels.

Keywords: *Anguilla australis*, *Anguilla dieffenbachii*, otoliths, growth checks, backcalculation,

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Age, growth and reproduction of the lane snapper, *Lutjanus synagris* (Linnaeus) in Jamaica, West Indies

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Abstract

Studies of age and growth of the lane snapper, *Lutjanus synagris* (Linnaeus) based on the examination of otoliths from commercial catches along the south coast of Jamaica, were conducted from January, 1996 to March, 1998. Sex ratio (F:M) was 2.3:1.0. Male fish achieved first maturity at 180 mm FL and female at 184 mm FL. Peak spawning season occurred between May and August. The percentage readable otoliths was 85%. Otolith sections revealed clear annual patterns of growth. Age composition based on whole otolith examination showed maximum age of five years. However, examination of sectioned otoliths revealed a maximum age of 13+ years. Length-frequency data indicate that though the maximum age is high, the majority of the population is comprised of individuals between 2 to 6 years old. Mean percentage of individuals with opaque zones at the otolith growing edge by month indicated that opaque zones were laid down in summer. It appears that the opaque zone is produced at the same time of year that there is maximum reproductive activity. Age at sexual maturity was approximately two years. Growth rate from ELEFAN analyses was $K = 0.230$, and $L_{\infty} = 460$ mm FL. Direct validation of daily growth increments in *L. synagris* by means of tetracycline marking experiments were unsuccessful due to high sensitivity to handling stress.

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AGE AND GROWTH OF *Plectorhinchus mediterraneus* FROM NORTH WEST AFRICA

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Abstract

Plectorhinchus mediterraneus is a common target species in artisanal fisheries occurring along the northwestern African coast between Morocco and Senegal. It also seems to constitute an important component in by-catches of industrial bottom trawling fisheries taking place in the region.

Despite the relative commercial importance of the species its biology is very little known especially in which relates to population and biological parameters relevant to stock assessment. This paper presents the results of an study on the age and growth of the species based in the comparative analysis of scales and the otoliths of 250 specimens, from 25 cm to 62 cm total length, caught in the Saharan coast between 21°N and 26°N.

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Growth and estimated hatch dates of juvenile Great Barracuda (*Sphyraena barracuda*) collected from adjacent but ecologically distinct habitats

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Abstract

Growth rates were estimated from otoliths of fish collected in Florida Bay, during three studies which were conducted from 1990 to the present. The study area is a shallow region bounded on the south and east by the Atlantic Ocean, on the north by land and on the west by the Gulf of Mexico. The region is undergoing an ecological shift with a decrease in seagrass, an increase in phytoplankton and a change in the species composition of the forage fish community. Mud banks divide the area into regions which differ in salinity and water transparency, as well as the abundance and species composition of both seagrass and forage fishes. Based on the observed environmental differences, we expected that the area's value as a nursery habitat for piscivorous fish might vary among areas and over time. We used growth rate as an index to evaluate differences in habitat value.

Average growth rates varied among regions with highest and lowest rates both occurring in interior regions of the bay. Growth rates in regions nearest the Atlantic and the Gulf of Mexico were approximately equal. Average growth rates were similar across years even though estimated spawning dates varied. Based on size and age at recruitment to a particular region of the bay, it appears that growth rate prior to nursery area recruitment and the region of eventual recruitment are related.

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Overwinter age and growth of juvenile windowpane, *Scophthalmus aquosus*, in the Middle Atlantic Bight, USA

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Abstract

In order to understand patterns of overwinter growth in two cohorts of windowpane, *Scophthalmus aquosus*, otoliths of spring- and fall-spawned individuals were marked with oxytetracycline (0.9 g/l). First, daily ring deposition was validated and an increment width-somatic growth relationship was established in separate experiments (n=103; 7-79 mm SL). Then, spring- and fall-spawned windowpane (n=16; 65-109 mm SL and n=28; 13-38 mm SL; respectively) were held in the laboratory under ambient conditions from 9 November 1996 - 22 April 1996. Analysis of sagittal otolith microstructure revealed that consistently low temperatures (< 2 °C) produced increments that were difficult to resolve in both cohorts, but when temperatures were high enough for somatic growth to progress, increments were laid down daily. Detectable growth occurred more often in fall-spawned windowpane. Instantaneous growth estimates for smaller, fall-spawned individuals were twice those for larger, spring-spawned fish throughout the winter (0.26 ± 0.10 %/d and 0.14 ± 0.01 %/d; respectively). Through otolith microstructure analysis, we were able to identify periods of overwinter daily increment deposition in juvenile windowpane. Thus, it may be possible to use this technique, in combination with estimates of growth, to assess the compensatory growth potential of fall-spawned fish.

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Comparison of otolith microstructure of two stocks of larval herring (Orkney-Shetland & English Channel) in the period 1991-1997

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Abstract

Herring larvae in the size group 7-25mm from the winter spawning stock in the English Channel (ICES area VII d) and the autumn spawners from The Orkney-Shetland area (ICES area Iva) were sampled during the ICES herring larvae surveys. The otoliths from the size group 15-25mm) were analysed for number and width of daily increments. Seasonal aspects, differences in hydrographic location and interannual fluctuations on the pattern of the otolith microstructure will be presented and discussed.

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Comparison of Two Age and Growth Studies and the Effect on Spawning Potential Ratio Values

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Abstract

Two age and growth studies of scamp, *Mycteroperca phenax*, from the southeastern United States were conducted using sectioned sagittal otoliths. The first one used specimens collected during the 1970's, and the most recent study used samples collected from 1979-1996 with the bulk of those (>60%) collected during the 1990's. This report will compare the lengths at ages and the growth parameters from the two time periods, and the resulting impacts on the estimates of the spawning potential ratio (SPR) values. Any significant differences in the SPR values could have a direct impact on the levels of harvest by the commercial and recreational fisheries

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Differences in otolith weight and length among populations of genus *Sebastes* in the North Atlantic

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Abstract

This paper presents the analysis of the differences in weight and length of sagitta otoliths from several populations of redfish in the North Atlantic. A total of 1031 otoliths from the coast of Norway, Svalbard, Flemish Cap, Grand Bank of Newfoundland and Saint Pierre Bank of *S. marinus*, *S. mentella* and *S. fasciatus* are analysed. Residuals of the linear regression with standard length are used to remove the size dependence of the data and analysis of Variance used to compare sets of data. Differences between both species and populations have been found in length and mainly in weight of the otolith.

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Growth differences of larval and juvenile small pelagics between the Kuroshio and California current systems

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Abstract

Growth trajectories were constructed for larval and juvenile sardines, anchovies, and sauries from the western Kuroshio current system and the eastern California current system in the north Pacific. Growth were generally faster in the western waters than in the eastern counterpart in the 3 species. We will discuss the growth differences in relation to productivities in the ecosystems characterized by the western boundary current (Kuroshio system) and upwelling (California current system).

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Age and growth of lumpfish (*Cyclopterus lumpus* L.) occurring in the southern part of the Baltic Sea, based on investigations of otoliths

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Abstract

The investigated lumpfishes have been caught in the inshore of the southern Baltic with the use of the net for cod fishing. The analysis of the age, rate of growth of length and mass of a body has been made on the ground of 230 of fish. It appeared that otoliths are good hard tissue letting us determine both the age and back-calculation. The relationship between the overall length and the radius of an otolith is rectilinear. The growth rate of the length of the lumpfish of the Baltic Sea is much slower to the lumpfish of the Atlantic Ocean. The lumpfish of the Baltic Sea has got the following increase in overall length; $L_1 = 2.7$; $L_2 = 7.3$; $L_3 = 10.8$; $L_4 = 13.4$; $L_5 = 15.4$; $L_6 = 16.9$; $L_7 = 18.8$. Individuals of the III and IV age groups have been dominating. Comparatively rich data of comparison enabled us to determine the time of accumulation of both the opaque and hyaline growth zones. The opaque probably accumulates between January and May. Four individuals of total length from 33 cm to 42 cm have been collected in the middle and western part of the Polish Coast. The comparison of the growth and measurements of the radius of otolith has shown that the investigated individuals have the most likely reached the Baltic Sea from the North Sea. The lumpfish in the Baltic Sea attains the length of 20 cm very rarely.

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Estimate of natural mortality for New Zealand orange roughy (*Hoplostethus atlanticus*)

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Abstract

Estimates of M have considerably affected the stock assessment of orange roughy in New Zealand. In the early 1980s preliminary data suggested that orange roughy were slow growing and long lived, and in the absence of any ageing data, a low (i.e., conservative) natural mortality (M) value (0.1) was thought to be appropriate for use in estimating yields. M was to be updated when ageing methodology and data improved. Age and growth data from a 1988 Chatham Rise juvenile study suggested that M should be about 0.05, and this figure was used in the 1988/89 stock assessment model. In 1994 M was estimated to be 0.04. This estimate used counts of assumed annual growth zones on adult otoliths collected from Chatham Rise fish in 1984. However the Chatham Rise fishery had started 5-6 years before 1984, and some considered that this revised M estimate was biased because exploitation of the stock before 1984 could have preferentially selected older fish. Thus, in 1996/97, a new estimate of M (0.037) was derived from an unexploited population (Bay of Plenty). This estimate was not statistically different from the estimate based on the Chatham Rise data.

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Mass-marking of whitefish (*Coregonus lavaretus*) larvae by thermally induced otolith banding pattern

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Abstract

Whitefish (*Coregonus lavaretus*), inhabiting numerous lakes of Northern Poland and brackish waters of southern Baltic Sea bays, plays an important role in Polish fisheries. Despite regular stocking, the total number of its population decreases constantly, which questions the effectiveness of stocking. Mass marking of the stocking material seems to be the best tool to resolve the problem. However, the choice of methods, enabling marking of early developmental phases of fish is limited. Although the technique of marking whitefish larvae by immersion in fluorescent substances is well developed, the need to elaborate a technique more appropriate for implementation in hatchery practice still exists. Positive results of mass marking alevins of 5 species of Pacific salmon by incubation temperature manipulations lead us to test the applicability of the method in whitefish. It makes it possible to mark all the incubated material at once, and enables obtaining bar-code-like symbols on fish otoliths, which helps to recognise different lots of the stocking material. As whitefish does not possess the alevin phase, we performed the tests on embryos, eleutheroembryos and 5-22 days old larvae. The latter fish were already fed with *Artemia nauplii*. Repeated short (4 hours) exposure to water chilled by 6°C produced clearly visible optically dense bands on whitefish otoliths. Their width corresponded to the time duration of intervals between subsequent thermal shocks. Fish tolerated the marking well. Although several problems must be solved still, the method may offer a reasonable alternative to the immersion.

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A comparison of growth rates of co-occurring Atlantic croaker and red drum (*Sciaenidae*) larvae in South Texas seagrass meadows

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Abstract

Spawning seasons for red drum (*Sciaenops ocellatus*) and Atlantic croaker (*Micropogonias undulatus*) overlap in October in south Texas, resulting in simultaneous occupation by similar-sized post-settlement larvae of both species in seagrass meadow nursery habitats. Red drum larvae are significantly more abundant in *Halodule* meadows than in *Thalassia* meadows while Atlantic croaker have similar abundance in both habitats. Growth rates, derived from otolith age estimates, are compared between habitats and between species. Direct comparison between species equates late-spawned red drum larvae with early-spawned Atlantic croaker larvae. Growth rates of post-settlement larvae of the two species are generally comparable and are strongly influenced by temperature.

* presenter

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Differences in age determination of Northeast Arctic cod. Consequences and improvements through regular exchange of material and personell

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Abstract

Since 1992 regular exchanges of personell and Barents Sea cod otoliths have been conducted by the Institute of Marine Research (Norway) and Polar Research Institute of Marine Fishery and Oceanography (Russia). Several samples (in particular, for the years 1992 and 1995) showed initial discrepancies in 40-50 % of the otoliths examined. In some years a systematic difference towards higher ages read by the PINRO specialists was observed. After discussing the problems the discrepancies in most cases were reduced to less than 10% of the material. Methods of cod otolith age reading are submitted, and the reasons behind the discrepancies are discussed as well as ways to overcome them. Some examples of consequences such differences in age reading may have on the Northeast Arctic cod assessment are shown.

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Classification of cod from different nursery areas in the Northeast Arctic by otoliths

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Abstract

For classification of cod in the northeast Arctic shape and growth pattern of the otoliths have been used for decades. At least three groups of cod are classified this way, i.e., the coastal cod and the North-east Arctic cod which may be further split into a Barents Sea type and a Svalbard type. This poster presents a photo-session of otolith-sections showing typical examples of each cod type.

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Use of Otoliths to Determine Spawning Periodicity and Requirements in the Arkansas River
Shiner, *Notropis girardi*

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Abstract

The Arkansas River shiner, *Notropis girardi*, historically was widely distributed throughout the Arkansas River system of Central United States. Recent declines in the distribution and abundance of the species are believed to result from reproductive failure; however, conditions necessary for successful reproduction are unknown. We collected young of year Arkansas River shiners from the Canadian River, upstream from Lake Meredith, Texas, during May through June, 1997. We used estimates of age determined from otoliths to identify environmental conditions at the time of hatching. Our results show that Arkansas River shiners spawned at least twice in 1997. Fractional spawning had been suggested, but not previously demonstrated, for this species. In both instances, spawning was associated with flood events in which river discharge exceeded 1350 cfs. Previous studies have suggested the Arkansas River shiner spawns in response to flood events, but thresholds for spawning have not been identified. If threshold conditions for spawning can be precisely determined, managers may be able to release water from an upstream reservoir to augment natural flood events in order to facilitate reproduction.

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Does mortality select size or growth potential in young sockeye salmon (*Oncorhynchus nerka*)? A simulation based on otolith-fish size relationships

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Abstract

There is conflicting evidence on the role of size-selective mortality in the demography of populations of young sockeye salmon. A previous field study suggested that increases in mean fork length and otolith size at emergence observed in a cohort of salmon between fry and smolt stages was due to size-selective mortality, such that fry with small fork lengths underwent higher mortality than larger individuals. However, a subsequent study used a simulation to show that such increases could not have been achieved by size-selective mortality without levels of survivorship of the cohort far lower than those that had been observed in the field. To account for field observations, the simulation study proposed that individuals with high metabolic rates had better survivorship, a process that was termed "selection for growth potential". Here we use a simulation approach to show that size-selective mortality may result in shifts in mean fork length and otolith size at emergence comparable to those observed in the field at total mortalities within the range of estimates of natural values. The contrasting outcomes of earlier simulation work and the present study are probably due to the assumption by the former that otolith and fish size in young salmon were weakly correlated and the use of an inappropriate model of size-selective mortality. We conclude that size-selective mortality can explain the results of previous field studies and that little empirical evidence exists to support the hypothesis of selection for growth potential in cohorts of young salmon.

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The early life history of three species of Indo-Pacific eels *Anguilla marmorata*, *A. bicolor bicolor*, *A. nebulosa nebulosa* revealed from their sagittae and lapilli

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Abstract

Anguilla glass eels and elvers were collected during anadromous migration into Indonesian estuaries. The otoliths (sagittae and lapilli) after extraction were examined by Scanning Electron Microscopy. The SEM micrographs of otoliths section were used for various measurements using image analysis. Sagittae and lapilli results were compared. Both otolith and the three species revealed the same microstructural patterns. Differences appear between increments counts on sagittae and lapilli. Duration was less with lapilli counts than with sagittae. No significant inter specific variability was evident during embryonic development. In contrast, the leptocephalus phase revealed considerable differences in relation with the distance from the spawning area.

Estimated larval durations were the following from sagittae:

A. marmorata (n=23), 97.3±12.3 days

A.b. bicolor (n=26), 102.2±6.7 d.

A.n. nebulosa (n=30), 106.4±11.1 d.

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Larval duration and oceanic growth of tropical reef fishes in French Polynesia: effect of the moon phase on larval stage duration

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Abstract

The biological cycle of coral reef fishes is characterised by two radically different phases: adults, which occur inside lagoons and oceanic larvae. In French Polynesia, due to the particular morphological structures of the reefs, the transition between these two phases occurs on the reef crest, which form a physical barrier between ocean and lagoons. Such features provide the capability, using a crest-net, to catch transported larvae while they are colonising the reef. Recent studies showed that colonisation of reefs by fish larvae in F.R. occurs at night, mainly on new moon periods. The aim of the present study was to evaluate the moon phase effect on the age at colonisation of tropical reef fishes. Larvae of four species of reef fishes (2 Acanthurids and 2 Pomacentrids) were therefore collected at night with a crest net during one moon cycle. For each species larval duration and growth were estimated from otoliths marks validated using Alizarine complexone. Results showed a very low variability in larval duration for three of four studied species (*Acanthurus triostegus*, *Pomacentrus pavo*, *Chromis viridis*). For the last species (*Ctenochaetus striatus*) very high variability was observed in both age and size at colonisation. Alizarine complexone appears as a very good marker for validation of deposits of daily rings in tropical reef fishes otoliths.

Key words: Coral reefs, Acanthurids, Pomacentrids, Lunar cycle, Larval stage duration, growth, validation Alizarine complexone

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Age and Growth Rate Comparisons on a Natural and Impounded Population of Striped Mullet

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Abstract

Age comparisons made between a natural population of striped mullet (*Mugil cephalus*) from coastal Louisiana and a confined population from a nearby freshwater impoundment provides further evidence of the coupling between somatic growth and otolith growth. Both populations were measured and aged through annual otolith increment analysis. Age validation was conducted on the natural population of striped mullet over a two-year period. A single annulus was laid down each year during the period of April through June. Although otoliths from the impounded population were not directly validated, they had similar translucent zones formed during the summer across all age classes.

The impounded population had significantly larger body and otolith weight. Age for age the impounded fish and its otoliths were larger than striped mullet from the natural population. Although otolith weight was greater in fish from the impounded population, age structure was similar between the two populations. Maximum ages were nine years and eight years from the natural and impounded populations.

Otolith increment width from both populations showed wider translucent and opaque zones in fish from the impoundment. Enhance growth rates in the impounded fish was theorized as being caused by physiological and metabolic changes due to environmental differences. The impounded fish cannot complete their reproductivity cycle; therefore, obtaining growth enhancement through the reabsorption of the unused oocytes. Environmental difference was further seen by the difference regression relationships between the two populations of otolith weight increasing as fish size and age increase.

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Settlement pattern of 0-group plaice, *Pleuronectes platessa*, determined by otolith microstructure

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Abstract

0-group plaice settlement was monitored in Port Erin Bay (54°20' N, 4°10' W) in 1993. Daily otolith increments were used to estimate the age of post-larvae and three sub-cohorts were identified. Length-frequency distribution of settlers indicated that settlement on the nursery ground occurred in two pulses. While pulses correlated with tidal amplitude, they did not correlate with metamorphosing sub-cohorts. It is suggested that sub-cohorts develop before settlement and spring tides are used for immigration to the nursery ground.

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Growth and mortality of stocked and native young-of-the-year Northern Pike (*Esox lucius* L.)

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Abstract

Large intracohort differences in size of juvenile fishes may increase cannibalism in piscivorous fish populations. These differences in size can be caused by variations in time of hatching and growth. In this study we examined the growth of stocked and native YOY Northern pike (*Esox lucius* L.) sampled from June to August in a shallow eutrophic lake. The age of 101 individuals was determined from otolith microstructure analyses, and growth estimates were obtained using daily increment widths. Daily increment formation was validated by analysis of the otoliths of known-age pike. Estimates of size-selective mortality of stocked and native pike will be presented, and implications for biomanipulation of shallow lakes discussed.

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Fish otoliths as seasonal indicators in prehistory

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Abstract

Otoliths of red cod (*Pseudophycis bachus*) were recovered from midden deposits at an archaeological site in North Otago, New Zealand. Age validation of this species had already been achieved by showing that in sectioned otoliths, one opaque and one translucent zone were laid down annually. By classifying the state of the margin on the sectioned archaic otoliths it was possible to estimate the most likely season of death for these fish, and thus, the season of occupation of the prehistoric site. The results were consistent with other independent estimates of in what season the site was occupied.

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Variable freshwater recruitment and duration at the estuary before upstream migration in the amphidromous goby *Rhinogobius gigas* in Eastern Taiwan

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Abstract

Amphidromous gobies are usually the most abundant freshwater fishes in tropical and subtropical regions and contribute significant fishery. Reproduction, freshwater recruitment and dispersion play an important role in the variance of fishery. The migratory dynamics between recruitment and subsequent dispersion into upstream in *Rhinogobius gigas* at the unique Hsuikulan River estuary, eastern Taiwan has been disclosed herein. Ages are determined in both pigmented and transparent juveniles collected at the riverside of downstream and the river mouth, respectively. Daily ring depositing in the otolith was verified by tetracycline marking. Experimental results revealed that ages of pigmented gobies ranged from 43.2 ± 3.8 (\pm SD) to 71.1 ± 12.1 d. Recruitment marks in the otoliths separated the life histories of pigmented gobies into marine and freshwater phase. Daily ages of transparent gobies extended from 33.7 ± 3.5 to 46.3 ± 6.3 d, indicating that the gobies required at least one month for marine planktonic stage. Statistical results of the daily ages in these two populations indicate the variable marine phase and short duration at the estuary depending on months. The length of marine and estuarine duration seems to be inversely related with water temperature of the river. The spawning dates back calculated from the ages extended from early December to mid May. The data reported in this paper demonstrate the necessary of short duration, susceptible to water temperature, at the estuary and provide useful information to management and protection of the goby fry fishery.

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Diachronic changes in growth rate of North Sea fish species in relation to anthropogenic activities

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Abstract

The project aims to study the compensatory response to the heavy exploitation of four demersal fish species (plaice, cod, haddock and saithe) by comparing present day growth rates to growth rates observed prior to the era of industrialised fishing. Growth rates will be estimated by back-calculation of the growth zones in (post-)medieval otoliths retrieved from archaeological excavations and otoliths collected recently during research vessel surveys and market sampling programmes. The hypothesis addressed is that prior to the century of heavy exploitation, when population abundances were substantially higher than at present, density-dependent reductions in growth were a common phenomenon. The compensatory response in growth to heavy exploitation, however, will differ across life history stages and across species because plaice, cod, haddock and saithe, as well as their juvenile and adult life history phases, occupy different ecological niches. Comparison of the changes in growth between time periods, and between species and life history phases, will reveal whether, and in which species / life history phase, compensatory responses in growth may have occurred.

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Incidence of Thermally Marked Pink, Chum, and Sockeye Salmon in the Coastal Waters of the North Pacific Ocean and Eastern Bering Sea

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Abstract

North Pacific Ocean and eastern Bering Sea research cruises during July and August 1996 and 1997 provided ocean recoveries of 878 pink (*Oncorhynchus gorbuscha*), 509 chum (*O. keta*), and 30 sockeye (*O. nerka*) salmon thermally marked during incubation at Alaskan (USA) and Canadian hatcheries. We obtained the recoveries from 3,119 juvenile pink, 3,938 juvenile and immature chum, and 2,243 juvenile and immature sockeye salmon examined for thermal marks. The marked juvenile (age .0) salmon migrated westerly along the coastal waters of the North Pacific Ocean; those released from southeastern Alaska hatcheries had migrated north and westerly as far as 900 km, whereas pink and chum released from Prince William Sound hatcheries had migrated westerly as far as 1100 km. Most marked juvenile salmon recovered had migrated between 100 - 1100 km over a 60-110 day period. The marked immature (age .1+) chum salmon from southeastern Alaska and Canadian hatcheries were found in the coastal waters of the North Pacific Ocean from Prince William Sound to the eastern Aleutian Islands and also in the coastal waters of the eastern Bering Sea. The marked immature sockeye salmon from southeastern and central Alaska were found in the coastal waters of the North Pacific Ocean from the eastern Aleutian Islands to the central Aleutian Islands.

Our results indicate that a modest research sampling program can collect sufficient numbers of thermally marked juvenile and immature salmon in the coastal waters of the North Pacific Ocean to provide detailed studies of Pacific salmon life histories. Studies of the early marine and oceanic life history stages will provide information on the migration, growth, development, and condition of individual hatchery stocks and may provide an opportunity to study wild and hatchery stock interactions.

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A SYSTEMATIC PRELIMINARY STUDY ON SPARIDAE (PISCES) EMPLOYING
OTOLITH CHARACTERS IN THE BAY OF IZMIR (AEGEAN SEA)

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Abstract

The otolith of every species has characteristic form and property. Thus, the otoliths have been used prevalently in the systematic research of otolith are valid not only for the defination of the species but also for the stomach analyze of the predators of fish and the systematic research of fossil of fish.

The seventeen of totaly twenty-two species of Sparidae living in Atlantic has been established in Aegean Sea. The members of the family have been giving very economical production in Bay of Izmir which is approved to be the one of the most productive regions. Since the morphological otoliths of these species in Aegean Sea has not been established by now. We tried to evaluate the similarity of otoliths characteristics morphologicaly by a systematic preliminary study of twelve species.

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Recruiting variation and the early life history of *Anguilla marmorata*: migrating from the spawning ground to the northern boundary, Taiwan

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Abstract

Anguilla marmorata is widely distributed in the fresh waters of the islands and coast of Indo-Pacific Ocean. Recruiting variation and behaviors of upstream migration still remain unknown despite a previous investigation which reported on its marine drifting period that were based on few samples, collected across extensively geographical locations. This study collects *A. marmorata* elvers on a daily basis at the estuary of Hsuikuluan River, eastern Taiwan for a one-year period. Recruitment of *A. marmorata* is panseasonal, indicating its whole year spawning nature; however, it has two peaks during November to December and May to June. Total lengths of elvers upon arrival at the estuary extend from 48.6 to 53.2 mm. Herein, the daily ages of the elvers are determined by examining presumed daily growth increment in otoliths. Age of the elvers at arrival in the estuary ranges from 116.8 to 132 d, indicating that migration from the spawning grounding to the estuary of the eels lasts approximately 4 months. Marine phase, report herein, is significantly longer than in the previous investigation. According to the estimated daily ages, back-calculated major spawning seasons occur in winter and summer, respectively. This study describes, for the first time, the population variation of *A. marmorata* elvers by continuous and long-term catch from Dec 1996 to Nov 1997.

Key words: otolith, *Anguilla marmorata*, microchemistry, daily ages, hatching date

Abstracts

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Otolith Composition

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A glance at 50,000 years of otoliths

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Abstract

Fish otoliths from the World Heritage Listed Willandra Lakes in the arid inland region of Australia provide a record of environmental change and a link with human prehistory that spans the last 50,000 years. The dry basins of the Willandra Lakes contain evidence of complex human social systems over 30,000 years old and the world's earliest substantial evidence for the extensive exploitation of freshwater resources. Campfires established by Australian Aborigines during the Pleistocene contain extensive faunal remains and, at many sites, these remains are dominated by the otoliths of golden perch *Macquaria ambigua*. Analysis of trace element, stable isotope, and increment width data from these Pleistocene otoliths provides a detailed picture of the drying and refilling of the Willandra Lakes over annual and decadal time scales and indicates the varying environmental conditions experienced during the last glacial cycle. Many basins in the Australian interior are characterised by their ephemeral nature, yet contain golden perch. These systems have been used to provide calibrations for relationships between a range of environmental proxies measured in otoliths including strontium and salinity, oxygen isotopes and temperature, and increment width and temperature. There is considerable scope for the application of otolith studies to global change research.

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Oscillatory Zinc distribution in Arctic char (*Salvelinus alpinus*) otoliths: the result of fish behaviour or environmental feedback?

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Abstract

Scanning proton microprobe (SPM) imaging was used to map the distribution of zinc (Zn) in otoliths of anadromous and non-anadromous Arctic char (*Salvelinus alpinus*) from the Canadian Arctic. Zn distribution patterns were oscillatory with Zn concentrations ranging from 35 to 240 ppm. Superimposition of the Zn distribution on optical images of the otoliths permitted correlation of Zn uptake with annular structure in the otoliths. Two patterns of Zn distribution were observed: (1) well defined oscillatory Zn in all annuli of non-anadromous fish (i.e. Zn uptake persisted throughout the fish's life) and (2) oscillatory Zn in the annuli of anadromous fish, prior to the first migration to sea, after which it diminished to background levels. Oscillatory zoning of Zn may indicate (1) nutrient availability in the environment particularly in the summer period when most of the growth is likely to occur, (2) temperature variations in the habitat occupied, or (3) a combination of nutrient and

thermal variation. As such, the systematic distribution of Zn in otoliths has the potential to provide additional temporally constrained information on fish habitat and or fish behaviour.

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Using Pb-210/Ra-226 disequilibrium age validation in rockfish (genera *Sebastes* and *Sebastolobus*)

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Abstract

Age determination of rockfish (genera *Sebastes* and *Sebastolobus*) is typically accomplished by counting growth zones in burnt cross-sections of the otoliths. Interpretation of patterns seen in the otolith's growth zones is often difficult and subjective so age validation is desirable. Unfortunately, age validation has been nonexistent for many rockfish species. The biology and life history of rockfish often makes age validation methods used for other species difficult. Therefore, we used radiometric ageing which employs the disequilibrium of Pb-210 and Ra-226 in the otolith. We utilized two methods of obtaining material from the otoliths: core samples and whole otolith samples. The Pb-210/Ra-226 ratio generally confirmed ageing criteria used in rockfish, but there was in some cases a bias between the growth zone counts and radiometric ages. We investigated two potential sources for the bias. First, the ratio of Pb-210/Ra-226 as incorporated into the otolith may have been overestimated. Second, the otolith core removal process may have inadvertently left excessive amounts of newer material.

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Juvenile out-migration events as recorded in adult otoliths: American shad (*Alosa sapidissima*) in the Hudson River, New York USA

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Abstract

Juvenile out-migration, or egression, from natal streams is the first major movement by anadromous fish. For some species of alosines (Clupeidae), the timing of this first migration can vary greatly throughout the first growing season. But which "tactic" (early or late egression) maximizes fitness? To begin examining this question, adult American shad were collected on or near their spawning grounds over the spawning season (spring 1995). Sagittal otoliths were removed and used for microstructural and microchemical analyses. Strontium:calcium ratios were analyzed along "life history" transects in each fish, noting the location at which Sr:Ca showed a marked increase, denoting egression. The patterns of egression are then related to age, early growth histories, sex, and time of spawning.

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Variation in otolith strontium and calcium ratios as indicator of life-history strategies of freshwater fish species within a brackishwater system

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Abstract

A possible life-history strategy of stenohaline fishes in brackish waters would be one of migrations between higher salinity rearing/feeding areas and low salinity spawning areas. This would allow the more salinity tolerant adults and sub-adults a greater foraging range, while increasing the survival of highly stenohaline eggs and larvae. We tested the feasibility of using the variation in otolith Strontium/Calcium ratios (Sr/Ca), presently used to track migratory pattern of diadromous species, as a method to investigate migrations of freshwater species living under oligo-mesohaline conditions. Zander (*Stizostedion lucioperca* L.) and common bream (*Abramis brama* L.) adults were collected in the brackish Kiel Canal and its freshwater tributaries. Reference fish were obtained from a closed freshwater lake. Otoliths were sectioned, polished and Sr and Ca concentrations measured along otoliths transects (10µm intervals) using a Cameca SX-50 wave-dispersive electron-microprobe (EPMA). Sr/Ca along otoliths axes of reference fish were fairly constant and low for common bream (mean = 0.0025, SD = 0.0005) and zander (mean = 0.001, SD 0.0004). Sr/Ca in zander and common bream from brackish waters varied from 0.001 to 0.009. Lowest Sr/Ca were measured in core zones (<0.003). Differences in patterns were observed, suggesting individual variations in migratory histories. Our results show that analysis of Sr/Ca has great

potential for describing the migratory histories of freshwater fishes within brackishwater systems.

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Utility of Otolith Microchemistry in Ecological Studies of Resident and Anadromous
Oncorhynchus mykiss

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Abstract

The ecological relationship of sympatric anadromous (steelhead) and resident rainbow trout (*Oncorhynchus mykiss*) is poorly understood and has been difficult to study given the identical appearance of juveniles. We are conducting a range-wide survey to confirm the expected relationship of Sr/Ca ratios in the primordia of anadromous morphs. Identification of maternal origin is essential in ecological studies of multiple life history morphs. We are using Sr/Ca ratios in the primordia and freshwater growth regions of the otolith to identify maternal origin (anadromous vs. resident) of juvenile *O. mykiss* collected from rearing habitats in the Deschutes River, Oregon. Using this method of identification, we can monitor the relative abundance of anadromous and resident progeny over time. We can also test for differences in growth and morphology of the two populations. Finally, we have used otolith microchemistry in the analysis of barriers to adult migration and the occurrence of anadromous morphs in stream basins. Otolith microchemistry was instrumental in confirming that log jams in the Sixes River, Oregon were not migration barriers to adult steelhead as was previously assumed. Otolith microchemical examination of Sr/Ca ratios provides an important and much needed method of identification and will significantly aid in ecological studies of sympatric anadromous and resident morphs of *O. mykiss*.

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High-Resolution Stable Isotope Records from North Atlantic Cod

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Abstract

Detailed stable oxygen (O-18) and carbon isotope (C-13) records have been obtained from the growth bands of cod otoliths, using new micro-sampling methods that allow for high-temporal resolution (up to 20 plus samples/yr). Otoliths were sampled from specimens of varied age (2 to 12 years), collected from different locations in the eastern North Atlantic, including the Faroes, Irish Sea, North Sea and Barents Sea. Generally, the seasonal O-18 signals are in phase with the otoliths' visible growth bands, confirming band-count age estimates. O-18 records from the first several years of growth show a close correspondence to the expected signal based on the temperature and salinity characteristics (annual mean and seasonal amplitude) of their respective capture sites. However, the seasonal signals tend to attenuate as the cod mature suggesting a change in behavior or habitat to more thermally constant conditions. Generally, the seasonal C-13 and O-18 signals are in phase, with the C-13 signal having ~twice the amplitude and also attenuating with age. In contrast, overall mean C-13 and O-18 for each otolith negatively correlate, with the most depleted C-13 values found in cod taken from the coldest regions. These results suggest a strong "vital" effect on cod otolith C-13.

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Life-history and paleoclimate: high-resolution records stored in otoliths

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Abstract

Stable isotope and elemental analyses conducted on whole otoliths provide lifetime-averaged information on fish behavior and environmental conditions. Otoliths however, function much like a flight data recorder, by storing ephemeral life-history information as variation in oxygen/carbon stable isotope ratios and elemental composition. Discrete microsampling provides a high-resolution reconstruction of feeding, metabolism, reproductive investment and migratory behavior. Carbon stable isotope values record seasonal fluctuation in metabolic activity related to temperature, feeding, reproductive investment and somatic growth signals. Because shallow water temperatures are similar to those of the atmosphere, oxygen isotope ratios of eurythermic shallow-water fish not only record thermal life-history, but may provide a record of seasonal atmospheric temperature variation and migratory behavior as well. Therefore, otoliths recovered from sediment and archaeological sites can be used to address secular trends in climate. Advances in computer-assisted microsampling of otolith carbonate coupled with isotopic and elemental analyses of carbonate has permitted recovery of thermal and metabolic records with a resolution of less than one week. Discrete sampling of carbonate reveals information unobtainable from whole otolith analysis. Data which illustrates application of microsampling techniques will be presented.

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The utility of whole otolith elemental approaches for stock identification - the need for complementary techniques

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Abstract

Whole otolith elemental techniques utilize an integrated chemical signal that represents the entire ontogenetic history and home range of individual fish. Variation in these otolith chemical signals of fish from different areas are presumed to reflect prolonged separation of populations, and ultimately stock divergence. However, these approaches only provide information about 'recent' stock structure and effectively preclude fine scale resolution of individual affinities with spawning grounds and larval habitats. Consequently, equally plausible but entirely different hypotheses, besides that of stock structure, could explain spatial patterns found in mean elemental compositions of whole otoliths from adult fish. Whole otolith elemental approaches, therefore, need to be complemented with biological information from other stock identification techniques, or alternatively, be restricted to analysis of whole otoliths from juveniles, or the core regions of otoliths from adult fish to accurately interpret stock relationships.

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Do microconstituents of otoliths vary with depth in which fish are collected?

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Abstract

Microconstituents are being used for applications such as stock assessment and to determine the movements of fishes. It is possible, however, that horizontal variation in concentrations may be confounded by variation with depth. Fish in shallow coastal waters (<5m) may be exposed to greater levels of pollution than those at depth. For example, low density plumes (3-4 m deep) are generated from estuaries and potentially expose fish to higher concentrations of pollutants at shallow depths. *Parma microlepis*, a territorial fish on coastal reefs throughout New South Wales (Australia), was sampled from two-three depth strata at multiple sites within each of four locations exposed to estuarine plumes. One otolith was analysed from each fish for a range of trace and microconstituents (e.g., Ba, Mn) using solution-based inductively coupled plasma mass spectrometry (ICP-MS) the remaining otolith was used for ageing fish. Differences in elements in otoliths were found among depths and/or among sites depending on the element. Results will also be interpreted based on the age of fish. Future studies may need to consider the depth at which fish are collected for unconfounded comparisons at different spatial scales.

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Validation of the annual formation of growth increments in the otoliths of Southern Bluefin Tuna (*Thunnus maccoyii*) through a large-scale strontium chloride marking experiment and bomb-radiocarbon chronometry

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Abstract

Southern Bluefin Tuna (SBT) is one of the most highly-valued seafood products on world markets today. The species has been the target of large and lucrative longline and surface fisheries in the southern Atlantic, Indian, Southern and Pacific Oceans since the 1950's and today the parent stock biomass is thought to be less than 10% of its pre-fishing level. The primary stock assessment tool used for SBT is VPA, for which an accurate catch-at-age matrix is essential. Prior to our study, attempts to estimate age of SBT had been limited to the first few age classes and catch-at-age matrices were based principally on data from tagging studies. These data were considered accurate for fish up to 6-8 years of age, but at larger sizes low tag return rates coupled with slowing growth restricted the use of growth models in estimating age from length or weight data. One tag, recovered after 18 years at liberty, had been used to estimate the longevity of 20 years for the species.

Our work estimated the age of SBT from otoliths, vertebrae and scales collected from the same fish. Marginal increment analysis of scale growth checks indicated that these are deposited annually for the first two to three years. However, fish scales became progressively more difficult to interpret, and less reliable for estimating age as size increased. Vertebrae provided accurate estimates of age up to 10 years (approximately 160 cm FL) – the age at which SBT begin to mature. At larger sizes vertebrae consistently provided an underestimate of age.

Increments in otoliths continue to form throughout life and our data indicate that the maximum age for SBT is over 40 years. We were able to validate the annual formation of otolith increments in three ways. First, a large-scale mark and recapture experiment, in which

over 10,000 1-4 year-old SBT were injected with strontium chloride, allowed us to demonstrate the annual formation of increments in 1-6 year-old fish. Second, otoliths from fish tagged as one year olds and recaptured 10-12 years later were found to have the expected 11-13 increments. Third, radiocarbon and stable carbon isotope analyses were used to examine the levels of radiocarbon in the inner regions of SBT otoliths (corresponding to the first year of growth). Data from radiocarbon analyses were used to determine the period when the radiocarbon was deposited in the otolith, from which an estimate of age could be derived. Estimates of age from increment counts and bomb radiocarbon levels in sister otoliths were very similar and confirmed the increment-based conclusions that SBT can live for well over 30 years.

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Variations in stable isotope ratios of carbon and oxygen in otoliths of cod (*Gadus morhua*) from Atlantic Canada

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Abstract

We analysed the $^{18}\text{O}/^{16}\text{O}$ and $^{13}\text{C}/^{12}\text{C}$ ratios in samples of cod otoliths obtained in NAFO Division 4Vs off of Nova Scotia. Sampled growth zones were deposited between 1982 and 1992. In all otoliths, successive zones display a large, linear increase in $^{13}\text{C}/^{12}\text{C}$ with age, reaching a maximum by age 4-6 y, after which $^{13}\text{C}/^{12}\text{C}$ declines slowly or remains constant. The early increase is probably due to a combination of a) increase in trophic level; and b) decrease in the metabolic rate (J/kg). The maximum may correspond to sexual maturity; subsequent decline could be due to migration to deeper water where $^{13}\text{C}/^{12}\text{C}$ of seawater is lower. $^{18}\text{O}/^{16}\text{O}$ measurements of otolith zones show two kinds of behavior: some fish (group 1) show steady increase in $^{18}\text{O}/^{16}\text{O}$ up to a maximum at age 4-6; group 2 displayed essentially constant $^{18}\text{O}/^{16}\text{O}$ ratios equal to the values eventually attained by group 1. Group 1 fish appear to have been recruited from lower $^{18}\text{O}/^{16}\text{O}$ waters, presumably near the St. Lawrence estuary. During the early 90's, average water temperatures (T) declined but $^{18}\text{O}/^{16}\text{O}$ ratios show that T experienced by cod remained approximately constant, suggesting that cod were migrating to deeper, warmer waters. This is consistent with $^{13}\text{C}/^{12}\text{C}$ record.

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OTOLITH ELEMENTAL FINGERPRINTS AS BIOLOGICAL TRACERS OF FISH STOCKS

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Abstract

Specific trace elements incorporated into the growing surface of the fish otolith reflect the physical and chemical characteristics of the ambient water, although not necessarily in a simplistic manner. Since fish which spend at least part of their lives in different water masses produce otoliths of different elemental composition, the otolith elemental composition ("elemental fingerprint") serves as an environmentally-induced tag of fish aggregations, independent of genetic identity. While there is no a priori reason to expect the elemental fingerprint to be stock-specific, there is every reason to expect it to serve as a seasonally-stable biological tracer, or natural tag, of pre-defined groups of fish, even during situations of extensive stock mixing. To illustrate the tracer approach, we present the results of an intensive, multidisciplinary study of cod stock mixing involving 7 adjacent Atlantic cod (*Gadus morhua*) stocks off of eastern Canada. On the basis of isotope dilution ICPMS (ID-ICPMS) assays of nearly 4000 adult cod otoliths, it has become clear that the elemental fingerprints are seasonally stable and that highly significant differences exist among all of the stocks. Using the fingerprints of the spring spawning aggregations as known-stock reference samples, the geographic distribution of the feeding (summer) and over wintering stocks was tracked and monitored over the course of two years. The stock composition of the dense, mixed-stock winter schools was readily determined using maximum likelihood-based analyses of the elemental fingerprints, and appears to have resulted in better stock discrimination than concurrent microsatellite DNA assays. In this instance, the biological tracer approach produced results of sufficient quality so as to guide fisheries management decisions. While the use of elemental fingerprints as natural tags is not suited to all stock mixing situations, suitability can probably be determined beforehand on the basis of existing environmental and biological information.

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Perspective on Regulation of Trace Metal Composition in Fish Otoliths

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Abstract

Understanding the factors affecting the elemental composition of fish otoliths is fundamental to the informed use of otolith composition as a chemical marker for groups of fish with common histories. Knowledge of the mechanism (s) of elemental accumulation in otoliths and its relationship to general regulation of essential and nonessential elements in fish will aid in the interpretation of otolith composition data and in the development of new approaches for the use of such data in addressing fisheries and ecological questions. We have examined an observational (monitoring) database for elemental data on feral Atlantic croaker (*Micropogonias undulatus*) and winter flounder (*Pleuronectes americanus*) (liver and otolith samples) and for data on their habitats (sediment and water samples) over a range in contamination levels to develop a perspective on the regulation of trace metal concentrations in otoliths.

Elements often found at elevated concentrations in contaminated marine habitats include fish micronutrients (Zn and Cu) and nonessential metals (Pb, Hg and Ag). Hepatic concentrations of these elements in fish vary in a complex and interdependent manner based on exposure to both metals and xenobiotic organic compounds. We observe both hepatic accumulations (Hg, Ag, PCBs, PAHs and DDTs) and depletions (Zn) in fish from habitats contaminated by these metals and organic materials. Such responses in liver are believed to result from the disruptive effects of the metabolism of organic contaminants on the regulation of nutrient and toxic metals in the same tissue. Similar responses are observed in otoliths, suggesting active regulation of their elemental composition and the potential for disruption of normal regulatory processes under stress of exposure to xenobiotic organic chemicals. Otolith chemistry may more closely record the physiological history of fish, as influenced by all environmental factors important in its life cycle, rather than simply recording the history of elemental exposure.

Contribution: 138

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Discrimination between two nurseries of the common sole (*Solea solea*) of the Bay of Biscay (France) from otolith trace element using ICPMS and LA-ICPMS analyses

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Abstract

Otolith trace elements of wild juvenile sole (*Solea solea*) were quantified to investigate the potential for discrimination between two main nurseries of the French Atlantic coast (Loire and Gironde estuaries). Two techniques were compared: Laser Ablation -Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) and solution based sample ICPMS. In the second technique, a micronebulizer system was used to assay individual samples of small volumes (100 µl). Otoliths processed with LA-ICPMS showed significant differences in Sr and Rb concentrations depending on sample origin. Differences in As and Mg concentrations were also observed with respect to the spot localization indicating a spatial heterogeneity in otolith composition. Bootstrap estimation gave a 73 % correct classification rate based on elemental composition in the antero-dorsal area whereas 79 % of correct classification was obtained based on elemental composition in the postero ventral area. The solution based sample analysis was found to be much powerful due to very low detection limits. A model with only two variables (Mg and Cd, Cd being a characteristic trace element in Gironde waters) resulted in 89 % of correct classification whereas a 6-variables model resulted in 93 % of correct classification (bootstrap estimations).

Contribution: 150

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Determination of Trace Elements in Fish Otoliths by Laser Ablation MicroProbe -
Inductively Coupled Plasma - Mass Spectrometry

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Abstract

Investigations have been undertaken into the application of Laser Ablation MicroProbe (LAMP) - ICP-MS for the determination of trace elements across otoliths of a number of species living in different environments. The instrumentation used in these studies is described, indicating both elemental detection limits and the routine accuracy and precision obtained by ablating craters of 25-40 μm . Ideally, the craters would have been less than the width of a daily growth ring of the fish otoliths concerned (usually $<2\mu\text{m}$). Craters of this size are within the capabilities of the LAMP ($< 1 \mu\text{m}$ diameter). However, the sensitivity of the ICP-MS was such that to reach the sub-ppm detection limits required for many elements, a crater of $> 25 \mu\text{m}$ diameter was required. These limitations will be considered in the context of studies by other workers.

The advent of certain modifications to the ICP-MS instrument promises improvements in sensitivity and a reduction in interferences for many elements. Perhaps the most exciting step forward is the development of magnetic-sector/multi-collector ICP-MS which will allow precise isotopic ratios to be determined for elements with natural variations such as Sr or stable isotopes added in tank tests. The future use of these developments will be discussed.

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Reconstructing variability in coastal ocean environments through stable isotope analysis of fish otoliths

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Abstract

The stable isotope chemistry of carbon, oxygen and strontium in otolith aragonite may represent a unique record of environmental conditions experienced by fish in both modern and ancient water masses. While commonly applied in work on invertebrate skeletons and shells, stable isotopes have been used only sparingly in otolith chemistry studies. Here, I outline the theoretical basis for stable isotope analysis, review the published literature in light of these theoretical constraints, and highlight some new analytical techniques that may be usefully applied to the stable isotope analysis of otolith aragonite. Data from larval and juvenile sciaenids raised in the laboratory under constant environmental conditions, and field collections from estuaries and near-shore waters along the U.S. Atlantic coast, are used to evaluate the hypothesis that stable isotopes are deposited in equilibrium with the ambient environment. These data demonstrate that C, O and Sr isotope ratios have considerable potential as high resolution tracers of the water mass residency of individual fish. When the isotope ratios are applied in conjunction with elemental data from otoliths, the resulting multivariate signatures are powerful markers of population structure in fish stocks, especially if genetic markers lack sufficient temporal resolution.

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Is otolith strontium a useful scalar of life-cycles in estuarine fishes?

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Abstract

The efficiency with which estuarine habitats produce fish is poorly understood due to the complexity of life cycles in estuarine fishes. Spatial dynamics of estuarine fishes comprise retentive and dispersive behaviors which occur on seasonal and ontogenetic scales. Salinity is an important scalar in the spatial dynamics of estuarine fishes, which may affect production and dispersal through its direct effect on metabolism, or through its colinearity with other estuarine features such as depth, predation risk, forage base, or flow. We have investigated estuarine movements of fishes by measuring strontium in the microchemistry of otoliths. In anadromous striped bass *Morone saxatilis*, American shad *Alosa sapidissima*, and Atlantic sturgeon *Acipenser oxyrinchus*, otolith Sr can record emigration of juveniles from oligohaline nurseries. In the case of striped bass and American shad, seasonal cycles in otolith Sr can support estimates of spawning run frequency. Microchemistry results for Bay anchovy *Anchoa mitchilli*, American eel *Anguilla rostrata*, and Japanese sea bass *Lateolabrax japonicus* support hypotheses on larval and juvenile ingress into estuarine systems. Not all applications have shown success: relationships between otolith Sr and ambient salinity could not be demonstrated for larval stage bay anchovy (but a positive relationship between these factors did occur for the juvenile stage), and Sr levels were often below detection limits in adult sturgeon otoliths. Research is underway to utilize otolith microconstituents other than Sr, to investigate the spatial dynamics of fishes along salinity and other chemical gradients in estuaries.

Contribution: 6

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Na, K, Ca, and Mg in otoliths and otoconia of vertebrates

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Abstract

The concentrations of Na, K, Ca, and Mg were determined in the otoliths and otoconia of lamprey, skate, guppy, and chicken. The K and Ca contents of otoliths in lamprey (*Cyclostomata*) markedly differ from that of otoliths and otoconia in other animals examined in this study (*Gnathostomata*). In all groups of animals but lamprey, only traces of K were found. The Na concentration in the otolith apparatus of the examined species varies from 0.37 to 1.04 mmole/g. Na seems to be bound to proteins of the organic matrix and plays an important role in the growth of otoliths and otoconia. The Ca concentration in otoliths and otoconia of the examined *Gnathostomata* was 9.09-9.63 mmoles/g. The organic compounds comprise about 4-10% of the entire mass of otoliths and otoconia. In lamprey the Ca concentration in otoliths was 5.33 mmoles/g, and share of the organic compounds constituted over 40% of the otolith mass. In the continually growing otoliths of fish the Mg concentration was significantly lower than that in the otoconia of fish (ray) and other vertebrates. This is presumably due to the fact that Mg inhibits the crystalline growth of calcium salts.

Contribution: 12

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Comparisons of the otolith elemental fingerprints of three species of tropical shad (*Tenualosa* spp.) and their value for defining stock structure in each species

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Abstract

The shads, *Tenualosa* species, support important fisheries in the estuaries of Sarawak, east Malaysia, Sumatra, Indonesia and Bangladesh. We have used otolith elemental fingerprinting with laser ablation microprobe (LAMP) - ICP- MS to help resolve fish movements and stock structure of each species in each study area. The Terubok, *Tenualosa toli*, is known to spawn in only two estuaries in Sarawak, Malaysia. The elemental fingerprint at the otolith core of fish from the two spawning estuaries differed, allowing the spawning location of fish from the coastal fishery to be identified. The second species, Hilsa *T. ilisha*, is the subject of a large fishery in Bangladesh and India. Previous studies suggested up to four sub-populations of Hilsa in the Meghna River system, Bangladesh. Our studies show that Hilsa spawns throughout the river and estuary and fish migrate and mix as they grow. The third species, Terubuk *T. macrura*, lives in the lower estuaries and adjacent coast of eastern Sumatra. The species is fished in four areas separated by > 100 km. We used the elemental fingerprint of otolith cores to determine if fish from each area are spawned at one site. Comparison of the results from these separate studies on closely-related species living in similar habitats may help highlight the situations where otolith elemental fingerprinting can be appropriate in studies of fish population structure.

Contribution: 16

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Use of radiocarbon from nuclear testing as a dated marker in the otoliths of three North Atlantic fish species

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Abstract

Radiocarbon (^{14}C) in the world's oceans increased sharply between 1950 and 1970 as a result of the atmospheric testing of nuclear weapons. Through comparison with the ^{14}C time series reconstructed from corals, the ^{14}C concentration measured in fish otolith cores has been used to confirm the annulus-based age estimates of several South Pacific fish species. Here I report the pre- and post-bomb ^{14}C chronologies of 3 North Atlantic fish species which extend and support the value of this age validation technique for confirming the absolute age of long-lived fish species. On the basis of accelerator mass spectrometry (AMS) assays, the ^{14}C in otolith cores of young, known-age haddock (*Melanogrammus aeglefinus*) and beaked redfish (*Sebastes mentella*) increased sharply and synchronously between 1958-68, with a timing and magnitude which was very similar to that of the surface marine bomb ^{14}C signal. In contrast, the ^{14}C signal recorded in the otolith cores of adult black drum (*Pogonias cromis*) more closely reflected the atmospheric chronology, in keeping with the estuarine habitat of the young-of-the-year black drum. In all 3 species however, the period of increasing ^{14}C left a clear and largely unambiguous dated mark on the otoliths. ^{14}C assays of adult otolith cores from all 3 species confirmed annulus-based age assignments of up to 40 years, with a mean error of less than 2-3 years.

Contribution: 22

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Application of otolith microchemistry analysis in hake (*Merluccius hubbsi*)

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Abstract

Merluccius hubbsi, or common hake, as it is known in South America, is spread over the Argentine Sea. Earlier researches on morphometrics, age and growth, genetic, parasites, among others, suggested the existence of at least two discrete stocks. Elemental analysis of fish otoliths has been applied to a diversity of fishery research including studies of spawning location, migrations associated with diadromy, stock discrimination, differentiation of spawning stocks, etc. The goal of this study was to evaluate the utility of otolith microchemistry as a tool for discriminating hake stocks. Juveniles and adults came from four different regions: Argentine-Uruguayan Fishing Common Zone (34°-39°30'); between 39°30'-44° S; South of 44° S; and San Matias Gulf. Analysis was based on the composition of sagittal otoliths of thirteen elements (Zn, Cu, Cd, Mn, Sr, K, Na, Ni, Ca, Mg, Li, Fe, Ba), measured using atomic absorption spectrophotometry with air-acetylene flame and background correction mechanism by ultraviolet light. Sample treatment was by an acid digestion (nitric: perchloric ,1:3) of the otolith matrix. Results were studied by using principal components analysis.

Key Words: otoliths, microchemistry, hake, stock differentiation

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Validation of the use of otolith strontium distribution for determining migratory behaviour of Arctic char (*Salvelinus alpinus*) using tag-recaptured fish

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Abstract

In previous studies we reported that life history patterns and aquatic habitats used by Arctic char (*Salvelinus alpinus*) can be inferred from scanning proton microprobe (SPM) analysis of otolith strontium (Sr) distribution. Strontium distribution patterns in otoliths of known anadromous char are low and relatively flat for the first several years of life followed by marked oscillatory increases and decreases in Sr content for the duration of the fish's life. In this study we tested the inferred patterns of life history and habitat use by using tag-recapture information from anadromous char from Nauyuk Lake, Northwest Territories, Canada. Superimposition of SPM-derived Sr distribution patterns on optical images of the otoliths confirmed the correspondence between oscillatory Sr concentration and annular structure in the otoliths. Back-calculated migratory events inferred from Sr distribution patterns for tagged fish, sacrificed at various stages of life history (e.g., migrating to sea for the first time;

fish known to have migrated to the sea several times; known spawners and post-spawners), coincided with observed migrations from recapture events.

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High strontium bands in otolith of European eel *Anguilla anguilla* (L.) - An alternative method of age determination

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Abstract

High concentration strontium (Sr) bands and growth zones in otolith of European eel, *Anguilla anguilla* (L.), from both brackish waters and lakes were examined by wavelength dispersive X-ray spectrometry on an electron microprobe and by visible light microscopy. In brackish-water, higher concentration (>0.3 wt%) Sr bands corresponded to narrow hyaline zones in the otoliths. The hyaline zones were deposited at a time of low temperature and high salinity, when fish growth is slow. This indicated that the eel migrated from brackish water to high saline seawater during winter. In freshwater lakes, Sr contents in otolith were very low and no highconcentration Sr bands are discernible. The number of hyaline zones in otolith corresponded to the age of the eel. Accordingly, Sr bands provide not only the migratory environmental history but also are an alternative method of age determination of the eel in brackish waters.

Key words: European eel, Otolith, Strontium X-ray map, Annulus, Age determination.

Contribution: 121

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Advances in computer-controlled microsampling of otoliths for stable isotope and elemental analyses

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Abstract

The accretionary nature of otolith carbonate deposition permits recovery of time-specific samples perpendicular to aragonite growth axes via computer-controlled microsampling. Analysis of time-specific otolith carbonate provides high-resolution details of life-history. Recent advances in microsampling allow discrete removal of carbonate at a sufficient resolution to study intra-annual variation in otolith chemistry on a timescale of days to weeks. A polished section (100 micron thickness) of an otolith is mounted to a glass slide which is fixed to a stage maneuvered by micropositioning motors. A color digital camera, mounted on a fourth motorized axis, provides a real-time image of the otolith section. A joystick control positions the otolith in three dimensions along desired sampling paths to build an array of (x, y, z) coordinates. Intermediate sampling paths (10 micron width) are interpolated between digitized paths permitting removal of high-resolution time-specific carbonate. A custom dental drill bit sequentially removes carbonate as the stage proceeds in three dimensions along the array of previously programmed and interpolated sampling paths. Techniques for microsampling of otolith carbonate will be presented.

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Analysis of Stock Differentiation in Lake Michigan Steelhead Using Otolith Trace Element Composition

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Abstract

Anadromous rainbow trout (*O. mykiss*), (steelhead) were introduced to the Great Lakes in the late 1800's. They now reproduce naturally and support important recreational fisheries. Variation in steelhead life history traits and allozyme frequencies indicates that multiple stocks exist among and within the Great Lakes. Existence of steelhead stocks within Lake Michigan has not been determined. We hypothesized that distinct steelhead stocks exist in Lake Michigan and can be distinguished through analysis of otolith trace element composition using inductively-coupled, plasma mass spectrometry (ICPMS). We used solution-based ICPMS to analyze elemental composition of whole otoliths from wild steelhead parr collected from six Lake Michigan tributaries. Elemental fingerprints in parr that match fingerprints in otolith primordia from wild adults would distinguish stocks. Five elements were found in detectable concentrations in parr otoliths, but varied little among rivers, or among sites within rivers. Significant differences among elements were found by grouping parr into geologically-distinct drainages, but misclassification rates (40%) of parr to natal origins were high. Research on other salmonid populations indicates analysis of discrete otolith segments using laser-ablation ICPMS and strontium isotope ratios may provide higher stock resolution, and is being pursued to identify Lake Michigan steelhead stocks.

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INVESTIGATION OF THE BLACKBACK-GREENBACK PHENOMENON IN STRIPED
BASS, *MORONE SAXATILIS*, POPULATIONS OF ATLANTIC CANADA

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Abstract

The striped bass, *Morone saxatilis*, is an anadromous species ranging along eastern North America from the St. Lawrence River to Florida, and along the Gulf of Mexico to Texas. In Atlantic Canada, several watersheds have populations in which individuals have either a black or green dorsal coloration pattern. Local fishermen believe that black bass overwinter in fresh waters, while green bass overwinter in the ocean. Both colormorphs are present on the spawning grounds at the same time. To test this hypothesis, otoliths of black and green bass were examined by laser ablation, and ovaries were analyzed for fatty acid composition. Fatty acid patterns of the ovaries were strikingly different between the two groups. Otolith microchemistry revealed Sr:Ca ratio patterns suggesting that the two groups inhabit different environments. The existence of this phenomenon appears real, but additional work is needed to understand the life history details and possible ecological significance.

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Elemental Composition of Otoliths of Fish from the Northwest Atlantic and Gulf of Mexico

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Abstract

Elemental analysis of otolith microconstituents has promising applications in fishery research. Based on the premise that differences in the physical and chemical properties of different aquatic environments are manifested in otoliths as differences in chemical composition, microconstituent analysis has been used to probe migratory patterns of anadromous fish, to differentiate between fish stocks and to describe environmental conditions experienced by fishes at different life history stages. We recently surveyed microconstituent levels in several northwestern Atlantic and Gulf of Mexico species using inductively coupled plasma mass spectrometry to analyze whole otoliths. Results of the survey showed that otolith elemental data are similar in certain respects to elemental data for a variety of biological matrices. For example, concentrations ranged from undetectable to % levels. That is, major elements were present at levels ranging from 0.1% to 38% (e.g., Na, Ca); minor element concentrations ranged up to 50 mg/Kg (e.g., Mg, Ba); trace elements were found at levels around 1 mg/Kg or less (e.g., Cu, Cr); and some elements were consistently below detection limits (e.g., Ag, Cd). Levels of minor elements tended to be highly variable among species. Finally, high variance within species was also observed, particularly for major and minor elements.

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Age, growth, and otolith trace metal analyses of fall and winter recruiting Atlantic croaker
(*Micropogonias undulatus*)

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Abstract

Atlantic croaker (*Micropogonias undulatus*) larvae recruit from offshore spawning areas to estuarine nurseries in the fall in the Chesapeake Bay (Virginia, USA) and to the Pamlico Sound (North Carolina, USA) during winter. Variation in cohort strength may be attributed to temporal and spatial differences in spawning as well as timing of subsequent advection to these estuaries. The trace metal composition of water masses through which a fish has migrated is recorded in the otoliths. The time and place of hatching, migration patterns, and nursery areas may be distinguished by relative differences in the trace metal concentrations occurring in the otolith. Using high-resolution laser-ablation ICPMS, cohorts can be contrasted based on trace metal profiles along otolith transects from the primordia to the edge. Juvenile Atlantic croaker, resident in upper tributaries of the Chesapeake Bay and Pamlico Sound, were collected for retrospective determination of age and growth and analyzed to demonstrate this laser-based technique of quantifying trace metals. This high-resolution approach provides a confident method of distinguishing Atlantic croaker spawning sites and migration patterns and could help clarify our understanding of stock structure and life history.

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Freshwater entry of Japanese sea bass juveniles : amphidromous migration or accidental immigration

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Abstract

Japanese sea bass *Lateolabrax japonicus* (Percichthyidae) distributed around Japan and western Korea is a typical euryhaline marine fish. The late larvae and early juveniles commonly occur in estuarine waters and occasionally immigrate into freshwater. Recent mitochondrial DNA analyses revealed that there is a distinct population in highly embayed Ariake Sea with a wide brackish water area and large tidal range. Based on preliminary observations, we speculate that the Ariake population has evolved amphidromous life history.

To test the hypothesis we analyzed microstructural increments and Sr/Ca ratio in larval and juvenile otoliths. The increment counts demonstrated that spawning occur in December and January, larvae appear in the Chikugo estuary 40~50 days after hatching and stay there for about 40 days, and finally immigrate into freshwater area as larvae transform to juvenile of about 17mm SL. A positive correlation between Sr/Ca ratio and ambient salinity was verified under salinity range between 0 and 10. Sr/Ca trajectory from otolith core to periphery revealed the highest value near the core and a following drastic reduction to very low level of 0 salinity under rearing experiments. Based on the relationship between body length and otolith radius, the apparent drop to 0 salinity level corresponded to 15~17mm SL. These findings strongly indicate amphidromous life history of the Ariake sea bass.

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Molluscus of Khor-e-Musa as Oil Pollution Bio-indicator

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Abstract

This research consists of measuring oil pollution in surficial sediments and also identifying molluscus and their distribution in Khor-e-Musa region in Iran. The research has been conducted by monthly sampling from August 1996 through March 1997. According to concentration of petroleum hydrocarbons varied between 4.6 to 163 μgg^{-1} /dry wet., the highest concentration was recorded in the first station (Khor-e-Ghazaleh) and the lowest was in the fourth station (Khor-e-Doragh). Diversity and abundance of molluscus was proved to be quite low so in these researches diversity indices, the shannon-weiner index in particular has been applied. The result of shannon-weiner index proves the fluctuation of this index during the forementioned months to be less than one ($H < 1$). Salinity is the most important environmental factor in determining the distribution of species. There was a significant difference between salinity and the shannon-weiner index. No significant difference has been observed between oil pollution and organic matter, grain size sediments, shannon-weiner index.

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A Time History of Pre- and Post-Bomb Radiocarbon in the Barents Sea Derived from Arcto-Norwegian Cod Otoliths

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Abstract

Radiocarbon measured in seawater dissolved inorganic carbon (DIC) can be used to investigate ocean circulation, atmosphere/ocean carbon flux, and provide powerful constraints for the fine-tuning of general circulation models (GCMs). Time series of $\Delta^{14}\text{C}$ are derived most frequently from annual bands of hermatypic corals, however, this proxy is unavailable in temperate and polar oceans. Fish otoliths, calcium carbonate auditory and gravity receptors in the membranous labyrinths of teleost fishes, can act as proxies for $\Delta^{14}\text{C}$ in most oceans and at most depths. Arcto-Norwegian cod otoliths are suited to this application due to the well-defined distribution of this species in the Barents Sea, the ability to determine age of individual Arcto-Norwegian cod with a high level of confidence, and the availability of archived otoliths collected for fisheries research over the past 60 years. Using measurements of $\Delta^{14}\text{C}$ derived from Arcto-Norwegian cod otoliths, we present the first pre- and post-bomb time series (1919 to 1992) of $\Delta^{14}\text{C}$ from polar seas and consider the significance of these data in relation to ocean circulation and atmosphere/ocean flux of radiocarbon. The data provide evidence for a minor Suess effect of only 0.2‰ per year between 1919 and 1950. Bomb radiocarbon was evident in the Barents Sea as early as 1957 and the peak in $\Delta^{14}\text{C}$ occurred in 1967, relatively early when compared with most records of ocean $\Delta^{14}\text{C}$. The data show a close link with records of $\Delta^{14}\text{C}$ obtained from corals in the tropical and subtropical North Atlantic and could be used to quantify input of North Atlantic Water (NAW) to the Barents Sea. Reduced transport of NAW to the Barents Sea, coupled with a high differential between atmosphere and ocean ^{14}C in that region, were likely to have

produced the early peak (1967) in Barents Sea $\Delta^{14}\text{C}$. Over the past two decades $\Delta^{14}\text{C}$ has declined at the rate of about 3‰ per year in the Barents Sea and indicates either a long residence-time and slow turnover of ^{14}C or constant input of NAW with a relatively high $\Delta^{14}\text{C}$.

Contribution: 219

2nd International Symposium on
Fish Otolith Research and Application
Radisson SAS Royal Bryggen Bergen
20 - 25 June 1998

Elemental analysis of eulachon (*Thaleichthys pacificus*) otoliths indicates partial homing fidelity to spawning grounds

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Abstract

Eulachons are anadromous smelts that spawn in about 30 different rivers from California to Alaska. Compared among rivers, eulachons vary in spawning time, size at maturity, fecundity and other characteristics. These differences indicate distinct population differences and perhaps homing to natal rivers but there are no apparent genetic differences. Using LA-ICPMS procedures, we compared elemental fingerprints of otoliths from 5 BC rivers. The null hypothesis was that elemental fingerprints did not vary among rivers. Data were grouped with discriminant analysis, based on the abundance of 24 elements relative to Ca 48. Fingerprints of most, but not all individuals could be distinguished among rivers so we could not completely reject the null hypothesis. We encountered an unforeseen source of (machine) variation related to the dates of analysis. This variation could be removed statistically with a fully blocked analysis sequence. Comparison of all the groups then indicated a 46% correct classification, but Fraser River and northern rivers eulachons were distinguished with 93% certainty. Unexpectedly, eulachons from the 1995 and 1996 runs within the Fraser River were distinguished with 88% certainty. If the elemental fingerprints indicate stock structure, then we suggest most eulachons home (about 80% fidelity) but some stray. Also, factors other than stock difference may also affect elemental fingerprints and we cannot account for the substantial inter-annual differences within the Fraser River. We conclude that elemental analysis of otoliths is useful for understanding the relationships among stocks, but unexpected inter-annual variation, and machine-based analytical variation, require caution in the interpretation of elemental signatures as consistent indicators of stock structure of eulachons, and perhaps other fish species.

Contribution: 222

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Using otolith chemistry to delineate natal areas and movement histories of highly migratory yellowfin tuna *Thunnus albacares*

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*Presenter

Abstract

Yellowfin tuna (*Thunnus albacares*) support major fisheries through the Western Pacific Ocean. Australia lies at the south-western extreme of their distribution in the Pacific and although fisheries in the Australian EEZ are small relative to the industrial fisheries to our east, the yellowfin catch is very valuable as it is sold as fresh fish onto the lucrative Japanese sashimi market. In the past, fishery managers have assumed that yellowfin recruiting into the Australian fishery come from the broad tropical Western Pacific. However, extensive tagging studies provide little support for this assumption.

We have used otolith microchemistry to address the key question of where recruits to the Australian yellowfin tuna fishery originate. Is it from tropical oceanic waters to the north and west of Australia, or from the tropical-sub-tropical waters of the Coral Sea?

Wave-dispersive electron micro-probe and proton probe analyses of otolith micro-constituents and SIMS analyses of oxygen isotope ratios of inner portions of the otolith matrix, laid down over the first month of life, have been used to identify differences between yellowfin natal areas. There are significant and persistent differences in the otolith chemistry of juvenile fish sampled from each of the natal areas. A notable feature of the variation is that fish spawned in tropical (10°N-10°S) latitudes appear to have significantly different chemical signatures to those originating from higher latitudes of the Coral Sea and Fiji.

The chemistry of inner portions of the majority of yellowfin caught along the temperate coast of South-east Australia is not significantly different from that of fish spawned in the Coral Sea and Fiji, but is significantly different from the tropical fish. Ongoing research is focused

on defining the differences between chemical signatures of the fish from known natal areas with the objective of providing better resolution of natal areas from fish of unknown origin.

Contribution: 223

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Daily and seasonal cycles in the concentration of strontium and other major constituents of tuna otoliths are primarily related to growth rather than temperature

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Abstract

In their early life stages tunas grow very fast, with growth rates in excess of 6 mm per day common in *Thunnus* species. During this period tuna otoliths also grow very fast. In yellowfin (*Thunnus albacares*) and southern bluefin (*Thunnus maccoyii*) tuna daily growth increments as large as 55 microns are common in postlarval and early juvenile stages. We have used these very large daily increments and a wave dispersive electron microprobe (WD-EMPA) to examine daily variation in levels of strontium, calcium, sodium, potassium, sulphur and chlorine within yellowfin tuna otoliths. These analyses show significant variation in the concentration of all of the elements analysed. For Sr, Ca and Cl the variation followed a daily cycle. In Sr and Cl, the highest concentrations occur during the slow growth period in each daily cycle; although less pronounced the opposite is the case for Ca. Strontium concentration varied by as much as 30% over a daily cycle. Water temperature variation over a daily cycle in the upper 30 m of the water column in the spawning grounds from which the fish originated is less than 1°C certainly not large enough to produce a 30% change in the precipitation rate of strontium within the matrix. We hypothesise that daily cycles in the concentration of strontium and other elements in the otolith are driven by diel cycles in the physiology of endolymphatic fluid, and that there is a link between growth rates and these cycles. To determine the links between seasonal and annual cycles in growth and otolith chemistry we have analysed variation in strontium and other elements in the otoliths of known age southern bluefin tuna (SBT). In these otoliths, strontium concentrations varied significantly over seasonal and annual cycles, with the variation being significantly correlated with fish growth rate. We know that otolith growth is also closely related to growth in length of the fish. At times when the fish and otoliths are growing slowly, the weight fraction of strontium within the total matrix is significantly higher than during periods of fast growth. Thus, although SBT experience seasonal cycles in water temperature, and these are likely to be a factor contributing to cycles in growth rates, we

believe on the bases of daily cycles in yellowfin otoliths and the seasonal cycles in SBT, that the variations in strontium and other elements within the otolith matrix are driven by growth characteristics of the fish and their otoliths rather than ambient water temperature.

Contribution: 236

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Retroactive determination of stock structure and movement-at-age in Patagonian Toothfish through laser-based elemental analysis of otoliths

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Abstract

Laser-based Inductively-Coupled Plasma Mass Spectrometry (LA-ICPMS) is being applied for the first time in the Southern Ocean to examine stock structure and movement-at-age in Patagonian toothfish (*Dissostichus eleginoides*). The Patagonian toothfish is a large semi-pelagic predator that is fished on the shelf and shelf-slope off the southern South American mainland, and through the Southern Ocean. We will present results from a study using LA-ICPMS to sample a suite of elements present across otolith sections of fish taken from the Atlantic, Indian and Pacific sectors of the Southern Ocean. By examining the outer edge of otoliths, we intend firstly to confirm that the technique can detect geographic separation at this scale in toothfish, and then to see if element concentrations at the otolith nucleus will discriminate between geographic sectors, indicating if spawning sites are separate. Using the results of an ageing validation study undertaken as part of this project, we will also compare known-age sites across and between otolith sections to examine retroactively changes in elemental concentrations corresponding to fish movement between water masses, and to characterize elemental variability between years. We will relate these results to water mass structure, and variability in the physical environment of the Southern Ocean associated with cyclic and long-term change.

Overview Timetable

Saturday 20 June 1998

1400 - 1900 Registration at Radisson SAS Royal Hotel
1900-2030 Reception at "Sardinen". Host: University of Bergen
2030 Get-together at "Sardinen". Music by: "Cajun Gumbo"

Sunday 21 June 1998

0800 - 0900 Registration at Radisson SAS Royal Hotel
0830 - 0900 Opening Symposium at **Radisson SAS Royal Hotel** by **Director Roald Vaage** (Institute of Marine Research). Music by **Bergen Kammerkor**

Session 1: Otolith Physiology and Morphology

0900 - 1530 Oral session
1000 - 1030 Coffee break
1230 - 1330 Lunch
1530 - 1700 Poster session
1530 - 1600 Coffee break
1700 - 1745 Oral session

Monday 22 June 1998

Session 2: Estimation of Fish Age and Growth

0830 - 1500 Oral session
1000 - 1030 Coffee break
1230 - 1330 Lunch
1500 - 1630 Poster session
1500 - 1530 Coffee break
1630 - 1830 Oral session
1930 - 2130 **Reception at the Institute of Marine Research.** Host: Institute of Marine Research

Tuesday 23 June 1998

Mid-conference break (committee meetings, workshops, field trips)

Wednesday 24 June 1998

Session 3: Otoliths in Studies of Populations

0900 - 1500 Oral session
1000 - 1030 Coffee break
1200 - 1315 Lunch
1500 - 1630 Poster session
1500 - 1530 Coffee break
1630 - 1845 Oral session

Thursday 25 June 1998

Session 4: Otolith Composition

0830 - 1430 Oral session

1000 - 1030 Coffee break
1215 - 1315 Lunch
1430 - 1600 Poster session
1430 - 1500 Coffee break
1600 - 1700 Oral session
1700 - 1740 Summing by Session Chairmens; Synthesis and future directions
1740 - 1800 Awards - closing remarks
1900 **Reception at Fløien Folkerestaurant. Host: Bergen Town**
2000 **Banquet (Fløien Folkerestaurant)**