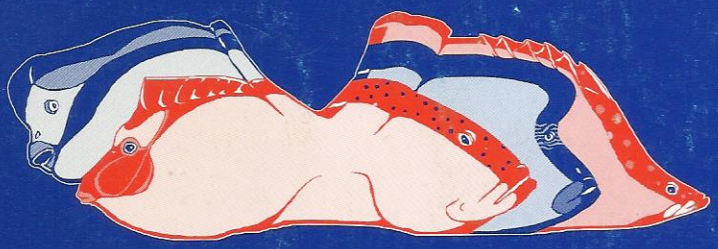
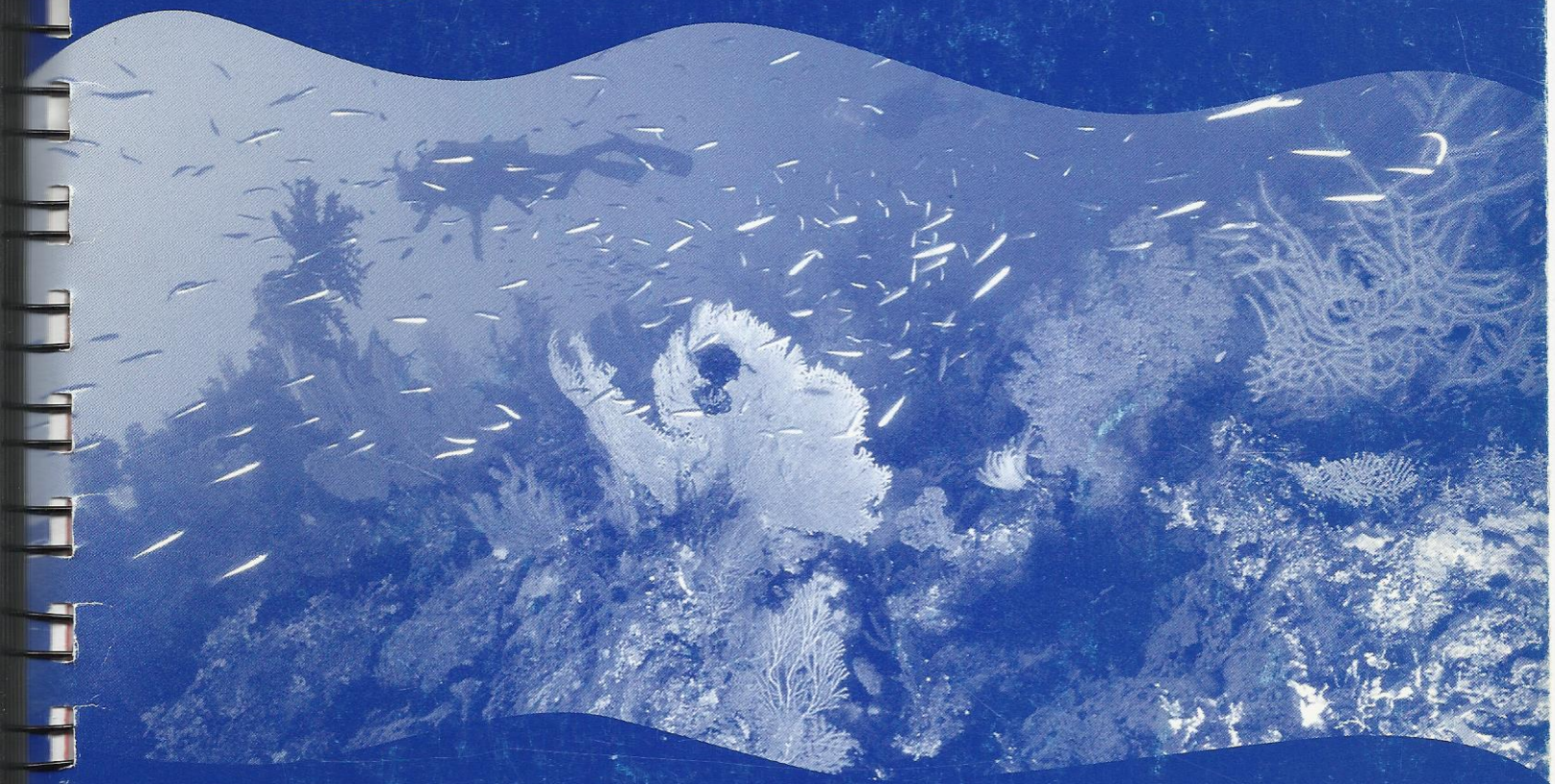
Handbook and Abstracts

Third International Symposium on Fish Otolith Research and Application



11-16 July 2004
Jupiter's Hotel and Casino
Townsville, Queensland Australia



Hosted by Major Sponsors

CRC Reef Research Centre

JCU James Cook University

Australia — an initiative of Backing Australia's Ability — The Commonwealth Government's Commitment to Innovation

Grant Support

This project is supported by the Innovation Access Programme-International Science and Technology, an initiative of the Government's Innovation Statement, Backing Australia's Ability.

Sponsors

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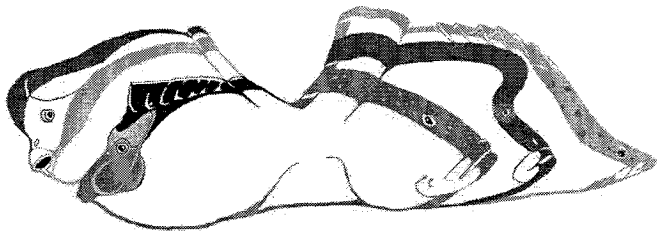


Third International Symposium on Fish Otolith Research and Application

Innovation and Implementation

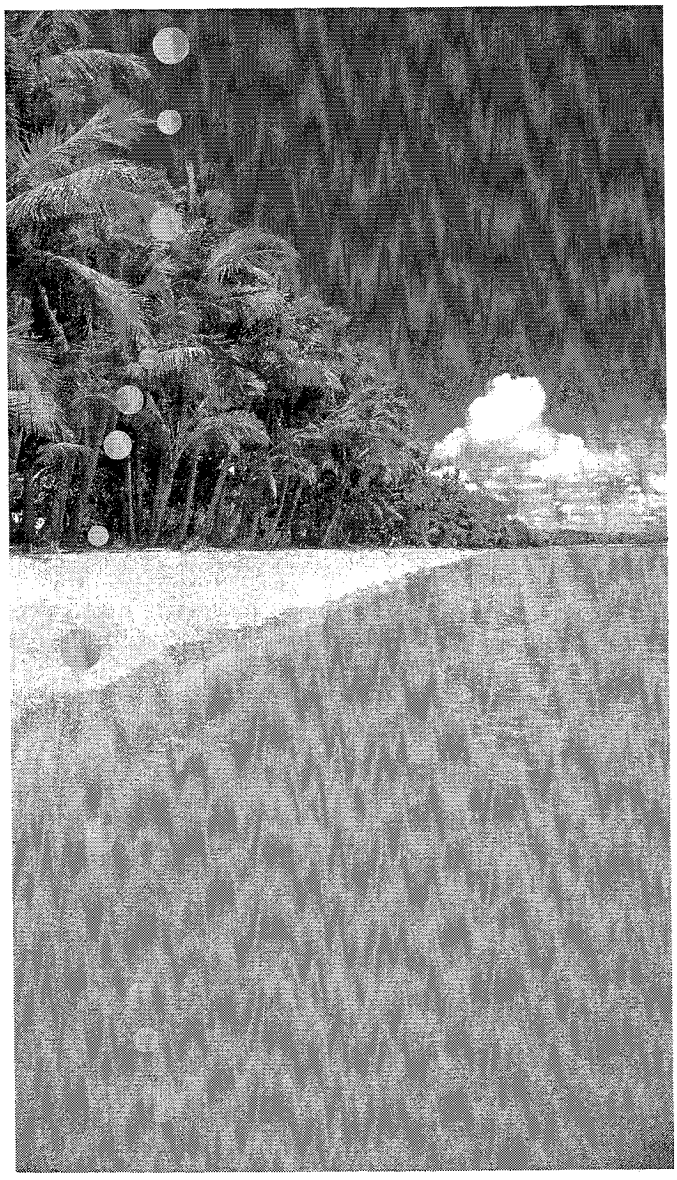


Table of Contents

Symposium Sponsors 2

SECTION 1

Welcome 5

Symposium Organising Committee 5

Location Map 6

General Information 7

SECTION 2

Symposium Oral Program 11

Symposium Poster Program 19

Symposium Social Functions 25

Floorplan of the Symposium Session Rooms – Jupiter's Hotel and Casino 25

Wednesday Tours 27

SECTION 3

Oral Abstracts Monday 12 July 2004 31

SECTION 4

Oral Abstracts Tuesday 13 July 2004 47

SECTION 5

Oral Abstracts Thursday 15 July 2004 69

SECTION 6

Oral Abstracts Friday 16 July 2004 93

SECTION 7

Poster Abstracts 111

Section One

General Information



Welcome

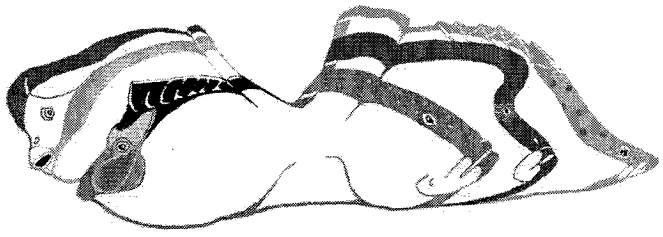
On behalf of the Symposium Organising Committee, I take great pleasure in welcoming you to Townsville for the Third International Symposium on Fish Otolith Research and Application. The event, which is being held in Queensland for the first time, is proudly hosted by the CRC Reef Research Centre and James Cook University.

We believe you will find the quality and range of the oral and poster presentations throughout the four day program to exceed your expectations in addressing the Symposium theme "Innovation and Implementation". The poster sessions and social program will provide an excellent opportunity for networking with friends and colleagues.

The Symposium is grateful for the generous support of all of our sponsors, in particular our Major and Host Sponsors, the CRC Reef Research Centre and James Cook University.

We hope you enjoy your stay in sunny Townsville and find the Symposium to be an interesting, informative and memorable event.

DR GAVIN BEGG
Symposium Chair



Symposium Organising Committee

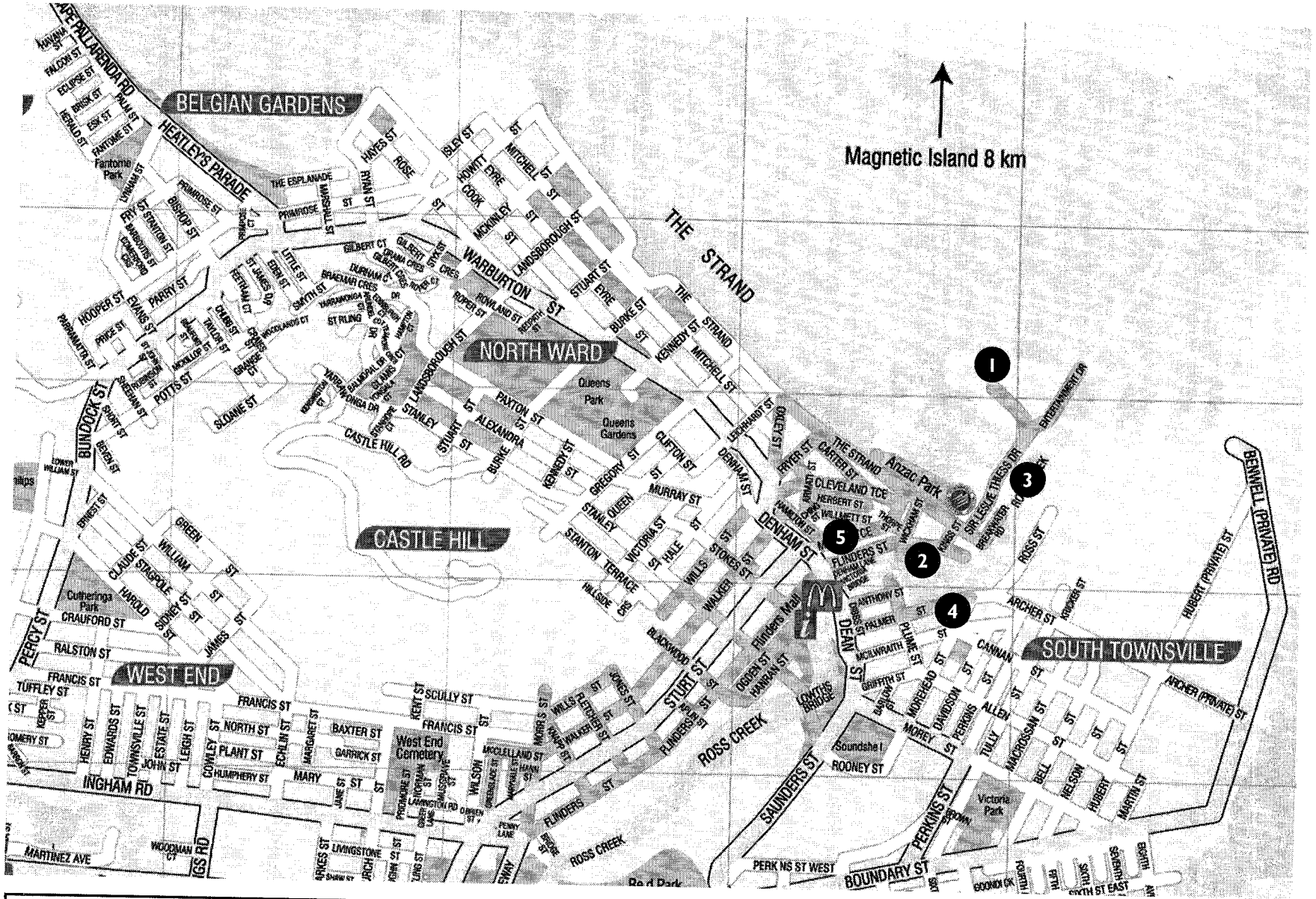
The following people and organisations are closely involved with the direction and planning of the Symposium:

Local Organising Committee:

Dr Gavin Begg	*CRC Reef Research Centre, Townsville* ***(Symposium Chair)***
Mrs Iesha Stewart	*CRC Reef Research Centre, Townsville*
Dr Annabel Jones	*CRC Reef Research Centre, Townsville*

International Scientific Committee:

Mr John Ackerman	*Australian National University, Australia*
Mr Allen Andrews	*Moss Landing Marine Laboratories, USA*
Dr Takaomi Arai	*Otsuchi Research Centre, Japan*
Dr Gavin Begg	*CRC Reef Research Centre, Australia*
Dr Steven Campana	*Bedford Institute of Oceanography, Canada*
Dr John Casselman	*Ontario Ministry of Natural Resources, Canada*
Dr Anthony Fowler	*South Australian Research & Development Institute, Australia*
Dr Audrey Geffen	*University of Liverpool, UK*
Dr Bronwyn Gillanders	*University of Adelaide, Australia*
Dr Churchill Grimes	*National Marine Fisheries Service, USA*
Dr Michael Kingsford	*James Cook University, Australia*
Dr Karin Limburg	*State University of New York, USA*
Dr Gudrun Marteinsdottir	*University of Iceland, Iceland*
Dr Mark Meekan	*Australian Institute of Marine Science, Australia*
Dr Erlend Moksness	*Flodevigen Marine Research Station, Norway*
Dr Beatriz Morales-Nin	*Departamento de Recursos Naturales, Spain*
Dr Henrik Mosegaard	*Danish Institute for Fisheries Research, Denmark*
Dr Jacques Panfili	*Institut de Recherche pour le Developpement, France*
Dr Malcolm Smale	*Port Elizabeth Museum, South Africa*
Dr Iain Suthers	*University of NSW, Australia*
Dr Ronald Thresher	*CSIRO, Australia*
Ms Dianne Tracey	*National Institute of Water & Atmospheric Research, New Zealand*
Dr Wann-Nain Tzeng	*National Taiwan University, Taiwan*
Dr Hakan Wickström	*Swedish National Board of Fisheries, Sweden*
Dr Peter Wright	*Fisheries Research Services, UK*



Legend

1. Jupiter's Hotel and Casino
   (Sir Leslie Thiess Drive, Townsville)
2. Reef HQ
   (2–68 Flinders Street, Townsville)
3. Ferry Terminal
   (Sir Leslie Thiess Drive, Townsville)
4. Quest Apartments
   (30–34 Palmer Street, Townsville)
5. Downtown Motel
   (121 Flinders Street East, Townsville)

General Information

Accommodation and Symposium Venue

Please ensure that the balance of your accommodation (if applicable) is paid directly to the Hotel on departure, as well as any incidentals you may incur.

Jupiter's Hotel and Casino

Sir Leslie Thiess Drive, Townsville
Telephone : + 61(0) 7 4722 2333
Facsimile : + 61 (0) 7 4772 4741

Please note Jupiter's Hotel and Casino is a non-smoking venue. Smoking is not permitted within the Session rooms or the poster display area.

Quest Apartments

30–34 Palmer St, Townsville
Telephone: +61 (0) 7 4772 6477
Facsimile: +61 (0) 7 4772 6766

Downtown Motel

121 Flinders St East Townsville
Telephone: +61 (0) 7 4771 5000
Facsimile: +61 (0)7 4721 5945

Symposium Manager

OzAccom Conference Services
PO Box 104
RBH POST OFFICE QLD 4029
Telephone: +61(0)7 3854 1611
Facsimile: +61(0)7 3854 1507
Email: otolith2004@ozaccom.com.au

Disclaimer

All information disclosed in the Symposium Program is correct at the time of printing. The Organising Committee reserves the right to alter the Symposium Program in the event of unforeseen circumstances.

Dress

Smart Casual attire is appropriate for Symposium Sessions.

Messages

All messages will be placed on the message board located near the registration desk at the Symposium. Please advise potential callers to contact Jupiter's Hotel and Casino on 07 4722 2333 or facsimile 07 4772 4741 and attention to the Third International Symposium on Fish Otolith Research and Application Registration Desk.

Delegates are asked to check the board regularly throughout the Symposium. The Symposium Manager takes no responsibility for messages not delivered to the delegate.

Name Badges

Delegates are requested to wear their name badge at all times during the Symposium. Please note, the Symposium Organising Committee can be identified by a colour ribbon attached to their name badge.

Personal Mail and Deliveries

Personal mail and deliveries should be sent to your accommodation address. The Symposium Manager does not accept responsibility for personal mail.

Poster Exhibition

Posters will be displayed in Coral Sea Rooms I & II of Jupiter's Hotel and Casino for the duration of the Symposium and rotated each day. Poster boards will be numbered as indicated in the program. Please refer to the program for further details.

Registration Desk

The registration desk located in the Ballroom Foyer of the Hotel will be staffed at the following times:

Sunday 11 July	4.00pm – 6.30pm
Monday 12 July	8.00am – 5.30pm
Tuesday 13 July	8.00am – 5.30pm
Thursday 15 July	8.00am – 5.30pm
Friday 16 July	8.00am – 4.30pm

Speaker Preparation Room

A speaker preparation room will be located in the Sunrise Room. Please check-in your presentation in the speaker's preparation room no later than the session before your presentation. Please note, the organisers will endeavour to provide the highest level of service, however, failure to meet their guidelines may compromise the delivery of this service.

Speakers and Chairpersons

As the Symposium has a full program, chairpersons of sessions are asked to meet their speakers in the appropriate session room at least 10 minutes prior to the commencement of the session. It is also the chairperson's responsibility to ensure speakers do not exceed their allotted presentation and question time.

Special Requirements

If you have any special dietary requirements and did not indicate this at the time of registration, please let the Symposium Managers know immediately so we can make the necessary arrangements for you.

If you have any medical or other special requirements or require wheel chair access, please let us know so we can assist you where necessary.

Telephones

All mobile phones and pagers are to be turned off when delegates are in session. Public telephones are located throughout the Hotel.

Tickets

Tickets will be required for entry into lunches, Welcome Reception, Symposium Dinner and all Wednesday Tours. Delegates who have paid for "additional" function tickets will be given the appropriate ticket(s) which will be inside your registration envelope – please check you have received tickets for all functions you have booked for at the time of registration.

Ticket Refunds

Ticket refunds for all social functions and tours will be not be available on-site as final catering numbers for all functions have been confirmed. Please see the registration brochure for the cancellation policy of function tickets.

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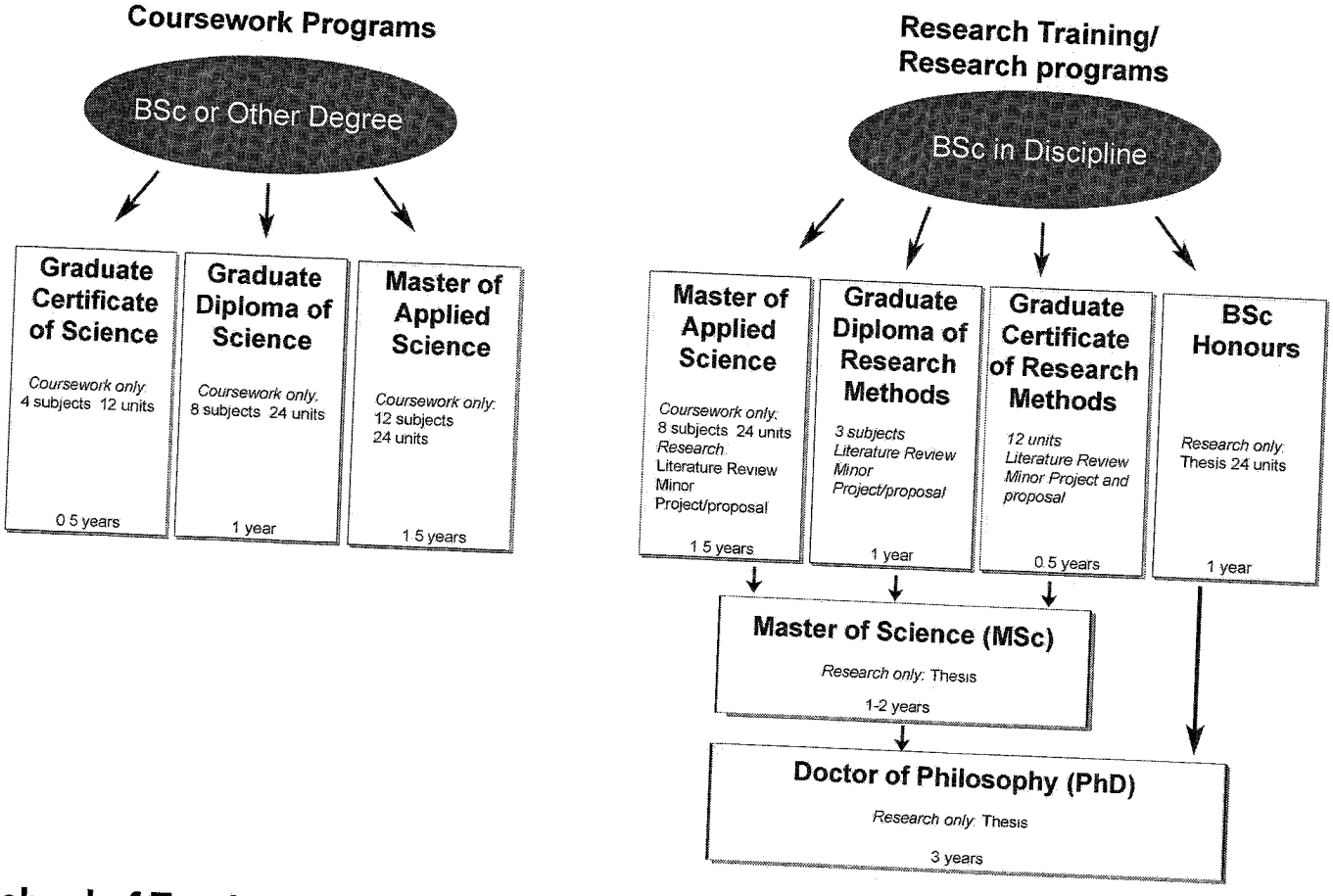
Marine Biology, within the School of Marine Biology and Aquaculture, offers a number of coursework and research postgraduate programs with an emphasis on Tropical Marine Ecology and Fisheries Biology with academic staff having internationally recognised expertise. Programs enable graduates to develop their knowledge and skills in quantitative marine ecology and in the biology, ecology and taxonomy of tropical marine organisms. Postgraduate courses offered lead to the following:



School of Tropical Environment Studies and Geography (TESAG)

The School of Tropical Environment Studies and Geography (TESAG) is a dynamic, multidisciplinary School that prepares students for academic challenges and rewarding careers. TESAG brings together physical, biological and social aspects of the environment under the roof of one single academic School. Staff are drawn from a wide variety of disciplines, deliberately brought together to find creative and dynamic solutions to environmental problems and to play an active role in best practice management.

Our graduate program offers the following qualifications:

Research Degrees

Master of Arts, Master of Social Science, Master of Science and Doctor of Philosophy in the following disciplines:

- Environmental Science (including Resource Management)
- Human Geography
- Geographic Information Systems and Spatial Analysis
- Physical Geography
- Tropical Urban and Regional Planning (Townsville only)

Coursework Degrees

The School offers four strands of study as a Graduate Certificate of Science, a Graduate Diploma of Science, or a Master of Applied Science. The strands are:

- Protected Area Management
- Geographical Information Systems and Spatial Analysis
- Natural Resource Management
- Tropical Urban and Regional Planning

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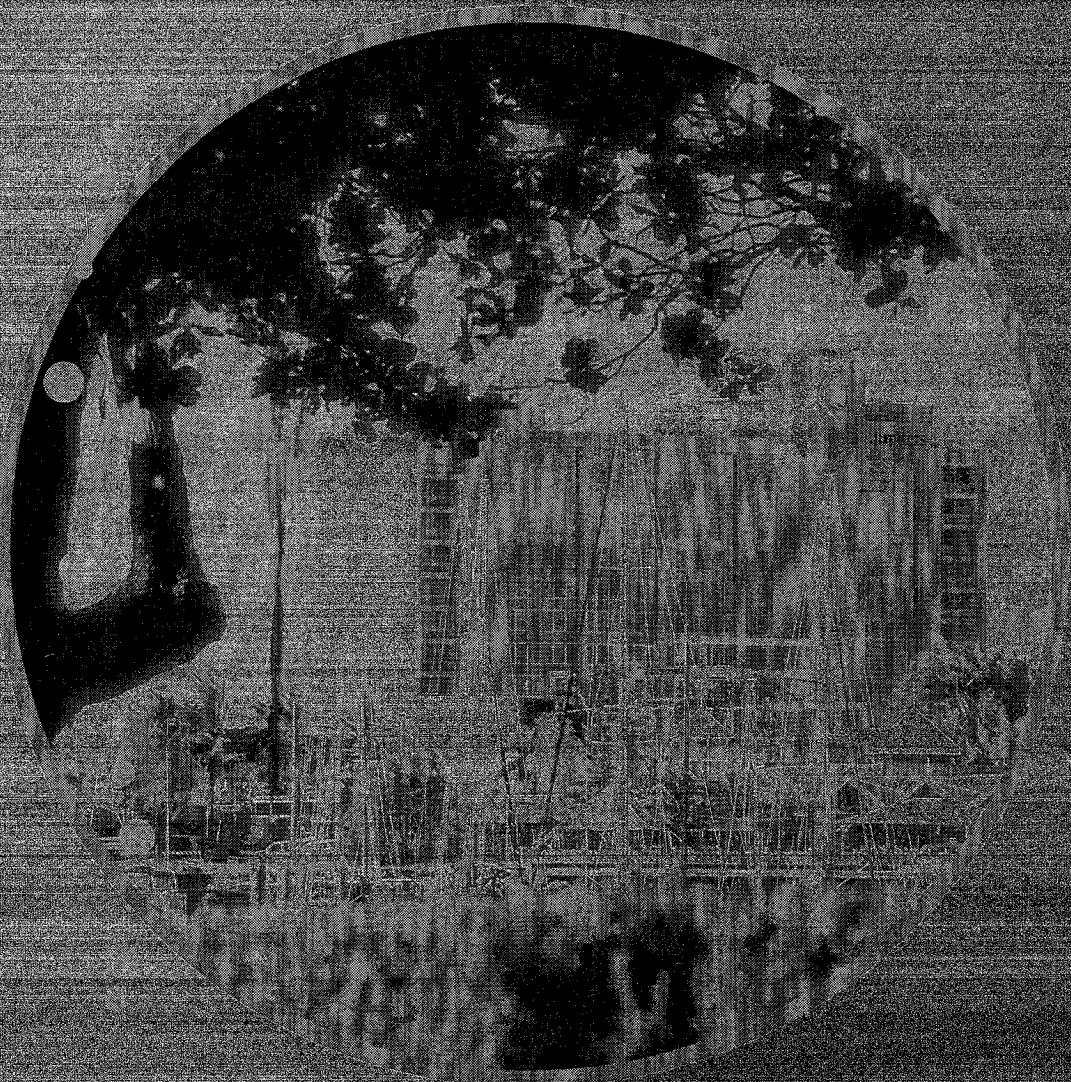
Section Two

Symposium Program



Program

Sunday 11 July 2004

4.00pm Symposium Registration commences

6.30pm Welcome Reception Reef HQ ***Sponsored by James Cook University***

Monday 12 July 2004

8.00am Registration

Opening Session
Room: Ballroom 1
Chair: Gavin Begg

	Opening Ceremony
8.50	*Welcome* **Gavin Begg,** Convenor and Chair
8.55	*Official Opening* **Ian McDonald,** Minister for Fisheries, Forestry and Conservation, Australia
9.05	*Traditional Owners' Welcome to Country*
9.10	Keynote Address: *Otolith Research and Application in the 21st Century* **Steven Campana,** Bedford Institute of Oceanography, Canada (p. 31)

10.00am Morning Tea ***Sponsored by Bureau of Rural Sciences***

Plenary Session
Room: Ballroom 1
Chair: Churchill Grimes

10.30	Theme 1 – Keynote Address: *Sciaenid Fishes: A "Model" System for Studies of Fish Otolith Organ Structure and Function* **Arthur Popper,** Department of Biology, University of Maryland, USA (p. 31)
11.00	Theme 3 – Keynote Address: *Age Determination and Validation: Structures, Methods, Analyses and Application* **Gregor Cailliet,** Moss Landing Marine Laboratories, USA (p. 32)

Theme 3 Age and Growth Estimation and Validation
Room: Ballroom 1
Chair: Churchill Grimes

11.30	*Age Validation of the Canary Rockfish* (Sebastes pinniger) *from the Northeastern Pacific Ocean using 210Pb:226Ra Disequilibria and Bomb 14C* **Allen Andrews** Moss Landing Marine Laboratories, USA (p. 32)
11.45	*Bomb Radiocarbon and Maximum Ages of Bluenose and Rubyfish: A New Approach* **Rodger Sparks** National Institute of Water and Atmospheric Research Ltd (NIWA), New Zealand (p. 33)
12.00	*Age Validation and Tests of Assumptions Using Bomb Radiocarbon from Canary Rockfish Otolith Cores* **Owen Hamel** Northwest Fisheries Science Center, NOAA, USA (p. 33)

Theme 1 Structure and Function
Room: Ballrooms 2 & 3
Chair: Henrik Mosegaard

Formation of Daily Growth Increments in Otolith of Pacific Tarpon (Megalops cyprinoides) *during Metamorphosing* **Hui-Lun Chen** Institute of Zoology, National Taiwan University, Taiwan (p. 34)
The Nature of Secondary Growth Structures in Temperate Marine Fishes **Peter Wright** FRS Marine Laboratory, Scotland (p. 34)
Evidence of Differences in Chemical Composition and Otolith Density between Opaque and Translucent Bands in Cod (Gadus morhua) *Otoliths* **Javier Tomas** Institut Mediterrani D'Estudis Avanats (CSIC-UIB), Spain (p. 35)

12.15pm Lunch

Plenary Session
Room: Ballroom 1
Chair: Audrey Geffen

1.30	Theme 4 Keynote Address: *Seasonality in Deep-Sea and Tropics Revisited: What Can Otoliths Tell?* **Beatriz Morales-Nin,** Departmento de Recursos Naturales, Spain (p. 35)

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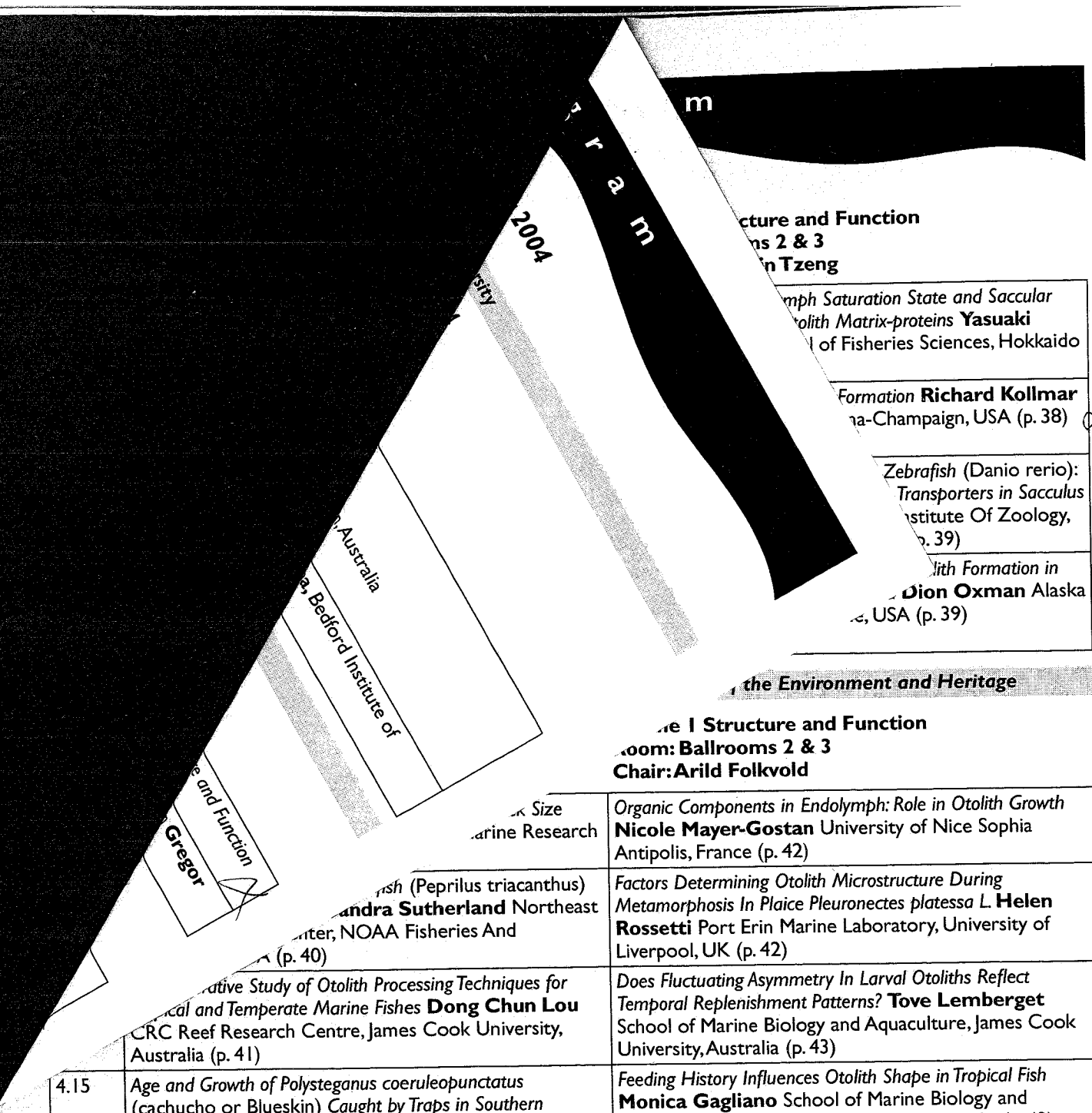
mph Saturation State and Saccular olith Matrix-proteins **Yasuaki** l of Fisheries Sciences, Hokkaido	
Formation **Richard Kollmar** na-Champaign, USA (p. 38)	
Zebrafish (Danio rerio): Transporters in Sacculus stitute Of Zoology, p. 39)	
lith Formation in **Dion Oxman** Alaska e, USA (p. 39)	

the Environment and Heritage

e I Structure and Function
oom: Ballrooms 2 & 3
Chair: Arild Folkvold

	k Size arine Research	*Organic Components in Endolymph: Role in Otolith Growth* **Nicole Mayer-Gostan** University of Nice Sophia Antipolis, France (p. 42)
	ish (Peprilus triacanthus) **andra Sutherland** Northeast nter, NOAA Fisheries And A (p. 40)	*Factors Determining Otolith Microstructure During Metamorphosis In Plaice Pleuronectes platessa L.* **Helen Rossetti** Port Erin Marine Laboratory, University of Liverpool, UK (p. 42)
	ative Study of Otolith Processing Techniques for cal and Temperate Marine Fishes **Dong Chun Lou** CRC Reef Research Centre, James Cook University, Australia (p. 41)	*Does Fluctuating Asymmetry In Larval Otoliths Reflect Temporal Replenishment Patterns?* **Tove Lemberget** School of Marine Biology and Aquaculture, James Cook University, Australia (p. 43)
4.15	*Age and Growth of Polysteganus coeruleopunctatus* (cachucho or Blueskin) *Caught by Traps in Southern Mozambique* **Rabia Gulamo Abdula Torres** Instituto Nacional De Investigation Pesqueira, Mozambique (p. 41)	*Feeding History Influences Otolith Shape in Tropical Fish* **Monica Gagliano** School of Marine Biology and Aquaculture, James Cook University, Australia (p. 43)



	Room: Coral Seas I & II
4.30pm	Poster Session & Reception ***Sponsored by The Department of Education, Science and Training***

Theme 4 Age Estimation in Deep Sea and Tropical Environments
Room: Ballroom 1
Chair: Audrey Geffen

Theme 1 Structure and Function
Room: Ballrooms 2 & 3
Chair: Wann-Nain Tzeng

2.00	*An Age-based Demographic Analysis of a Coral Reef Fish Across the Indo-Pacific Ocean* **Elisabeth Lamantrip** School of Marine Biology and Aquaculture, James Cook University, Australia (p. 36)	*Diel Changes in Endolymph Saturation State and Saccular mRNA Expressions of Otolith Matrix-proteins* **Yasuaki Takagi** Graduate School of Fisheries Sciences, Hokkaido University, Japan (p. 38)
2.15	*Age Estimation in Deep-water Macrourid Fishes* **Sarah Swan** Scottish Association For Marine Science, Scotland (p. 36)	*Molecular Genetics of Otolith Formation* **Richard Kollmar** University Of Illinois at Urbana-Champaign, USA (p. 38)
2.30	*In Situ Tagging of Deepsea Fish* **Helene De Pontual** IFREMER, France (p. 37)	*Mechanism of Otolith Formation in Zebrafish* (Danio rerio): *Immunocytochemical Evidence of Ion Transporters in Sacculus Epithelium Cells* **Jen-Chieh Shiao** Institute Of Zoology, Academia Sinica, Republic Of China (p. 39)
2.45	*Regional Patterns in the Age and Growth of a Suite of Epinepheline Serranid Species Caught in the Reef Line Fishery of the Great Barrier Reef* **Amos Mapleston** CRC Reef Research Centre, James Cook University, Australia (p. 37)	*Genetic and Environmental Effects on Otolith Formation in Pink Salmon from Auke Creek, Alaska* **Dion Oxman** Alaska Department of Fish and Game, USA (p. 39)

3.00pm Afternoon Tea ***Sponsored by Australian Government – Department of the Environment and Heritage***

Theme 3 Age and Growth Estimation and Validation
Room: Ballroom 1
Chair: Di Tracey

Theme 1 Structure and Function
Room: Ballrooms 2 & 3
Chair: Arild Folkvold

3.30	*Use of Otolith Weight in the Determination of Stock Size* **Peter Stephenson** Western Australia Marine Research Institute, Australia (p. 40)	*Organic Components in Endolymph: Role in Otolith Growth* **Nicole Mayer-Gostan** University of Nice Sophia Antipolis, France (p. 42)
3.45	*Indirect Age Estimation of Butterfish* (Peprilus triacanthus) *Based on Otolith Weights* **Sandra Sutherland** Northeast Fisheries Science Center, NOAA Fisheries And Ecosystems, USA (p. 40)	*Factors Determining Otolith Microstructure During Metamorphosis In Plaice Pleuronectes platessa L.* **Helen Rossetti** Port Erin Marine Laboratory, University of Liverpool, UK (p. 42)
4.00	*A Comparative Study of Otolith Processing Techniques for Tropical and Temperate Marine Fishes* **Dong Chun Lou** CRC Reef Research Centre, James Cook University, Australia (p. 41)	*Does Fluctuating Asymmetry In Larval Otoliths Reflect Temporal Replenishment Patterns?* **Tove Lemberget** School of Marine Biology and Aquaculture, James Cook University, Australia (p. 43)
4.15	*Age and Growth of Polysteganus coeruleopunctatus* (cachucho or Blueskin) *Caught by Traps in Southern Mozambique* **Rabia Gulamo Abdula Torres** Instituto Nacional De Investigation Pesqueira, Mozambique (p. 41)	*Feeding History Influences Otolith Shape in Tropical Fish* **Monica Gagliano** School of Marine Biology and Aquaculture, James Cook University, Australia (p. 43)

	Room: Coral Seas I & II
4.30pm	Poster Session & Reception ***Sponsored by The Department of Education, Science and Training***

Program

Tuesday 13 July 2004

8.00am Registration

Plenary Session
Room: Ballroom 1
Chair: Tony Fowler

8.30	**Keynote Session *Sponsored by CRC Reef Research Centre*** Theme 7 – Keynote Address: *Otoliths, Recruitment, and Stock Assessment* **Stephen Ralston,** National Marine Fisheries Service, USA (p. 47)
9.00	**Keynote Session *Sponsored by James Cook University*** Theme 5 – Keynote Address: *Estimating Population Connectivity in Marine and Anadromous Fishes using Geochemical Signatures in Otoliths: State-of-the-art and Future Directions* **Simon Thorrold,** Woods Hole Oceanographic Institution, USA (p. 47)

Theme 5 Climate, Ecology and Population Biology
Room: Ballroom 1
Chair: Tony Fowler

Theme 7 Stock Assessment and Fisheries Management
Room: Ballrooms 2 & 3
Chair: Hakan Wickstrom

9.30	*High-Resolution Stable Isotope Records from Otoliths: Past, Present and Future* **William P. Patterson** University of Saskatchewan, Department of Geological Sciences, Canada (p. 48)	*Age-based Assessments in Tropical Developing Countries – An Expensive Folly or Worth Every Penny?* **Graham Michael Pilling** CEFAS, UK (p. 49)
9.45	*Isotopic Indicators of Climate Regime Shifts from Marine Fish Otoliths* **Yongwen Gao** Makah Fisheries Management, USA (p. 48)	*Size-selective Mortality in the Fast Growing Tropical Sprat, Spratelloides gracilis* **Mark Meekan** Australian Institute of Marine Science (AIMS), Australia (p. 49)

10.00am Morning Tea ***Sponsored by Department of Agriculture, Fisheries and Forestry, Australia***

Theme 5 Climate, Ecology and Population Biology
Room: Ballroom 1
Chair: Steven Swearer

Theme 7 Stock Assessment and Fisheries Management
Room: Ballrooms 2 & 3
Chair: Michael Schirripa

10.30	*Plaice Settlement Patterns Over a Five-year Period Identified From Otolith Increments* **Richard Nash** Port Erin Marine Laboratory, University of Liverpool, UK (p. 50)	*Discrimination of Hatchery and Wild Chinook Salmon Using Otolith Microstructure* **Churchill Grimes** National Marine Fisheries Service, USA (p. 53)
10.45	*Diversity of Migration in Diadromous Fishes, as Revealed by Otolith Microchemistry* **Takaomi Arai** International Coastal Research Center, The University of Otsuchi, Japan (p. 50)	*The Effect of Ageing Errors on the Management Advice of the Namibian Horse Mackerel, Trachurus capensis* **Margit Wilhelm** Ministry of Fisheries and Marine Resources, Nambia (p. 54)
11.00	*Connectivity Between Juvenile Fish in Estuaries and Adult Populations on Open Coasts* **Bronwyn Gillanders** School of Earth and Environmental Sciences, University of Adelaide, Australia (p. 51)	*Stock Discrimination of Central Valley, California Chinook Salmon Using Otolith Microstructure* **Martha Volkoff** California Department of Fish and Game, USA (p. 54)
11.15	*Flexible Life History Strategies in Two New Zealand Diadromous Fish Species; Giant Kokopu and Common Bully* **Bernard Barry** National Isotope Centre, Institute of Geological and Nuclear Sciences, New Zealand (p. 51)	*Age Reading through 50 Years of History and Quality of Long-term Stored Northeast Arctic Cod Otoliths. Might it Cause Time Trends in Biological Parameters?* **Natalya Zuykova** Knipovich Polar Research Institute of Marine Fisheries and Oceanography, Russia (p. 55)
11.30	*From Hatching to Catching: Reconstructing the Lifetime Movements of Plaice by Linking Natural and Electronic Data Records* **Audrey Darnaude** CEFAS, UK (p. 52)	*Patterns of Aging Error among some Gulf of Mexico Fishes* **Gary Fitzhugh** National Marine Fisheries Service, USA (p. 55)
11.45	*Tests of the Potential Use of Concentrations of Trace and Minor Elements in Barramundi (Lates calcarifer) Scales as Indicators of Nursery Salinity Regimes* **Mike Cappo** Australian Institute of Marine Science (AIMS), Australia (p. 52)	*Mixing of Spawning Stocks or Year Class Twinning in Norwegian Spring Spawning Herring?* **Aase Huseboe** Institute For Marine Research, Norway (p. 56)
12.00	*Otolith Growth of Fishes in Relation to Thermal Requirements, Environment, and Climate* **John Casselman** Ontario Ministry of Natural Resources, Canada (p. 53)	*Stock Discrimination of Cod (Gadus morhua) in Icelandic Waters using Otolith Shape Analysis* **Ingibjorg G. Jonsdottir** The Marine Research Institute, Iceland (p. 56)

12.15pm Lunch

Plenary Session
Room: Ballroom 1
Chair: Michael Kingsford

1.30	Theme 2 – Keynote Address: *Endolymph Chemistry and Otolith Growth* **Patrick Payan,** University of Nice Sophia Antipolis, France (p. 57)

Theme 3 Age and Growth Estimation and Validation
Room: Ballroom 1
Chair: Allen Andrews

Theme 2 Chemistry and Composition
Room: Ballrooms 2 & 3
Chair: Michael Kingsford

2.00	*Age-validation and Otolith Growth of Sprat* (Sprattus sprattus) *in the Skagerrak and Kattegatt, Eastern North Sea* **Michele Casini** Swedish National Board of Fisheries, Institute of Marine Research, Sweden (p. 57)	*Relationships Between Anadromous and Non-anadromous Rainbow Trout* (Oncorhynchus mykiss) *in California Rivers* **Christopher Donohoe** National Marine Fisheries Service, USA (p. 59)
2.15	*Evidence for Growth and Mortality Trade-offs in Simulated "Match-Mismatch" Environments and those Consequences for Fitness in Atlantic Cod* (Gadus morhua) **Vivian Buehler** Institute for Marine Sciences, Universität Kiel, Germany (p. 58)	*The Use of Natural Chemical Tags in Otoliths to Investigate Nursery Origins and Population Mixing of Snapper, Pagrus auratus, in Victorian Waters* **Gregory Jenkins** PIRVic Marine and Freshwater Systems, Australia (p. 60)
2.30	*Validation of Daily Increment and Age Estimation of Juvenile Skipjack Tuna* (Katsuwonus pelamis) *in the Western Pacific* **Toshiyuki Tanabe** National Research Institute of Far Seas Fisheries, Japan (p. 58)	*Tracing the Diadromous Migrations of Australian Grayling Using Otolith Chemical Analyses* **David Crook** Arthur Rylah Institute For Environmental Research, Australia (p. 60)
2.45	*Variation in the Periodicity and Timing of Increment Formation in Red Throat Emperor Otoliths* **Ashley John Williams** CRC Reef Research Centre, James Cook University, Australia (p. 59)	*Model Analysis and Numeric Simulation of Fish Otolith Accretion* **Henrik Mosegaard** Danish Institute For Fisheries Research, Denmark (p. 61)

3.00pm Afternoon Tea ***Sponsored by South Australia Research & Development Institute – Aquatic Sciences***

Theme 3 Age and Growth Estimation and Validation
Room: Ballroom 1
Chair: Jacques Panfili

Theme 2 Chemistry and Composition
Room: Ballrooms 2 & 3
Chair: Takaomi Arai

3.30	*Is it Necessary to Validate the Otoliths of Every Species we Study?* **John Howard Choat** School of Marine Biology, James Cook University, Australia (p. 61)	*Comparison of Genetic and Chemical Signatures in Northeast Atlantic Cod* (Gadus morhua) *Populations* **Audrey J. Geffen** Department of Fisheries and Marine Biology, University of Bergen, Norway (p. 63)
3.45	*Translucent Zones Form Annually in Otoliths of Antarctic Toothfish* (Dissostichus Mawsoni) **Colin Sutton** National Institute of Water and Atmospheric Research Ltd (NIWA), New Zealand (p. 62)	*Use of Geochemical Tracers to Elucidate Life History Trajectories of Gray Snapper* (LUTJANIDAE: Lutjanus griseus) *within South Florida's Marine Ecosystems* **Monica Lara** Cooperative Institute of Marine and Atmospheric Studies, USA (p. 64)
4.00	*Validation of Age Estimates from a Temperate Wrasse Including a Robust Approach to the Use of Marginal Increment Analysis* **Graeme Ewing** Tasmanian Aquaculture and Fisheries Institute, Australia (p. 62)	*Tracing the Life History of Barramundi using LA-MC-ICP-MS Strontium Isotopic and Trace Element Compositions of Otoliths* **Malcolm Thomas McCulloch** Research School of Earth Sciences, Australian National University, Australia (p. 64)
4.15	*Validation of Otolith Daily Increments for Yellowfin and Bigeye Tunas by Injection of Fluorescent Substances* **Takayuki Matsumoto** National Research Institute of Far Seas Fisheries, Fisheries Research Agency, Japan (p. 63)	*Otolith Microchemistry and DNA Microsatellites in Black Rockfish* (Sebastes melanops) **Jessica Miller** Institute of Marine Biology, University of Oregon, USA (p. 65)

	Room: Coral Seas I & II
4.30pm	Poster Session & Reception ***proudly sponsored by The Department of Education, Science and Training***

Wednesday 14 July 2004

Optional Tours

1. Great Barrier Reef Cruise
2. Billabong Sanctuary Tour
3. Charters Towers Outback Tour
4. Magnetic Island Tour
5. Hinchinbrook Tour
6. Rainforest Tour

Thursday 15 July 2004

8.00am Registration

	Theme 3 Age and Growth Estimation and Validation **Room: Ballroom 1** **Chair: Malcolm Smale**	**Theme 2 Chemistry and Composition** **Room: Ballrooms 2 & 3** **Chair: Karin Limburg**
8.30	*Historical Review of Cephalopod Growth* **Marek Lipinski** Sea Fisheries Research Institute, South Africa (p. 69)	*Unravelling Life Histories of Bluenose and Rubyfish using Otolith Stable Isotope Chemistry* **Helen Neil** National Institute of Water and Atmospheric Research (NIWA), New Zealand (p. 72)
8.45	*Batoid Age and Growth: A Review of Ageing Structures, Techniques, and Interpretation* **Julie A. Neer** Coastal Fisheries Institute – LSU, USA (p. 69)	*Resolution of Early Life History Using Otolith Chemistry: What are Reef Fish doing Before they Settle?* **Heather Patterson** Department of Zoology, University of Melbourne, Australia (p. 72)
9.00	*Statoliths as Black Boxes (life recorders) in Squid and Cuttlefish* **Alexander Arkhipkin** Fisheries Department, Falkland Islands Government, Falkland Islands (p. 70)	*Tracking Continental Habitat Shifts of Eels Using Otolith Sr: Ca Ratios: Validation and Application to the Coastal, Estuarine and Riverine Eels of the Girande-Garonne-Dordogne Watershed* **Francoise Daverat** Cemagref, France (p. 73)
9.15	*Investigations of Radiocarbon in the White Shark* (Carcharodon carcharias) *from the Eastern Pacific* **Lisa A. Kerr** Moss Landing Marine Laboratories, USA (p. 70)	*Proximal Causes for Variable Otolith Strontium and Manganese Levels in Juvenile Gag Along Florida's Gulf Coast* **Peter J. Hanson** NOAA Fisheries, USA (p. 73)
9.30	*Growth and Life History Characteristics of North Queensland Reef Sharks* **William David Robbins** School of Marine Biology and Aquaculture, James Cook University, Australia (p. 71)	*Stock Identification and Life History Interpretation Using Trace Element Signatures in Fish Otoliths* **Sukyung Kang** Department of Marine Science, Pukyong National University, South Korea (p. 74)
9.45	*Complex Steps to Ageing Deep-sea Corals in New Zealand Waters* **Dianne Tracey** National Institute of Water And Atmospheric Research Ltd (NIWA), New Zealand (p. 71)	*Stable Isotope Analyses of Cod Otoliths to Examine the Timing of Otolith Macrostructure Formation* **Hans Hoie** Department of Biology, University of Bergen, Norway (p. 74)

10.00am Morning Tea ***Sponsored by Fisheries Research & Development Corporation***

Theme 3 Age and Growth Estimation and Validation
Room: Ballroom 1
Chair: John Casselman

Theme 2 Chemistry and Composition
Room: Ballrooms 2 & 3
Chair: Bronwyn Gillanders

10.30	*Influence of Reproduction on Otolith Microincrement Deposition* **Jacques Panfili** Institut de Recherche pour le Développement (IRD), France (p. 75)	*Spatial Variation in Otolith Chemistry at a Range of Scales: Implications for the Design of Sampling Programs aimed at the Identification of Natural Tags in Otoliths* **Paul Hamer** PIRVic Marine and Freshwater Systems, Australia (p. 78)
10.45	*Otolith Size Trends in Different Depth Marine Communities* **Antoni Lombarte** Institut De Ciències Del Mar, CMIMA-CSIC, Spain (p. 75)	*Using ICP-MS Analysis of Coral Reef Fish Otoliths to Examine Connectivity Between Islands of French Polynesia* **Alain Lo-Yat** Australian Institute of Marine Science, Australia (p. 79)
11.00	*Otolith Shape Analysis of Cod* (Gadus morhua) *in the NE Atlantic* **Johan Modin** Department of Marine Ecology, Goteborg University, Sweden (p. 76)	*Determining Essential-fish Habitat with Otolith-geochemical Tags: Fine-scale Habitat use by Spotted Seatrout* (Cynoscion nebulosus) **Cynthia Jones** Center For Quantitative Ecology, USA (p. 79)
11.15	*Age and Growth of Broadbill Swordfish* (Xiphias gladius) *from Australian Waters* **Jock Young** CSIRO Marine Research, Australia (p. 76)	*Otolith Microchemistry as Indicator of Anthropogenetic Stress* **Catherine Aliaume** University of Montpellier, France (p. 80)
11.30	*Age and Growth of Juvenile Goliath Grouper* (Epinephelus itajara) *including a Comparison of Ageing Methods* **Jennifer Schull** NOAA – Southeast Fisheries Science Centre, USA (p. 77)	*Microchemistry of Atlantic Redfish Otoliths: Geographic Variation, Migration and Temporal Stability* **Christoph Stransky** Federal Research Centre For Fisheries, Germany (p. 80)
11.45	*Patterns of Growth, Mortality and Size of a Tropical Damselfish Acanthochromis polyacanthus Across and Along the Great Barrier Reef* **Michael Kingsford** School of Marine Biology and Aquaculture, James Cook University, Australia (p. 77)	*The Use of Strontium Isotopes and Trace Elements to Determine Natal Origins for Delta Smelt* (Hypomesus Transpacificus) *in the San Francisco Estuary* **James Hobbs** Bodega Marine Laboratory, University of California, USA (p. 81)
12.00	*Migratory Behaviour Between Brackish Lagoons and the Mediterranean Sea for the Gilthead Sea Bream Sparus aurata* **David Mouillot** Ecosystemes Lagunaires, France (p. 78)	*The Use of Otolith Microchemistry and Morphology for Stock Identification of an Exploited Tropical Reef Fish* **Mikaela Bergenius** CRC Reef Research Centre, James Cook University, Australia (p. 81)

12.15pm Lunch

Plenary Session
Room: Ballroom 1
Chair: Erlend Moksness

1.30	Theme 8 – Keynote Address: *Quality Control in Ageing Facilities and Data Processing* **Sandy Morison,** Department of Primary Industries Victoria, Australia (p. 82)

Theme 5 Climate, Ecology and Population Biology
Room: Ballroom 1
Chair: Jill St John

Theme 8 Quality Control in Ageing Facilities and Data Processing
Room: Ballrooms 2 & 3
Chair: Erlend Moksness

2.00	*Relationship Between Elemental Concentration and Age from Adult Snapper Otoliths – Implications for Movement and Stock Structure* **Anthony Fowler** SARDI Aquatic Sciences, Australia (p. 82)	*Optimising Fish Ageing Using Otolith Weight and Shape – Confirmation with Known Age Cod* **Max Cardinale** Swedish National Board of Fisheries, Sweden (p. 84)
2.15	*Using Otolith Microchemistry to Gauge Dispersal Scales and Connectivity among Marine Populations* **Michael Sheehy** Marine Science Institute, University of California, USA (p. 83)	*Quality Control of Age Estimations for a Long-lived Reef Fish* **Ross Marriott** CRC Reef Research Centre, James Cook University, Australia (p. 85)
2.30	*Determining Production Sources and Spatial Structure of Chinook Salmon Using Geochemical Markers* **Rachel Barnett-Johnson** UC Santa Cruz/ NMFS, USA (p. 83)	*Quality Control Mechanisms at the Alaska Fisheries Science Center* **Daniel K. Kimura** Alaska Fisheries Science Center, USA (p. 85)
2.45	*Annual Growth of Pacific Hake* (Merluccius productus) *in Response to Oceanographic Conditions* **Michael Schirripa** NOAA Fisheries, USA (p. 84)	*Increasing Precision in Age Estimation of Cod* (Gadus morhua) *and Hake* (Merluccius merluccius) *Otoliths using Image Analysis Computational Technology* **Miquel Palmer** IMEDEA, Spain (p. 86)

3.00pm Afternoon Tea ***Sponsored by Marine and Freshwater Systems***

Theme 5 Climate, Ecology and Population Biology
Room: Ballroom 1
Chair: Greg Jenkins

Theme 8 Quality Control in Ageing Facilities and Data Processing
Room: Ballrooms 2 & 3
Chair: Ian Brown

3.30	*Otolith Elemental Signatures in Endemic Species: What Exactly does a Self-Recruitment Signature Look Like?* **Steven Swearer** Department of Zoology, University of Melbourne, Australia (p. 86)	*Using Digitised Pictures and Otolith Size and Shape Information to Improve Precision in Routine Age Determinations of Greenland Halibut (Reihnardtius hippoglassoides) Otoliths* **Alf Harbitz** Institute of Marine Research, Norway (p. 88)
3.45	*Reconstructing Environmental Occupancy of Bream Using Otolith Chemistry* **Travis Samuel Elsdon** School of Earth and Environmental Science, University of Adelaide, Australia (p. 87)	*Difficulty of Age Determination Between Pacific Hake, (Merluccius productus) Pacific Ocean Perch (Sebasles alutus), and Sablefish (Anoplopoma fimbria)* **Susan Coccetti** Pacific States Marine Fisheries Commission, USA (p. 89)
4.00	*The Relationship between Juvenile Habitat Use and Adult Population Structure of White Perch in the Patuxent River Estuary, Maryland USA* **Richard Kraus** Department of Marine Biology, Texas A&M University Galveston, USA (p. 87)	*Comparison of Otolith Readings, Image Analysis and Genetics in Stock Separation of Atlantic Cod* **Alf Harbitz** Institute of Marine Reserch, Norway (p. 89)
4.15	*From Desert Heat to Ice-Age Cool – Climate Signals in Australian Golden Perch Otoliths* **Janet Pritchard** Australian National University, Australia (p. 88)	*EFAN & TACADAR: A Cooperative Effort to Exchange Experience and Protocols Between Fish Institutes* **Erlend Moksness** Institute of Marine Research, Norway (p. 90)

	Room: Coral Seas I & II
4.30pm	Poster Session & Reception ***proudly sponsored by The Department of Education, Science and Training***

Friday 16 July 2004

8.00am Registration

Plenary Session
Room: Ballroom 1
Chair: Peter Wright

8.30	Theme 9 – Keynote Address: *Otolith Research Techniques: Improving the Old and Embracing the New* **Malcolm Smale,** Port Elizabeth Museum, South Africa (p. 93)

Theme 3 Age and Growth Estimation and Validation
Room: Ballroom 1
Chair: Iain Suthers

Theme 9 Technological Developments
Room: Ballrooms 2 & 3
Chair: Petter Fossum

9.00	*Age and Growth in a Euryhaline Subantarctic nototheniid, Eleginops maclovinus (Cuv & Val., 1830)* **Paul Brickle** Fisheries Department, Falkland Islands Government, Falkland Islands (p. 93)	*AFORO: An Interactive Shape Analysis and Classification System for Fish Otoliths* **Oscar Chic** Institut De Ciències Del Mar (CMIMA-CSIC), Spain (p. 95)
9.15	*Seasonal Variation of Larval Growth Rate of Stelophorus insularis and its Connection to Survivorship* **Han Chu** Institute of Fisheries Sciences, National Taiwan University, Taiwan (p. 94)	*A Comparison of Electron and Proton Microprobe Analyses of Strontium Distribution in Salmonid Otoliths* **Randy J. Brown** U.S. Fish And Wildlife Service, Fairbanks FWFO, USA (p. 96)
9.30	*Hatchdate Distributions and Mortality of Cape Anchovy, Engraulis encrasicolus, in the Southern Benguela Ecosystem* **Margit R Wilhelm** Ministry of Fisheries and Marine Resources, Namibia (p. 94)	*Otolith Shape Feature Extraction Oriented to Artificial Neural Network Classification* **Jaume Piera** Universitat Politècnica De Catalunya, Spain (p. 96)
9.45	*Otolith Microstructure Analysis Reveals Selective Survival of Young-of-the-Year (YoY) sprat, Sprattus sprattus, from the Central Baltic Sea* **Hannes Baumann** Institute For Hydrobiology and Fisheries Science, Germany (p. 95)	*Otolith Shape Contour Analysis using Affine Transformation Invariant Wavelet Transforms and Curvature Scale Space Representation* **Vicenç Parisi** Universitat Politècnica De Cataluny, Spain (p. 97)

10.00am Morning Tea ***Sponsored by Department of Fisheries – Western Australia***

Plenary Session
Room: Ballroom 1
Chair: Peter Horn

10.30	Theme 6 – Keynote Address: *Estimating Age from Otolith Measurements: A Review and a New Approach* **Chris Francis,** National Institute of Water And Atmospheric Research Ltd (NIWA), New Zealand (p. 97)

Theme 3 Age and Growth Estimation and Validation
Room: Ballroom 1
Chair: Beatriz Morales-Nin

Theme 6 Statistics and Modelling
Room: Ballrooms 2 & 3
Chair: Peter Horn

11.00	*What can the Microstructure of Otoliths Tell Us About the Early Life-history of Yellowfin Whiting?* **David Schmarr** Environmental Biology, University of Adelaide, Australia (p. 98)	*How to Estimate Philopatry and Movement using Otoliths as Natural Tags* **Cynthia Jones** Center For Quantitative Ecology, USA (p. 100)
11.15	*Seasonal Growth of Otoliths of White Perch, a Warm-water Species, in Temperate Great Lakes Waters* **Satoshi Katayama** Biological Sciences, Tohoku University, Japan (p. 98)	*Numerical Reconstructing of Age Distribution in a Population using Fredholm First-kind Equation* **Vladimir Troynikov** Marine and Freshwater Systems, Department of Primary Industries, Australia (p. 101)
11.30	*The Importance of Rapid Growth for Early Life History Stages of Sablefish* **Susan Sogard** National Marine Fisheries Service, USA (p. 99)	*Testing Larval Fish Dispersal Hypotheses Using Maximum Likelihood Analysis of Otolith Microchemistry Data* **Stuart A. Sandin** Scripps Institution of Oceanography, USA (p. 101)
11.45	*Effects of Age and Environment on the Shape of European Eel* (Anguilla anguilla) *Otoliths* **Håkan Wickström** Swedish National Board of Fisheries, Institute of Freshwater Research, Sweden (p. 99)	*Statistical Learning Applied to Fish Age and Growth Analysis* **Ronan Fablet** Ifremer/LASAA, France (p. 102)
12.00	*Dynamics of Growth Histories in 0-age of Two Clupeid: Etrumeus teres and Sardinops melanostictus* **Guido Plaza** National Research Institute of Fisheries Science, Fisheries Research Agency, Japan (p. 100)	*Modelling Otolith Growth A New Approach to Age Validation in Tailor* (Pomatomus saltatrix) **Ian Brown** Department of Primary Industries, Australia (p. 102)

12.15pm Lunch

Theme 3 Age and Growth Estimation and Validation
Room: Ballroom 1
Chair: Mark Meekan

Theme 6 Statistics and Modelling
Room: Ballrooms 2 & 3
Chair: Cynthia Jones

1.30	*Contrasting Growth Rates and Stable Isotope Signatures of Larval Fish in Upwelling Regions* **Iain Suthers** School of Biological, Earth & Environmental Sciences, University of New South Wales, Australia (p. 103)	*Cross-correlating Time Series of Otolith Growth Increments to Validate Ages in Long-lived Fishes* **Bryan Black** Hatfield Marine Science Center, USA (p. 106)
1.45	*Revealing Fitness Costs of High and Low Metabolic Rates for Larval Herring Using Otolith Microstructure* **Anders Bang** Department of Marine Ecology, University of Aarhus, Denmark (p. 103)	*Using Mixed-Effects Models To Analyze Data From Otoliths: Applications In Fisheries Science* **Laurent Vigliola** Secretariat of The Pacific Community, New Caledonia (p. 106)
2.00	*Effects of Environment on Survival and Abundance of Larval Suckers From Upper Klamath Lake, Oregon* **Mark Terwillinger** Oregon State University, USA (p. 104)	*Comparing Growth Curves: Statistical Significance is not the Same as Biological Significance* **Michael John Manning** National Institute of Water and Atmospheric Research Ltd (NIWA), New Zealand (p. 107)
2.15	*Growth-Mortality Hypothesis Evaluation for Atlantic Menhaden* (Brevoortia tyrannus) *larvae* **Dariusz Fey** Sea Fisheries Institute, Poland (p. 104)	*A Statistical Methodology for Otolith Ageing Validation via The Bomb Radiocarbon Chronometer* **Owen Hamel** Northwest Fisheries Science Center, Northwest Fisheries Science Center, NOAA, USA (p. 107)
2.30	*Short-term Uncoupling of Otolith and Somatic Growth Induced by Food Level Changes in Post-larval Baltic sprat, Sprattus sprattus* **Hannes Baumann** Institute For Hydrobiology And Fisheries Science, Germany (p. 105)	*Determining Appropriate Sample Size to Measure Differences between Two Age Estimates* **Michael Schirripa** NOAA Fisheries, USA (p. 108)
2.45	*Multiple Condition and Growth Measures of Individual Larvae: How do they Compare?* **Arild Folkvord** Department of Fisheries and Marine Biology, University of Bergen, Norway (p. 105)	*Otolith Based Analysis of Survival and Size-selective Mortality of Stocked 0+ Pike* (Esox lucius L.). **Peter Grønkjaer** Department of Marine Ecology, University of Aarhus, Denmark (p. 108)

3.00pm ***Queensland Fisheries Service*** Afternoon Tea

Closing Session
Room: Ballroom 1

3.30pm	Closing Ceremony
4.00pm	Symposium Closes

7.00pm Pre-Dinner Drinks, Poolside Gardens, Jupiter's Hotel & Casino
7.30pm Symposium Dinner ***Sponsored by the CRC Reef Research Centre***

Poster Program

Monday 12 July 2004

Poster No.

Theme 1 – Structure and Function

Variations On Otolith Microstructure Of Sea-Bass (Dicentrarchus labrax L.) Larvae Under Different Food Regimes **Belen Aguilera** Institut De Ciencies Del Mar, Cmima – Csic, Spain (p. 111) 1

The Relationship Between Metabolic Rate And Otolith Size At Hatch For Zebrafish **Anders Bang** Department Of Marine Ecology, University Of Aarhus, Denmark (p. 111) 2

The Difference In Otolith Microstructure Between Damselfishes And Angelfishes At Early Life Stage **Kuan-Yu Chen** Institute Of Fishery Science,Ntu,Taiwan (p. 111) 3

The Relationship of the Otolithic Spatial Distribution and Morphology of Fish Heads:An Ecological Perspective **Lishu Chen** National Museum of Marine Science and Technology,Taiwan (p. 112) 4

Nutritional Conditions And Growth Rates In Sardine Larvae Off Northern Portugal **Maria Chicharo** University Of Algarve, Portugal (p. 111) 5

Crystalline Structure On Sulcus Acusticus Of Some Thai Fish Sagittae From Different Habitats **Suwit Jitpukdee** Faculty Of Science And Fisheries Technology, Rajamangala Institute Of Technology,Thailand (p. 112) 6

Comparative Features Of Otolith Microstructure In The Young Of Several Fish Species Of The White Sea **Anastasia Khrustaleva** Russian Federal Research Institute Of Fisheries And Oceanography (VNIRO), Russia (p. 112) 7

Cephalopod Statolith Formation, Structure And Function **Marek Lipinski** Sea Fisheries Research Institute, South Africa (p. 112) 8

Otolith Atlas Of The Central Atlantic Ocean And Western Mediterranean Sea **Antoni Lombarte** Institut De Ciències Del Mar, Cmima-Csic, Spain (p. 113) 9

Influence Of Sea Temperature And Other Factors On The Formation Of Annual Growth Zones Within North Sea Cod Otoliths **Graham Michael Pilling** Centre For Environment, Fisheries And Aquaculture Sciences Cefas, UK (p. 113) 10

Otoliths of Some Fish Species of the Irminger Sea **Oleg Smirnov** Knipovich Polar Research Institute of Marine Fisheries & Oceanography, Russia (p. 113) 11

Determining Natal Origin Of Lake Ontario Chinook Salmon (Oncorhynchus tshawytscha) Using Otolith Microstructure **Nathan Smith** Department Of Natural Resources, Cornell University, USA (p. 113) 12

Properties And Localization Of Carbonic Anhydrase Involved In Otolith Calcification In Inner Ear **Hidekazu Tohse** University Of Tokyo, Japan (p. 114) 13

Otoliths of Marine Fish of the Barents Sea **Natalia Yaragina** Knipovich Polar Research Institute of Marine Fisheries & Oceanography, Russia (p. 114) 14

Theme 2 – Chemistry and Composition

Estuarine Residence, Ocean Entry and Iteroparity:What Can Salmonid Otolith Microchemistry Divulge? **Richard A Bush** John Muir Institute For The Environment, University Of California, USA (p. 115) 15

Comparing Otolith Chemistry and Microstructure As Life History Indicators **Molly Cobleigh** United States Geological Survey, USA and **Hilary Limont** University of Washington, USA (p. 115) 16

Comparison Of Three Age Structures As Recorders Of Migration Histories In Rainbow Trout (Oncorhynchus mykiss) **Christopher Donohoe** National Marine Fisheries Service, USA (p. 115) 17

Otolith Elemental Fingerprints Of Juvenile Pacific Swordfish (Xiphias gladius) **Robert L. Humphreys** National Marine Fisheries Service, USA (p. 115) 18

Comparative Sr/Ca Electron Microprobe Analysis Of 4 Species Otoliths **Maylis Labonne** IRD, France (p. 116) 19

The Use Of Otolith Microchemistry To Monitor And Evaluate The Movement Of Coral Reef Fish In South Florida Waters **Monica Lara** Cooperative Institute Of Marine And Atmospheric Studies, USA (p. 116) 20

High Resolution Mapping Of Otolith Trace Elements With Synchrotron X-Ray Fluorescence **Karin Limburg** College of Environmental Science & Forestry, State University Of New York, USA (p. 116) 21

Effect Of Salinity And Feeds On Otolith Sr/Ca Ratio Of Japaness Eel,Anguilla japonica **Shih-Huan Lin** Institute Of Zoology, National Taiwan University,Taiwan (p. 117) 22

Age-Related Trends In Otolith Microchemistry Of Merluccius Merluccius From The Northeastern Atlantic Ocean And The Mediterranean Sea **Beatriz Morales-Nin** IMEDEA, Spain (p. 117) 23

Use Of Elemental Analysis In Stock Discrimination Of Bristol Bay Sockeye Salmon **Donald Mortensen** Noaa/Nmfs/ Auke Bay Laboratory, USA (p. 117) 24

Evaluation Of Strontium And Calcein For Marking Hatchery And Wild Juvenile Chum Salmon **Donald Mortensen** NOAA/NMFS/ Auke Bay Laboratory, USA (p. 118) 25

Improved Interpretation Of Labeled Fish Otoliths: Cost-Effective Tool in Sustainable Fisheries Management **Teuvo Niva** Finnish Game And Fisheries Research Institute, Finland (p. 118) 26

Otolith Analysis: Key To Understanding The Ecology Of A Rockfish **Guido Plaza** National Research Institute Of Fisheries Science, Fisheries Research Agency, Japan (p. 118) 27

Elemental And Isotopic Fingerprints Of Juvenile Winter Flounder (Psuedopleuronectes americanus) **Richard Pruell** US Environmental Protection Agency Nheerl- Atlantic Ecology Division, USA (p. 119) 28

The Migratory History Of Pacific Tarpon, megalops cyprinoides As Revealed From Otolith Sr/Ca Ratios **Kang-Ning Shen** Institute Of Zoology, National Taiwan University, Taiwan, R.O.C. (p. 119) 29

Origins Of Red Drum Stocks: Assessing The Contribution Of Different Nursery Grounds Using Chemical Signatures **Greg Stunz** Texas A&M University – Corpus Christi, USA (p. 119) 30

Effects Of Handling And Storage Methods On The Concentrations Of Elements In Deep-Water Fish Otoliths **Sarah Swan** Scottish Association For Marine Science, Scotland (p. 119) 31

Microchemistry Of Bluemouth And Hake Otoliths As An Aid To Stock Discrimination **Sarah Swan** Scottish Association For Marine Science, Scotland (p. 120) 32

Chemical Marking Techniques For The Stock Enhancement Of Mulloway (Argyrosomus japonicus) **Matt Taylor** Fisheries And Marine Environmental Research, University Of NSW, Australia (p. 120) 33

Experimental Investigation Of Element Incorporation In Larval And Juvenile Fish Otoliths **Simon Thorrold** Woods Hole Oceanographic Institution, USA (p. 120) 34

Recruitment In Experimental Releases Of Brown Trout: Patterns In Dispersal And Survival Relative To Fry And Otolith Growth **Robert Titus** California Department Of Fish And Game, USA (p. 121) 35

Elemental Composition In Otoliths Of European Eel Anguilla anguilla **Wann-Nian Tzeng** Institute Of Fisheries Sciences, National Taiwan University, Taiwan (p. 121) 36

The Relative Contributions Of Food And Water To Otoliths **Benjamin Walther** Woods Hole Oceanographic Institution, USA (p. 121) 37

Geographical Variation On Chemical Composition Of The Statolith Of Veined Squid Loligo forbesi **Chia-Hui Wang** Institute Of Fisheries Sciences, National Taiwan University, Taiwan (p. 122) 38

Effects Of Handling On Elemental Composition Of Otoliths In Age-2 Pacific Halibut **Stephen Wischniowski** International Pacific Halibut Commission, USA (p. 122) 39

Theme 4 – Age Estimation In Deep Sea And Tropical Environments

Age Estimation Of Sicyopterus And Cotylopus Gobiids (Adults And Offspring) In Mascarene Islands **Raymonde Lecomte-Finiger** University Of Montpellier, France (p. 133) 40

An Assessment Of Fish Ageing Errors From Otolith Sectioning Procedure **Dong Chun Lou** CRC Reef Research Centre, James Cook University, Australia (p. 133) 41

Aspects Of The Early Life, Age And Growth Of Mulloidichthys flavolineatus In The Indian Ocean (Mauritius Island And Reunion Island) **Karine Pothin** Laboratoire D'écologie Marine, Faculté Des Sciences, France (p. 133) 42

Long-Lived Fish Down Under **Dianne Tracey** National Institute Of Water And Atmospheric Research Ltd (NIWA), New Zealand (p. 134) 43

Relationships Between Otolith Growth And Somatic Growth In A Deep-Water Fish From Northeastern Mediterranean Waters **Vassiliziki Vassilopoulou** National Centre For Marine Research, Greece (p. 134) 44

Tuesday 13 July 2004

Theme 5 – Climate, Ecology and Population Biology

Discrimination Between Icelandic Cod Populations From Adjacent Spawning Grounds Based On Otolith Growth And Shape **Gavin Begg** CRC Reef Research Centre, James Cook University, Australia (p. 135) 45

Ocean Ecology Of Juvenile Bluefish, Pomatomus saltatrix, In Maryland Coastal Waters **Jody Callihan** Chesapeake Biological Laboratory, USA (p. 135) 46

Temperature-Dependent Otolith Growth Responses In Cod Larvae – Pitfalls And Potentials **Arild Folkvord** Department Of Fisheries And Marine Biology, University Of Bergen, Norway (p. 135) 47

The Use Of Otolith Microchemistry To Monitor And Evaluate Coral Reef Fish In South Florida Waters. **Trika Gerard** NOAA, SE Fisheries/Florida A&M University, USA (p. 135) 48

Comparison Of Stable Isotopic Compositions In Otoliths Of North Pacific Chum Salmon (Oncorhynchus keta): Stock Identification And Life History Understanding **Suam Kim** Department of Marine Science, Pusan National University, South Korea (p. 136) 49

Chaetodon Speculum Of New Caledonia As An Indicator Of Environmental Conditions **Maylis Labonne** IRD, France (p. 136) 50

Tracing Migration Routes Of European Eel Larvae **Raymonde Lecomte-Finiger** CNRS, France (p. 136) 51

Tracing Life History Of Barramundi (Lates calcarifer) Using Otolith Microchemistry **Andrew McDougall** Natural Resources & Mines, Australia (p. 137) 52

Otolith Microchemical Analysis Of Juvenile Yellowfin Tuna From Nursery Areas In The Atlantic Ocean **Eric Morize** IRD, Plouzane, France (p. 137) 53

Fluctuating Asymmetry In Otolith Shape And Heterozygosity In Ethmalosa fimbriata (Clupeidae) In An Estuary Stressful Environment (West Africa) **Jacques Panfili** IRD, France (p. 138) 54

Derivation Of High-Resolution Life History Records From Fish Otoliths: Applications For The Study Of Thermal Preference, Migration, And Natal Origin **William P. Patterson** Department Of Geological Sciences, University Of Saskatchewan, Canada (p. 138) 55

Theme 7 – Stock Assessment And Fisheries Management

Spawning Season Fidelity In Sympatric Populations Of Atlantic Herring (Clupea harengus L.) **Deirdre Brophy** Galway-Mayo Institute Of Technology, Ireland (p. 140) 56

Influence Of Maternal Effects On Mesocosms Reared Cod (Gadus morhua) Inferred By The Otolith Microstructure Analysis **Vivian Buehler** Institute for Marine Sciences, Universität Kiel, Germany (p. 140) 57

Stock Discrimination Of King Mackerel, Scomberomorus cavalla, In U.S. Waters With Otolith Morphology **Todd Clardy** Dauphin Island Sea Lab, University Of South Alabama, USA (p. 140) 58

Validation Of The Application Of Otolith Microstructure For Determination Of Spawning Type In Herring (Clupea harengus). **Lotte Askgaard Worsøe Clausen** Danish Institute For Fisheries Research, Denmark (p. 140) 59

Regional Structure In Yellowfin Tuna Populations Of The South West Pacific Ocean **Naomi Clear** CSIRO Division Of Marine Research, Australia (p. 141) 60

Spatial Variation In Otolith Elemental Fingerprints Of Early Juvenile Halibut In Alaskan Waters **Timothy Loher** International Pacific Halibut Commission, USA (p. 141) 61

Post-Settlement Population Mixing In Gulf Of Mexico Red Snapper, Lutjanus campechanus, Inferred From Otolith Chemistry **William F Patterson** University Of South Alabama, USA (p. 141) 62

Utility Of Transformed Elliptic Of Fourier In The Discrimination Between Populations Of Glass Eels From The Shape Otolith **Ilyesse Rahhou** University Mohamed Premier, Morocco (p. 142) 63

Reducing Variability In Samples For Otolith Chemistry: Detecting Spatial Dynamics Of Fishes In The Absence Of High Environmental Gradients **Jill St John** Department of Fisheries, Western Australia, Australia (p. 142) 64

Does Reader Experience Count? A Case Study Using New Zealand Snapper (Pagrus auratus, Sparidae) **Cameron Walsh** National Institute Of Water And Atmospheric Research Ltd, New Zealand (p. 142) 65

Ten Years Of Routine Annual Exchanges Of Age Reading Comparisons Between Norway And Russia – The Lesson Learned **Natalia Yaragina** Knipovich Polar Research Institute of Marine Fisheries & Oceanography, Russia (p. 142) 66

Theme 8 – Quality Control In Ageing Facilities And Data Processing

Identification Of The First Annual Ring In The Otolith As A Tool To Age Triglalucerna **Paulo Santos** University Of Porto, Portugal (p. 143) 67

Inter-Agency Comparison Of Age Estimates Derived From Spanish Mackerel (Scomberomorus commerson) Otoliths: Implications For Stock Assessment And Data Sharing Arrangements **Amos Mapleston** CRC Reef Research Centre, James Cook University, Australia (p. 143) 68

The Otolin System: Preparing Demersal Fish Otoliths For Age Determination **William James McCurdy** Department Of Agriculture And Rural Development For Northern Ireland, UK (p. 143) 69

TACADAR – Towards Accreditation And Certification Of Age Determination Of Aquatic Resources **Erlend Moksness** Institute Of Marine Research, Norway (p. 143) 70

EFAN (European Fish Ageing Network): A Cooperative Effort To Exchange **Erlend Moksness** Institute Of Marine Research, Norway (p. 144) 71

A Comparison Of The Performance Of Different Types Of Neural Networks For Automatically Estimating Fish Age **Sandy Morison** Marine And Freshwater Systems, Primary Industries Research Victoria, Australia (p. 144) 72

The Fear Of Losing Control; Digital Image Analysis And Semi-Automated Age Estimation **Andrew Michael Muir** Chippewas Of Nawash First Nation, Canada (p. 145) 73

The Influence Of Several Successive Generations Of Otolith Readers On The Interpretation Of Annual Increments **Simon Robertson** Primary Industries Research Victoria, Australia (p. 145) 74

A Practical Handbook For Determining The Age Of Gulf Of Mexico Fishes **Steve Vanderkooy** Gulf States Marine Fisheries Commisssion, USA (p. 145) 75

Theme 9 – Technological Developments

Improving Otolith Scanning Precision And Throughput In A Proton Microprobe **Bernard John Barry** National Isotope Centre, Institute Of Geological And Nuclear Sciences Ltd, New Zealand (p. 146) 76

Automatic Multiple Acquisition Of Otolith Images For Routine Aging **Ronan Fablet** Ifremer/Lasaa, France (p. 146) 77

Can Fish Age And Growth Be Actually Estimated Automatically Using 1d Or 2d Techniques? The Case Of Plaice (Pleuronectes platessa) **Ronan Fablet** Ifremer/LASAA, France (p. 146) 78

Combining The Extraction Of Partial 2D Rings Within Otolith Images And Statistical Growth Modeling For The Bayesian Estimation Of Fish Age And Growth **Ronan Fablet** Ifremer/LASAA, France (p. 147) 79

Toward An Automatic Estimation Of Individual Fish Growth **Ronan Fablet** Ecole Nationale D'ingénieurs De Brest, France (p. 147) 80

High Precision and Automatic Cutting Machine for Mass Production of Otolith Thin Slices **Petter Fossum** Institute of Marine Research, Norway (p. 147) 81

Development Of Optimum Conditions For Electron Microprobe Analysis Of Sr/Ca Ratios In Fish Otoliths **Yoshiyuki Iizuka** Instiute Of Earth Sciences, Academia Sinica, Republic Of China (p. 147) 82

Otolith Morphological Characteristics Of Juvenile Bluefin Tuna Using Image Analysis Techniques **Persefoni Megalofonou** Department Of Biology, University Of Athens, Greece (p. 148) 83

Annulus 1.0: Advanced Software For Fish Calcified Structure Analysis **Andrew Michael Muir** Chippewas Of Nawash First Nation, Canada (p. 148) 84

Comparison Of Techniques Based On Outline Analyses And Geometric Morphometrics For Identifying Tropical Anchovies From The Shape Of Their Otoliths **Dominique Ponton** IRD, New Caledonia (p. 149) 85

Microscale Otolith: A Software Tool For Otolith Microstructure Analysis **Ilya Valuev** Moscow Institute Of Physics And Technology, Russia (p. 149) 86

Thursday 15 July 2004

Theme 3 – Age And Growth Estimation And Validation

Comparative Growth Of Three Larval Fish Species In The Bay Of Biscay: Anchovy (Engraulis encrasicoulus), Mackerel (Scomber scombrus) And Hake (Merluccius merluccius): Ecological Implications **Paula Alvarez** Foundation AZTI, Spain (p. 123) 87

Otolith Microstructure Analysis Reveals Selective Survival Of Young-Of-The-Year (YoY) Sprat, Sprattus sprattus, From The Central Baltic Sea **Hannes Baumann** Institute For Hydrobiology And Fisheries Science, Germany (p. 123) 88

Age And Growth Of The Eastern Freshwater Cod (Maccullochella Ikei) From The Mann-Nymboida Rivers Of NSW, Australia **Gavin Butler** NSW Fisheries And Southern Cross University, Australia (p. 123) 89

The Use Of Back-Calculation For Ageing Sharks: Which Method Is Most Appropriate? **John Carlson** National Marine Fisheries Service/Southeast Fisheries Science Center, USA (p. 123) 90

Geographic Variation Of Early Life History Traits Of Apogon doryssa In The Coastal Waters Of Taiwan **Han Chu** Insitute Of Fisheries Sciences, National Taiwan University, Taiwan (p. 124) 91

Otolith Micro-increment Periodicity of Captive Juvenile (age 0) Sablefish, Anoplopoma fimbria, Experimentally Immersed in Strontium Chloride (SrCl2) **Dean Courtney** Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries, USA (p. 124) 92

Direct Validation Of Daily Increment Deposit On Otoliths Of Juvenile European Hake (Merluccius merluccius) **Helene De Pontual** Ifremer, France (p. 124) 93

Do We Underestimate Growth Of European Hake (Merluccius merluccius)? **Helene De Pontual** Ifremer, France (p. 125) 94

Analysis Of Otolith Microstructure For Estimation Of Influence Of Environmental Conditions On Hatching Date And Growth Rate Of Herring And Cod Larvae **Maria Dolgikh** Russian Federal Research Institute Of Fisheries And Oceanography (VNIRO), Russia (p. 125) 95

Interannual Differences In Growth And Hatch Date Distributions Of Age-0 Walleye Pollock From The Shumagin Islands Region Of The Gulf Of Alaska **Annette Dougherty** NOAA, USA (p. 125) 96

Effect Of Otolith Type And Preparation Technique On Age Estimation Of Larval And Juvenile Spot (Leiostomus xanthurus). **Dariusz Fey** Sea Fisheries Institute, Poland (p. 125) 97

Validation Of Back-Calculation Methods For Laboratory Reared Spot (Leiostomus xanthurus). **Dariusz Fey** Sea Fisheries Institute, Poland (p. 126) 98

Recruitment Processes In Norwegian Spring Spawning Herring **Petter Fossum** Institute Of Marine Research, Norway (p. 126) 99

Larval Herring Otoliths: Coping With Reality **Audrey J. Geffen** Department Of Fisheries And Marine Biology, University Of Bergen, Norway (p. 126) 100

Is Corroborating Ages A Valid Concept For Walleye Pollock (Theragra chalcogramma) Fish Age Determination? **Daniel K. Kimura** Alaska Fisheries Science Center/National Marine Fisheries Service, USA (p. 126) 101

The Direct Validation Of Otoliths For Use In The Age Estimation Of Patagonian Toothfish, Disstostichus eleginoides **Kyne Krusic-Golub** Central Ageing Facility, Marine & Freshwater Systems, Primary Industries Research, Australia (p. 126) 102

An Age-Based Analysis Of Sexual Size Dimorphism In The Coral Reef Surgeonfish Ctenochaetus striatus **Elisabeth Lamantrip** School Of Marine Biology And Aquaculture, James Cook University, Australia (p. 127) 103

Otolith Based Evidence For Sub-Stock Structure In Gulf Of Mexico Red Grouper (Epinephelus morio) **Linda Lombardi-Carlson** National Marine Fisheries Service/SEFSC, USA (p. 127) 104

Integrated Approach To The Biological Basis Of Age Estimation In Commercially Important Fish Species **Beatriz Morales-Nin** Imedea, Spain (p. 127) 105

Growth Of Pomadasys argenteus From New Caledonia (West Pacific) **Eric Morize** IRD, France (p. 128) 106

Age And Growth Of Spotted Goatfish, Pseudupeneus maculatus (Pisces: Mullidae) Off Northeastern Brazil **Eric Morize** Dimar – Departamento De Pesca – UFRPE, Brazil (p. 128) 107

Growth Variability And Evidence Of Growth Dependent Survival Of Larval Whiting (Merlangius merlangus) From The North Sea **Peter Munk** Danish Institute For Fisheries Research, Denmark (p. 128) 108

Otolith Diagnostic Characters Reveal Older Age Range Of Walleye Pollock (Theragra chalcogramma) **Kristen M. Munk** Alaska Department Of Fish And Game, USA (p. 129) 109

Age-Based Demography And Reproductive Ontogeny Of Angelfish (Family Pomacanthidae) **Tebaua Barerei Onorio** School Of Marine Biology, James Cook University, Australia (p. 129) 110

Age And Growth Of The Freshwater Sawfish, Pristis microdon, In The Gulf Of Carpentaria Australia **Stirling Charles Peverell** DPI Northern Fisheries Centre, Australia (p. 129) 111

Growth Of 0-Group Hake (Merluccius merluccius) From The 'Southern Stock' Estimated By Otolith Microstructure Analysis **Carmen Pineiro** Instituto Espanol De Oceanografia, Spain (p. 129) 112

Growth History And Age At Recruitement Of European Glass Eels (Anguilla anguilla) As Revealed By Otolith Microstructure **Ilyesse Rahhou** University Mohamed Premier, Morocco (p. 130) 113

Growth Of Juvenile Fish From Douro Estuary, Portugal, Based In Microincrement Count **Paulo Santos** University Of Porto, Portugal (p. 130) 114

Using Age-Structure Of An Adult Barramundi Population To Investigate Relationships Between Environmental Variables And Survival Of Young Fish **Michelle Sellin** Department Of Primary Industries And Fisheries, Australia (p. 130) 115

Effect Of Thyroid Hormone And Thiourea On Otolith Growth Of Metamorphic Leptocephalus, Megalops cyprinoides **Jen-Chieh Shiao** Institute Of Zoology, Academia Sinica, Republic Of China (p. 130) 116

Age And Growth Of New Zealand Right-Eyed Flatfish (Family Pleuronectidae) **Darren Wayne Stevens** National Institute Of Water And Atmospheric Research (NIWA) New Zealand (p. 131) 117

Translucent Zones Form Annually In Otoliths Of Antarctic Toothfish (Dissostichus mawsoni) **Colin Sutton** National Institute Of Water And Atmospheric Research (NIWA) New Zealand (p. 131) 118

Comparative Growth Between Widely Separated Populations Of Striped Trumpeter (Latris lineata): Assessed Via Otolith Morphometrics, Increment Analysis And Growth Modelling **Graeme Ewing** Tasmanian Aquaculture And Fisheries Institute, Australia (p. 131) 119

Growth Variation Of Juvenile Jack Mackerel (Trachurus japonicus) Off The Pacific Coast Of Western Japan **Shinji Uehara** National Research Institute Of Fisheries Science, Japan (p. 131) 120

Early Life History Traits Of Sillaginids (Sillago spp) In The Northern Taiwan As Indicated From Otolith Daily Growth Increment **Chia-Hui Wang** Institute Of Fisheries Sciences, National Taiwan University, Taiwan (p. 132) 121

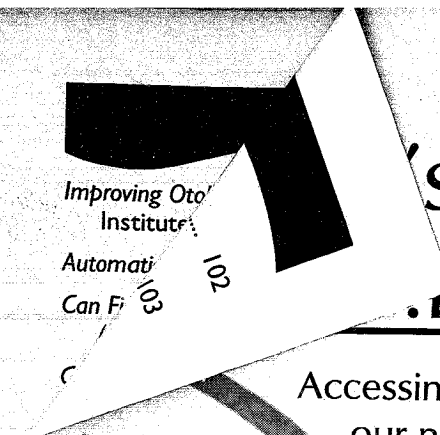
Growth Rates Of Larval And Juvenile Anchovy, Engraulis Encrasicolus, In The Southern Benguela Ecosystem **Margit R Wilhelm** Ministry Of Fisheries And Marine Resources, Nambia (p. 132) 122

Description of a Pacific Halibut Chronology of Bomb Radiocarbon from 1944-1981 and a Validation of Ageing Methods **Stephen Wischniowski** International Pacific Halibut Commission, USA (p. 132) 123

Distinct Annuli Inside the Chondrophores of Horse Clams **Zane Ziyang Zhang** Pacific Biological Station, Department Of Fisheries And Oceans, Canada (p. 132) 124

Theme 6 – Statistics and Modelling

Comparing The Functional Form Of The Radiocarbon Chronometer In Coral To Known-age Marine Fish Reference Curves **Kevin Piner** NOAA Fisheries, USA (p. 139) 125



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With its sparsely populated, 13,000 km coastline, Western Australia has many fisheries based in remote, pristine waters. WA's finfish live in a wide range of habitats strongly influenced by the warm, southward-flowing Leeuwin Current, ranging from coral reefs in tropical waters to limestone beds in cool temperate southern waters. For over 35 years, the Fisheries Research Division has conducted high-quality scientific research to support the sustainable management of WA's $1 billion fishing industry.

Our research institute maintains some of the world's longest-running tropical/temperate fisheries databases, in many cases covering the full history of exploitation. Pioneering research on otolith microchemistry has been used with conventional otolith-based ageing to determine stock status for discrete finfish populations on an annual basis.

Having completed ESD-based assessments of all our major commercial fisheries, our next goal is Integrated Fisheries Management. This will involve setting specific catch shares for commercial, recreational and customary fishers and for biodiversity conservation purposes.

Further information on our fisheries research and management programs is available online at **www.fish.wa.gov.au**. The annual State of the Fisheries Report is available in full at **www.fish.wa.gov.au/sof/index.html**.

Fish for the future

Symposium Social Functions

Welcome Reception *proudly sponsored by James Cook University*
Sunday 11 July 2004
6.30pm – 8.30pm
Venue: Reef HQ

After registering for the Symposium, take the opportunity to mingle with other delegates at the official Welcome Reception to be held at the Great Barrier Reef Aquarium. You will be entertained with a live dive show and guides will be available to take delegates around the aquarium and introduce you to local fish and coral species.

Inclusive *for all full-time delegates*
Additional Tickets: AUD55.00 *per person*

Poster Reception *proudly sponsored by the Department of Education, Science and Training*
Monday 12 July 2004
4.30pm – 6.00pm
Venue: Coral Seas Rooms I & II, Jupiter's Hotel and Casino

Take the opportunity to view the poster displays and network with fellow delegates and sponsors. Light refreshments will be provided.

Inclusive *for all full-time delegates*
Additional Tickets: AUD30.00 *per person*

Symposium Dinner *proudly sponsored by the CRC Reef Research Centre*
Friday 16 July 2004
Pre-Dinner Drinks 7.00pm
Symposium Dinner 7.30pm
Venue: Poolside Gardens, Jupiter's Hotel and Casino

The Symposium dinner promises to be the social highlight of the week. Join us poolside, under the stars for an evening of music, sumptuous food and local wines and great entertainment.

Inclusive *for all full-time delegates*
Additional Tickets: AUD95.00 *per person*

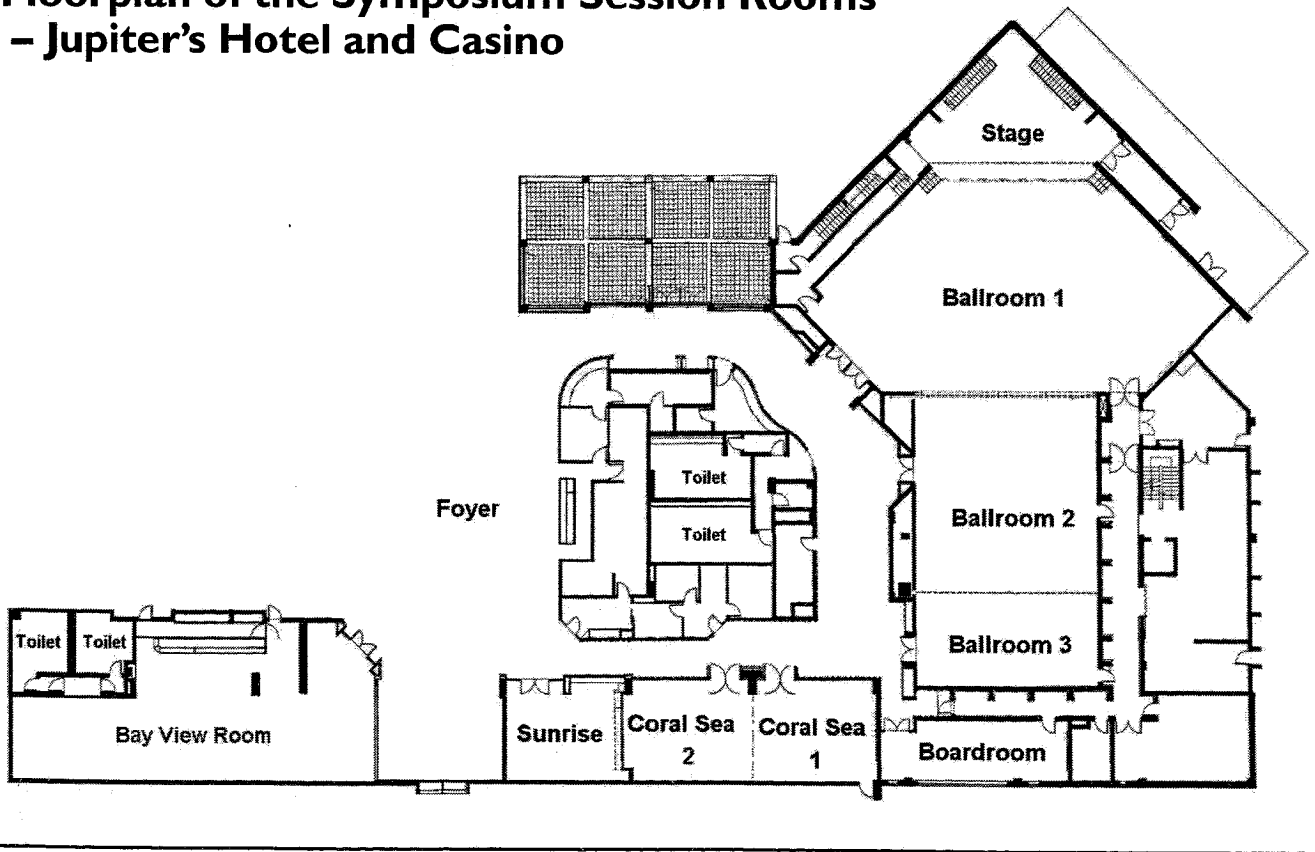
Lunches, Morning and Afternoon Teas

Lunches will be held in the Aqua Restaurant each day. This modern restaurant is located on the lower lobby level of Jupiter's Casino and overlooks the beautiful tropical pool area.

Morning and Afternoon teas will be held in and around the poster viewing area each day.

Inclusive *for all full-time delegates and day delegates on their registered day*
Additional lunch tickets: AUD30.00 *per person*

Floorplan of the Symposium Session Rooms – Jupiter's Hotel and Casino





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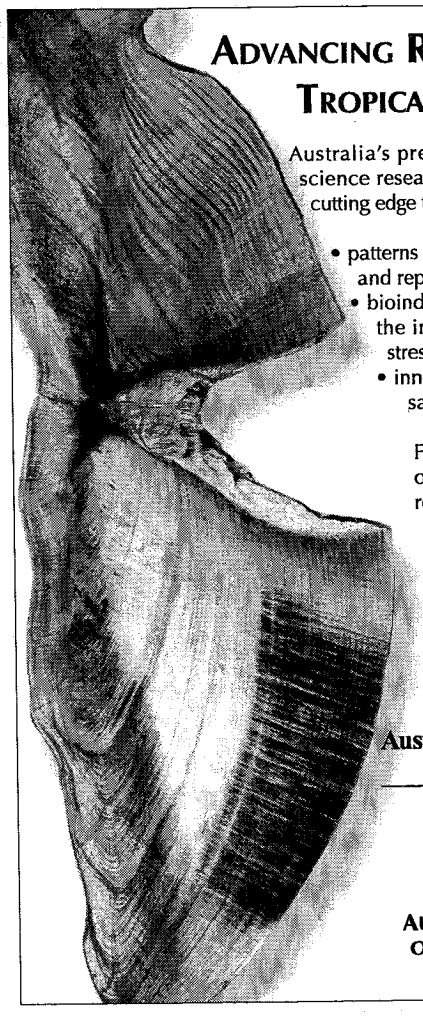

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Wednesday Tours

A variety of additional tours have been identified for delegates and partners to be held on Wednesday 14 July 2004. All tours are in addition to the Symposium Registration.

Outer Barrier Reef

Cost: AUD140.00 per person (includes lunch, morning and afternoon tea)

Departs: 8.30am – Return at 5.20pm. Require to be at Breakwater Ferry Terminal by 8.00am.

Cruise to the Outer Barrier Reef by luxury fast catamaran to spend 5 hours at the spectacular John Brewer Reef. Swim in crystal clear waters of the Great Barrier Reef surrounded by tropical fish and coral. A local marine biologist will answer any questions you may have on coral reef habitats as you enjoy being surrounded by one of the world's greatest natural wonders. The ferry departs from Breakwater Ferry Terminal, an easy stroll from Jupiter's Hotel.

Price Includes:

- Full day cruise to the Great Barrier Reef
- Unlimited snorkelling with equipment supplied
- Morning and afternoon tea
- Tropical buffet lunch
- Glass bottom boat tours with marine biologist
- Diving (certified and introductory) available at extra cost

Billabong Sanctuary Tour – "Breakfast with the Crocodiles"

Cost: AUD45.00 per person (includes buffet breakfast)

Departs: 7.30am – Return at 11.00am. Bus pick up from Jupiter's Hotel, Quest Apartments and Downtown Motel.

Be amazed at the sights and sounds of the wildlife during the morning hours. Nestled next to the Billabong you will be treated to a breakfast that will have you amazed "fresh from the BBQ". After a delicious breakfast our rangers will escort your group personally through the Sanctuary with informative talks and hands on experience with koalas, wombats, crocodiles and pythons.

Price Includes:

- Entry to Billabong Sanctuary and Buffet style Breakfast
- Champagne & Orange on arrival is optional
- Personal Tour of the Sanctuary and interaction with koalas, wombats, crocodiles and pythons
- Personalised Crocodile Show
- Bus transfers to and from Symposium Accommodation Venues

Charters Towers

Cost: AUD150.00 per person (includes morning tea and lunch)

Departs: 8.30am – Return at 5.00pm. Bus pick up from Jupiter's Hotel, Quest Apartments and Downtown Motel.

At Christmas time 1871 the aboriginal lad Jupiter Mosman picked up a shining nugget that sparked off the greatest gold rush ever seen in the north. Visit the historic gold rush city of Charters Towers once dubbed "The World" due to its cosmopolitan nature. You'll see the site where gold was discovered, the Venus Battery gold crushing plant, the old Stock Exchange, Towers Hill and the Zara Clark Museum. The city boasts a wealth of historic buildings, fascinating stories and characters.

Price Includes:

- Bus transfers to and from Symposium Accommodation Venues
- Entry to all historical sites
- Morning Tea & Lunch
- All sightseeing

Magnetic Island

Cost: AUD60.00 per person (includes morning tea)

Departs: 8.10am – Return time is optional (subject to when you want to return). Require to be at Breakwater Ferry Terminal by 7.50am.

Depart Townsville and relax while you travel 25 minutes to Magnetic Island by fast catamaran. The catamaran departs from the Breakwater Ferry Terminal which is within an easy stroll of Jupiter's Hotel. Be welcomed by a local and unwind while they show you around the island. Enjoy morning tea on Magnetic Island at one of scrumptious restaurants, and then continue your tour of the island. Swim, walk and learn the history of Magnetic Island.

Price Includes:

- Ferry transfer from Breakwater Ferry Terminal to Magnetic Island and return
- A fascinating three hour guided tour of the island
- Morning tea
- Unlimited bus pass for the rest of the day

Hinchinbrook Island

Cost: AUD150.00 per person (includes light lunch)

Departs: 6.30am – Return at 7.30pm. Bus pick up from Jupiter's Hotel, Quest Apartments and Downtown Motel.

Travel by coach to Cardwell, where you will cruise over the sea to Cape Richards. Cruise through Missionary Bay to the mysterious maze of the Mangrove Everglade Forest. Disembarking at the boardwalk, which provides access via a 300-metre stroll to magnificent Ramsay Bay, noted for its ancient Aboriginal Midden and eight million-year-old fossilised crabs. Whilst on this beautiful island you have the opportunity to go on a self-guided walk or alternatively, just laze on the beach. A light tropical lunch is also provided.

Price Includes:

- Bus Transfers to and from Symposium Accommodation Venues
- All cruising
- A light tropical lunch

Rainforest Tour

Cost: AUD145.00 per person (includes morning tea and lunch)

Departs: 8.30am – Return at 5.30pm. Bus pick up from Jupiter's Hotel, Quest Apartments and Downtown Motel.

Fully interpreted all day tour of the World Heritage Listed Rainforest of the Paluma Range National Park and adjacent eucalypt woodland. Experience the cool crisp mountain air, learn about ancient trees and plants, view birds and animals in diverse and dramatic landscapes and swim in a cascading waterfall amidst lush tropical rainforest.

Price Includes:

- Bus Transfers to and from Symposium Accommodation Venues
- Full day guided tour
- Morning Tea & Lunch

Section Three

Oral Abstracts

Monday 12 July 2004



Keynote Address – Opening Session
Room: Ballroom 1
Time: 9.10am – 10.00am

Otolith Research and Application in the 21st Century

Campana, S
Marine Fish Division, Bedford Institute of Oceanography, Nova Scotia, Canada

Otolith-derived ages serve as the basis for most analyses of fish populations around the world. While the prevalence of otolith age determinations continues to increase worldwide, the rigor underlying the ageing process is improving even more quickly as the age validation and quality control advances of the past decade are translated into routine practice. In addition, non-ageing otolith applications continue to increase in popularity, in part because of their independence from traditional approaches. Taking a bird's eye view, I offer a summary of recent developments in the field of otolith research and application since the time of the last Otolith Symposium in 1998. A crystal ball look at the future suggests that substantially more progress is to be expected.

Keynote Address, Theme 1 - Structure and Function
Room: Ballroom 1
Time: 10.30am – 11.00am

Sciaenid Fishes: A "Model" System for Studies of Fish Otolith Organ Structure and Function

Popper, A
Department of Biology, University of Maryland, College Park, USA

The three inner ear otolith organs provide fishes with information used in two sensory systems – the vestibular senses (balance and orientation relative to gravity) and hearing. Comparative studies, using a wide range of species, suggest that there is a strong correlation between hearing capabilities of fishes and the structure of the otolith organs, and their physical relationship to the swim bladder. This relationship is perhaps best seen in the sciaenid fishes where there is extraordinary inter-specific diversity in the proximity of the swim bladder to the ear. Correlated with this diversity are substantial inter-specific differences in the size and shape of the saccular otolith, the size, shape, and ultrastructure of the saccular sensory epithelium, and in the range of sounds detected and the auditory sensitivity of hearing. Sciaenids in which the swim bladder contacts the ear, such as weakfish (Cynoscion regalis), hears a wider range of sounds (e.g., 100 to ~~2,000 Hz)~~ than do species in which there is considerable distance between the organs (e.g., spot, Leiostomus xanthurus, hearing range 100 to 700 Hz). Species where the swim bladder comes close to the inner ear, but does not contact it, such as the Atlantic croaker (Micropogonias undulatus), have intermediate hearing range (100 to 1,000 Hz). These and other results from diverse Sciaenid species demonstrate that this group can be used for a wide range of studies that provide new and important insights into the hearing capabilities of fishes.

Keynote Address, Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 11.00am – 11.30am

Age Determination and Validation: Structures, Methods, Analyses and Application

Cailliet, G*, Andrews, A, Kerr Ferrey, L
Moss Landing Marine Laboratories, California State University, Moss Landing, USA

Validated age estimates are important for age-structured models to produce effective fishery management policies for exploited organisms, including invertebrates and fishes. This review will highlight the structures utilized to estimate ages of these organisms, including recent novel structures used in ageing such as neural arches and caudal thorns in elasmobranch fishes. Included will be the methods and analytical approaches used to assign ages to these structures. Of special significance for correct interpretation of growth, especially for deep-dwelling, long-lived organisms, are approaches that verify (assess precision of) age estimates (i.e. MIA and MIR: Marginal Increment Analyses and Ratios) and those that validate (ascertain the temporal periodicity of) these age estimates and growth parameters. We will focus specifically on three methods used to validate age, growth, and longevity estimates: tag-recapture analysis, the disequilibria of lead-210 and radium-226, and the time-specific, bomb-produced radiocarbon marker. We will summarize results from published studies on elasmobranchs, bony fishes, and corals, and evaluate the veracity of the validation techniques used. Finally, we will discuss the uses of the resulting growth and longevity parameters for producing reasonable mortality coefficients, demographic parameters, and age-structured management policies for assessing the population dynamics and recovery probabilities of exploited populations.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 11.30am – 11.45am

Age Validation of the Canary Rockfish (Sebastes pinniger) from the Northeastern Pacific Ocean Using 210Pb:226Ra Disequilibria and Bomb 14C

Andrews, A[1]*, Kerr-Ferrey, L[1], Cailliet, G[1], Lundstrom, C[2], Brown, T[3], Coale, K[1]
1. Moss Landing Marine Laboratories, California State University, Moss Landing, USA
2. Department of Geology, University of Illinois, Urbana, USA
3. Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratories, USA

The canary rockfish (Sebastes pinniger) has been an important part of the recreational and commercial rockfish fisheries from southeast Alaska to southern California, but stocks have declined considerably over the past few decades. This rockfish is thought to be long-lived with an estimated longevity approaching 84 years based upon detailed analysis of growth zones in otolith sections. For the purpose of monitoring stocks, age composition is routinely estimated by counting growth zones in these otoliths using the break-and-burn technique; however, such age estimates and high longevities for this species have remained unvalidated. Typical age validation techniques have limited application for the canary rockfish because they are deep dwelling and appear to be long-lived fish. In this study, we have taken the unaged otolith of the pair from aged fish and applied one of two radiometric age validation techniques: 1) the ratio of 210Pb: 226Ra and 2) the bomb-produced radiocarbon marker. By removing core material from otoliths and either analyzing it for 210Pb:226Ra or bomb 14C we have validated the age of the canary rockfish to at least 45 years old with strong support for the age estimation procedures used to determine the longevity exceeding 80 years. These findings present a useful corroboration of the two age validation techniques. This work was performed, in part, under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 11.45am – 12.00pm

Bomb Radiocarbon and Maximum Ages of Bluenose and Rubyfish: A New Approach

Horn, P[1], Neil, H[2], Paul, L[2], Sparks, R[3]*

1. *National Institute of Water and Atmospheric Research Ltd (NIWA), Nelson, New Zealand*
2. *National Institute of Water and Atmospheric Research Ltd (NIWA), Wellington, New Zealand*
3. *Rafter Radiocarbon Laboratory, Institute of Geological and Nuclear Sciences (GNS), Lower Hutt, New Zealand*

Bluenose (Hyperoglyphe antarctica) and rubyfish (Plagiogeneion rubiginosum) have otoliths with complex growth zones. From zone counts, maximum age estimates for bluenose have ranged from 15 to 50 years. Rubyfish have a maximum age from zone counts of 80+ years. The bomb chronometer procedure of radiocarbon (14C) dating was used to determine whether these ages were realistic. The 14C level in carbonate samples drilled from otolith cores confirmed that the selected fish (5 of each species) were born pre-bomb. Samples were then drilled in a sequence across otolith cross-sections to locate the position of the 1950–60 rise in 14C. This position defined a known time interval that was compared with the number of growth zones, on the other otolith of each pair, allocated to this interval by count. We consider that this procedure has advantages over the core-only method. Consideration was given to the time-lag issue – the time required for 14C to move from surface waters down to the depth (500–1000 m) at which the adults of both these species reside.

Theme 7: Stock Assessment and Fisheries Management
Room: Ballroom 1
Time: 12.00noon – 12.15pm

Age Validation and Tests of Assumptions Using Bomb Radiocarbon from Canary Rockfish Otolith Cores

Hamel, O

Northwest Fisheries Science Center, NOAA, Seattle, USA

The population of canary rockfish off the West Coast of the United States has fallen to historically low levels in recent years. Because it is part of a multi-species fishery, the low stock size is constraining to the management of not only canary rockfish but also other the shelf groundfish harvested in the same fishery. Changes in the age composition of the population through time have helped shape the view of canary population dynamics. This study uses measured radiocarbon levels in canary rockfish otolith core to validate the annulus counts determined by a break and burn ageing methodology. A sampling design that controlled for ageing error allowed the testing of the assumption of parallelism of the standardized rates of bomb radiocarbon increase of the validation and reference species. A second sampling design that related linearly the estimated age and birth year allowed for testing of the assumption of the consistency of the ageing errors. This study determined that neither assumption could be proven invalid. Since neither assumption is rejected the combined data is used to determine the accuracy and bias of the ageing method.

Theme I - Structure and Function
Room: Ballrooms 2 & 3
Time: 11.30am – 11.45am

Formation of Daily Growth Increments in Otolith of Pacific Tarpon (Megalops cyprinoides) During Metamorphosing

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1. Institute of Zoology, National Taiwan University, Taipei, Taiwan
2. Institute of Fisheries Sciences, National Taiwan University, Taipei, Taiwan

To understand if the deposition rate of the growth increments in otolith of Pacific tarpon (Megalops cyprinoides) will be influenced by metamorphosis, the tarpon leptocephali were collected at estuarine arrival. Their total length (TL) was 27.52±1.16 mm (mean±SD) and mean age was 26.4±3.4d, with most of them were in the stage of metamorphic interval (Phase II). After one day acclimation, the leptocephalus were marked with tetracycline hydrochloride (TC) and then they were reared for 18 days at 25°C under the same photoperiod in four different groups with the salinities at 10 and 34.5ppt, and the feeding condition of feed (+) and starvation (–) using a two-way ANOVA experimental designs. Mean daily growth increments from TC marking to otolith edge of the tarpon in each groups were not significantly different from 18d ($P>0.05$). This indicates that formation of daily growth increments in otolith of Pacific tarpon during metamorphosing was not affected by metamorphosis itself neither by salinity nor starvation. Otolith increment width in the Phase II from 2–3d before TC marking and approximately 10d after was significantly wider than that in the pre- metamorphic leptocephali (Phase I)($P<0.01$), but the increment width became narrow after metamorphosis. This might imply that the otolith growth became faster during metamorphosis even if the fish growth is negative and the duration of metamorphosis lasted approximately 2 weeks for the fed leptocephali.

Ontogenia
→ metamorphis influenza
actua sobre el crecimiento,
→ crecimiento?

Theme I - Structure and Function
Room: Ballrooms 2 & 3
Time: 11.45am – 12.00pm

The Nature of Secondary Growth Structures in Temperate Marine Fishes

Wright, P*, Neat, F, Gibb, I, Gibb, F

FRS Marine Laboratory, Aberdeenshire, United Kingdom

In many species the estimation of annual increments is made difficult by the presence of non-periodic 'secondary' zones, such as false rings. In this study we have investigated microstructural characteristics of secondary growth zones in wild marine fish and attempted to recreate such structures through the use environmental manipulation experiments. Changes in feeding and temperature both at a daily and seasonal periodicity were shown to have marked influences on otolith opacity and macroscopic appearance. Comparison between the macrostructures and microstructures of sagittae indicated that the commonly observed false ring can be distinguished from true translucent zones at the microscopic level by differences in mean and rate of change in increment width. Translucent structures, similar to false rings, were induced by sudden changes in food intake during warm summer temperatures. The implications of these findings to routine interpretation of age in temperate marine species will be discussed.

~~opaque~~ - estrés.
translucent → Mecanismo overall
respuesta a ↓ temperatura

Theme 1 - Structure and Function
Room: Ballrooms 2 & 3
Time: 12.00pm – 12.15pm

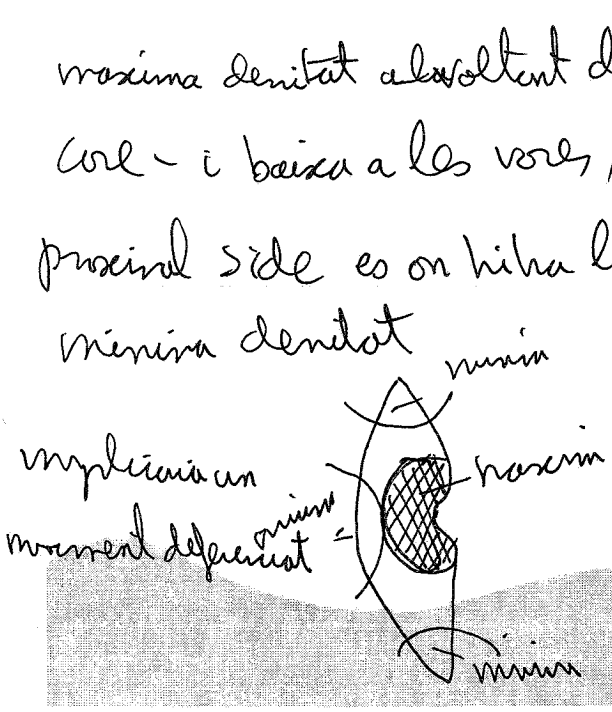
Evidence of Differences in Chemical Composition and Otolith Density between Opaque and Translucent Bands in Cod (Gadus morhua) Otoliths

Tomás, J[1]*, Perry, M J[2]

1. Institut Mediterrani d'Estudis Avançats, CSIC-UIB, Esporles, Balearic Islands, Spain

2. Avon Orthopaedic Centre, Southmead Hospital, Bristol, United Kingdom

Otoliths of cod (Gadus morhua) display an alternation of wide opaque and translucent bands which are used for age estimation. Wavelength Dispersive Spectrometry (WDS) analyses of Sr, Na and Ca across these bands have shown that they are characterised by different chemical composition. Translucent bands and checks are rich in Sr whereas Na concentrates preferably in opaque bands. Depleted at the core, Sr peaks at its maximum in the first translucent band from the nucleus and decreases towards the edge always peaking with translucent bands. Na concentrations do not show great variations across bands. Analyses of the relative mineral density of opaque and translucent bands were carried out using high spatial resolution Dual-Energy X-Ray Absorptiometry (DEXA). The pattern of variation of otolith density across bands showed a close resemblance with that of Sr, clearly peaking at the first translucent band and decreasing at the core. These results show that the internal structure of the otolith is not homogenous in density. Moreover, results suggest that translucent bands are denser than opaque bands. Thus, otolith structure also influences the otolith chemical composition. The implications of these results are discussed in regard to otolith growth, otolith composition and the understanding of the physico-chemical differences existing between opaque and translucent bands.



Keynote Address, Theme 4 – Age Estimation in Deep Sea and Tropical Environments
Room: Ballroom 1
Time: 1.30pm – 2.00pm

Seasonality in Deep-Sea and Tropics Revisited: What Can Otoliths Tell?

Morales-Nin, B

IMEDEA , Illes Balears, Spain

The generally accepted idea that fish otoliths from deep-sea and tropical environments do not present seasonal growth increments, due to the absence of seasonality, is re-evaluated. The number of studies showing apparent or validated seasonal marks has recently increased for these environments. The supposedly aseasonal nature of both ecosystems is questioned and examples are included. The main seasonal fluctuation in deep-seas is due to the transfer of organic material from the productive upper-areas to the deep bottom. The evidence of seasonal patterns of growth is relevant, although the validation of seasonal structures is limited due to the difficulties inherent to deep-water studies. Tropical areas present an extremely high diversity of water environments, ranging from fresh to hyperhaline waters, and from equatorial to dry regions. In fact very few of these environments are aseasonal, and almost all areas present strong hydrological seasons, mainly annual but sometimes biannual. Temperature variations can also interact as a supplementary effect. These climatic fluctuations have undoubtedly an effect on the otolith growth, leading then to a succession of different incremental zones. Examples of species living in very different environments, from continental to marine waters, are given here to support these observations. New techniques for examining otoliths can also help in the interpretation of seasonal marks under deep-sea and tropics (e.g. staining, image processing), whereas the possible difficulty for interpreting these marks is discussed. The lack of previous knowledge on this impact of seasonality is probably due to the previous low exploitation or economic interest of fish from both ecosystems, and consequently the absence of age-based assessments which require important investments. This trend has now changed possibly due to the increased exploitation of the resources, and to the greater involvement of the international and national fishery management bodies.

Theme 4 – Age Estimation in Deep Sea and Tropical Environments
Room: Ballroom 1
Time: 2.00pm – 2.15pm

An Age-based Demographic Analysis of a Coral Reef Fish Across the Indo-Pacific Ocean

Lamantrip, E[1,2]*, Choat, H[1], Robertson, R[3], Wilson, D[4]

1. *School of Marine Biology and Aquaculture, James Cook University, Townsville, Australia*
2. *CRC Reef Research Centre, James Cook University, Townsville, Australia*
3. *Smithsonian Tropical Research Institute, Balboa, Panama*
4. *Department of Marine and Wildlife Resources, Pago Pago, American Samoa*

The effects of local adaptation and growth plasticity on demography and associated life history remain largely unresolved for many fish. Previous research has largely focused on latitudinal relationships between temperature and growth. This study examines the demography of a widely distributed species Ctenochaetus striatus (Acanthuridae) over significant latitudinal and geographical scales. Over 1000 individuals were collected on a longitudinal scale from the Seychelles in the Indian Ocean to American Samoa in the western Pacific area, along a latitudinal gradient from Papua New Guinea to the southern Great Barrier Reef, and across-shelf in inner and outer reef habitats. Age was estimated from transversely sectioned sagittal otoliths, and the relationship between size and age was analyzed for three critical parameters: mean adult body size, longevity, and growth rate. The demography of C. striatus populations differed between ocean basins: individuals were larger and shorter lived in the Indian Ocean than in the Western Pacific. This suggests that the evolutionary history of the species plays a central role in determining intrinsic demographic characteristics of a given population. Populations of both oceans responded in a similar fashion to habitat: individuals in more sheltered inner reefs grew larger than outer-shelf reef individuals. Results also confirmed the correlation between adult body size, age and latitude found in many species, individuals growing larger and living longer in higher latitudes. This study shows that life-history and demography of fish can vary considerably across scales, and are driven by evolutionary history as well as regional and local environmental conditions.

Theme 4 – Age Estimation in Deep Sea and Tropical Environments
Room: Ballroom 1
Time: 2.15pm – 2.30pm

Age Estimation in Deep-Water Macrourid Fishes

Swan, S*, Gordon, J

Scottish Association for Marine Science, Oban, Scotland

The increased targeting of some deep-water fish species is leading to concerns about their sustainability, because they are generally perceived to be long-lived and slow-growing. There is also a growing awareness of the impact of fishing, especially trawling, on non-target species. It is unlikely that any discards will survive and there will also be a high mortality of escapees. These removals are likely to have a significant impact on the deep-water ecosystem. The family Macrouridae (grenadiers) are one of the most diverse and abundant families of deep-water fishes, with a world-wide distribution from the upper continental slope to abyssal depths. The otoliths of macrourid fishes exhibit growth zones, although their complexity appears to be species dependent. However, it is difficult to validate the annual nature of these zones because most traditional validation methods used for shallow-water species are not applicable to the deep-water fishes. Some validation of juvenile stages has been possible and in this poster we build on this to present some age estimates for six species of macrourid: Coryphaenoides armatus, C. guentheri, C.mediterraneus, C. rupestris, Caelorinchus labiatus and Trachyrincus murrayi. Although age estimation in deep-water fishes is not without controversy, we believe that it is important to have such estimates in order to effectively apply ecosystem-based management to deep-water fisheries.

Theme 4 – Age Estimation in Deep Sea and Tropical Environments
Room: Ballroom 1
Time: 2.30pm – 2.45pm

In Situ Tagging of Deepsea Fish

de Pontual, H[1]*, Troadec, H[1], Lorance, P[2], Latrouite, D[2]

1. IFREMER, Laboratoire de Sclérochronologie des Animaux Aquatiques, Brest, France
2. IFREMER, Laboratoire de Ressources Halieutiques, Brest, France

Age estimation of deepwater fish often leads to controversial results because seasonal periodicity of the macrostructure deposition is not easily validated. Ageing a species such as orange roughy (Hoplostethus atlanticus) is complex and different methods based on the interpretation of either macrostructures or microstructures provide large discrepancies in age estimates and resultant biological parameters. Indirect validation studies using refined radiometric ageing have supported the hypothesis of a slow growing and long-lived species. However, to date there have been no direct validation studies reported on. We developed an approach to investigate whether or not otolith microstructure are daily deposited. Previous trials using traps had been unsuccessful. During the OBSERVHAL 98 research cruise we undertook a pilot study using Nautile, a manned submersible enabling complex operations to be carried out. We will present a video showing this experiment. After a brief overview of the marine fauna living in this habitat (Meriadzec Terrace, off the French coast of Brittany), we present the operating sequence: fish pursuit, capture, anaesthesia, oxytetracycline tagging and transfer toward a cage while maintaining the fish at the normal habitat depth (1200 m). At the end of the experiment, four marked fish were held in two cages equipped with an acoustic system for ballast release. Each cage held one orange roughy and one deepsea scorpionfish (Trachyscorpia cristulata echinata). Only one cage could be retrieved 30 days later. Post mortems indicated that the death of each fish was recent. No tetracycline mark could be observed on the otoliths of either specimen.

Theme 4 – Age Estimation in Deep Sea and Tropical Environments
Room: Ballroom 1
Time: 2.45pm – 3.00pm

Regional Patterns in the Age and Growth of a Suite of Epinepheline Serranid Species Caught in the Reef Line Fishery of the Great Barrier Reef

Mapleston, A[1]*, Pears, R[1], Wiebkin, A[1], Mapstone, B[1,2], Begg, G[1], Davies, C[3]

1. CRC Reef Research Centre, James Cook University, Townsville, Australia
2. Antarctic Climate and Ecosystems CRC, Hobart, Australia
3. CSIRO Antarctic Division, Hobart, Australia

The catch taken in reef line fisheries is often characterised by a diverse number of species groups with very little information known about many of the species. Within this diversity, Epinephelines, often referred to as groupers or cods, are the basis of many important fisheries throughout the tropical and subtropical regions of the world. Providing accurate biological parameters for the purpose of assessment and management of these fishes is of key concern to fisheries managers. This study focuses on nine Epinepheline Serranid species which are taken as part of the Great Barrier Reef line fishery by commercial, recreational and charter boat fishers. This suite of species represents a broad collection of body sizes and 4 genera. Age estimates indicate that many of the species are long lived and slow growing with maximum ages ranging from 20 to 40 years. Determining the degree of variation in age and growth and the scale at which differences occur has been explored in this study. Samples were collected annually from 1995 to 2002 from 4 regions spanning 7 degrees of latitude along the Great Barrier Reef. Age estimates derived from sectioned otoliths were used to compare age-based characteristics including growth, maturity, mortality, longevity and recruitment to the fishery. When determining biological parameters for these species, age data is very important given that many species approach maximum size early in life, resulting in a poor length at age relationship. Determining valid life history parameters and regional patterns in age and growth for these species can aid in improved management of complex multi-species fisheries.

Theme 1 – Structure and Function
Room: Ballrooms 2 & 3
Time: 2.00pm – 2.15pm

Diel Changes in Endolymph Saturation State and Saccular mRNA Expressions of Otolith Matrix-proteins

Takagi, Y[1]*, Tohse, H[2], Murayama, E[2], Nagasawa, H[2]

1. Graduate School of Fisheries Sciences, Hokkaido University, Hakodate, Japan
2. The University of Tokyo, Tokyo, Japan

The teleost fish otolith consists of calcium carbonate (aragonite) polycrystals and organic matrices. Otolith growth should, therefore, be regulated by both aragonite crystallization rate and matrix production rate. Theoretically, aragonite crystallization rate of the otolith is proportional to an aragonite saturation state (Sa) of the endolymph. We developed techniques to simultaneously quantify the endolymph Sa and mRNA expressions of two major otolith matrix-proteins, OMP-1 and otolin-1, from an individual rainbow trout, and studied their diel variations. Endolymph was collected into grass capillaries from left and right sacculi dissected from the individual fish. The Ca2+ level, CO2 partial pressure (pCO2) and pH were simultaneously measured and the Sa was calculated. After endolymph sampling, total RNA was isolated from the individual sacculus and was treated with DNase I. cDNAs synthesized from 30 ng of total RNA was applied for a real-time PCR to quantify OMP-1 and otolin-1 mRNA expression levels. The endolymph pH had significant diel variations with high values in night period. The pCO2 levels also showed daily changes, but high levels were observed in day period. The Ca2+ levels did not have meaningful diel variations. The Sa tended to show a moderate peak in night period. Expression of otolin-1 mRNA had apparent diel variations with high levels at night, but OMP-1 mRNA expression did not changed. These data strongly suggest that both aragonite crystallization rate and matrix production rate change daily in the rainbow trout sacculus. Such diel variations may relate to microincriment formation in the otolith.

Theme 1 – Structure and Function
Room: Ballrooms 2 & 3
Time: 2.15pm – 2.30pm

Molecular Genetics of Otolith Formation

Kollmar, R

University of Illinois, Urbana, USA

Otoliths of ray-finned fish, like the homologous otoconia of tetrapods, are acellular accretions of protein and more than 95% calcium carbonate that often display strikingly elaborate shapes. They convey linear accelerations to sensory hair cells in the utricle, saccule, and lagena and are, therefore, essential components of the vestibular apparatus. The growth of otoliths precisely matches their underlying sensory maculae; however, we know very little about the mechanisms that regulate this process. In other biominerals it is known that the constituent proteins play critical roles: One class of proteins, the large and insoluble framework proteins, form a matrix for the biomineral to grow in; their local secretion determines the site of morphogenesis. A second class, the highly charged control proteins, interact with the ions and promote or inhibit nucleation or the growth of specific crystallographic faces, thus determining the biomineral's shape. Unfortunately, the identities of most of the proteins in otoliths and otoconia are unknown. We have begun to test this simple model by taking advantage of the unique combination of experimental approaches possible with the zebrafish, Danio rerio. First, we are establishing a standard atlas of otolith formation in the zebrafish. Second, we are identifying its otolith proteins by sequencing peptides and mining its genome assembly. We will then be able to manipulate the proteins' expression in the zebrafish in vivo and thus examine their function in otolith formation.

Otolin 1 Murayama et al 02
otolith matrix protein · 1
Murayama et al 00
Starmaker
Soellner et al. 03
Otoprotein. . . .
OMP-1
– orthologous otolith –
– null similar però
en diferencies interspecifiques

Physiology 1

Theme 1 – Structure and Function
Room: Ballrooms 2 & 3
Time: 2.30pm – 2.45pm

Mechanism of Otolith Formation in Zebrafish (Danio rerio): Immunocytochemical Evidence of Ion Transporters in Sacculus Epithelium Cells

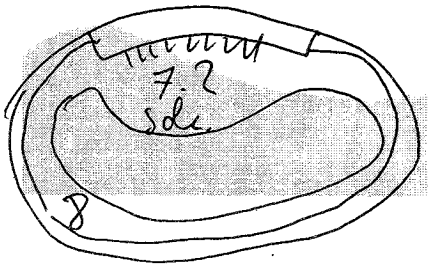
Jen-Chieh, S[1]*, Pung-Pung, H[1,2]

1. The Ichthyological Society of Taiwan, Taipei, Republic of China
2. Fisheries Society of Taiwan, Taipei, Republic of China

Although at least five types of sacculus cells were identified, their functions on otolith deposition were still unclear. The existence of carbonic anhydrase and ion transporters associated with acid-base regulation were validated in the specific sacculus cells of zebrafish Danio rerio by immunocytochemical staining. Ionocytes and transitional cells show prominent immno-staining of carbonic anhydrase in the cytoplasm. These two cells exhibit interlacing and irregular arrangement and form a ring around the sensory macula. The ionocytes also show prominent immuno-reactivity of Na+-K+-ATPase in the tubular system of the cytoplasm as well as the basolateral membrane. Furthermore, the strongest immuno-reactivity for Na+/H+ exchanger was found in the basolateral membrane of ionocytes and less intense staining in the cytoplasm. These results suggest that proton may be secreted by Na+/H+ exchanger driven by Na+-K+-ATPase in the ionocytes and the ionocytes are also probably responsible for the transepithelial transport of bicarbonate ion across the sacculus membrane. On the other hand, H+-ATPase was localized in the stereocilia and the apical membrane of the hair cells, indicating the possibility of proton secretion into endolymph by the hair cells and creates a pH gradient. The lowest pH value near the hair cells may retard the CaCO3 deposition and forms the sulcus in the proximal surface of otoliths.

interessa hi ha un proces per mantenir l'equilibri entre otolit i les cel·lules regulat per H+-ATPasa (el sole seria produit per aquest proces) a la resta de la cel·lula gelatinosa hi ha cel. dimmersos (otocits) ↳ pH=8

pH 7.2



Theme 1 – Structure and Function
Room: Ballrooms 2 & 3
Time: 2.45pm – 3.00pm

Genetic and Environmental Effects on Otolith Formation in Pink Salmon from Auke Creek, Alaska

Oxman, D[1]* and Gharrett, A[2]

1. Alaska Department of Fish and Game, Mark Tag and Age Laboratory, Juneau, USA
2. Juneau Center, School of Fisheries and Ocean Sciences, University of Alaska Juneau, USA

Because variation in otolith structure is the result of fluctuating metabolic processes which are influenced by temperature and heredity, some degree of genetic control over otolith development is expected. Little, however, is known about how much of this observed variation can be attributed to inheritance. To examine the relative contribution of inheritance and temperature on otolith morphology, control and F2 hybrid pink salmon from Auke Creek, Juneau, Alaska were crossed within groups using a nested half-sib 2X2! design. Hybrid individuals were created by crossing Auke Creek females with males from Pillar Creek, Kodiak Island, Alaska. Pillar Creek is located approximately 1,000 miles west of Auke Creek, thus mixing is essentially non-existent, and the spatial separation has resulted in genetically distinct populations. Consequently, comparisons between these groups enable us to assess the effects of outbreeding on otolith development. Families were incubated separately under three temperature regimes: ambient Auke Creek stream temperatures, chilled water, and heated water. Temperatures in the artificial regimes were changed daily to simulate natural conditions. After yolk absorption, otoliths were removed from 10 randomly chosen individuals within each family and rearing environment. Those otolith characteristics used to discriminate among stocks and assess life history traits (shape, ring number, and band-width) are currently being measured using Optimas image analysis software. Factorial ANOVAs and maximum likelihood estimators will be used to partition variation observed in otolith morphology among rearing environments, crosses, families, and parents, calculate genetic parameters, and estimate the proportional impact inheritance and environment have on otolith development.

Atenció! aprenent.

Vaterita no està estudiada sedimentar, sino en les temperatures baixes d'Alaska.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 3.30pm – 3.45pm

Use of Otolith Weight in the Determination of Stock Size

Stephenson, P*, Jackson, G
Western Australia Marine Research Institute, North Beach, Australia

The pink snapper in Shark Bay consist of four separate stocks. The oceanic stock, outside the bay, targeted by commercial fishers, and three inner bay stocks in Denham Sound, Freycinet Inlet, and the Eastern Gulf. The Eastern Gulf stock was severly depleted in the late 1990's resulting in its closure to pink snapper fishing from 1998 to 2002. Recent assessments of the Denham Sound and Freycinet Inlet stocks in 2002 found them to over-exploited. In 2003 the Eastern Gulf was opened with a pink snapper TAC of 15 tonnes per year and catch limits of 10 tonnes and 5 tonnes set for Denham Sound and Freycinet Inlet. The collection of fish lengths and otoliths has occurred in the inner gulf fisheries from 1997 to 2003 during boat ramp surveys of recreational fishers and research surveys. Although there are limited resources available to measure fish and collect otoliths, it is becoming increasing difficult to find resources for aging the fish from sectioned otoliths. With catch limits set in the inner gulf fisheries, it is necessary for the catches in these fisheries to be closely monitored and a structured programme developed for determination of age composition, including the number of otoliths to be collected and number to be aged. The changes in the estimate of stock size from an age structured model and changes in the risk analysis were determined for different numbers of otoliths collected and weighed and also for different numbers sectioned and aged.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 3.45pm – 4.00pm

Indirect Age Estimation of Butterfish (Peprilus triacanthus) Based on Otolith Weights

Sutherland, S*, Monroe, N, O'Neill, E, Burnett, J
Northeast Fisheries Science Center, NOAA Fisheries, Woods Hole, USA

A challenge currently confronting many production-aging labs is how to meet increased demand for age data while restricted by fixed or diminishing staff and resources. Technological advances offer a partial solution, but the reality of limited age-reader hours often necessitates other approaches. In this study, we investigated the feasibility of predicting ages of butterfish (Peprilus triacanthus) from otolith weights. The goal was to develop a method that provides acceptable age estimates for stock assessment modelling, yet can be done in less time by a less highly-trained technician than traditional age determinations. Butterfish are a short-lived species, attaining a maximum age of six years and a length of about 25 cm. The Northeast Fisheries Science Center has aged butterfish using whole otoliths for over 25 years. We developed predictive relationships between otolith weight and fish age, after accounting for possible left/right otolith differences, a priori growth differences between inshore and offshore groups of fish, and effects of fish length, sex, and sampling year. Predicted age distributions were compared to those obtained from traditional age determinations. A time-cost analysis was performed to evaluate the trade-off between savings and age determination accuracy.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 4.00pm – 4.15pm

A Comparative Study of Otolith Processing for Tropical and Temperate Marine Fishes

Lou, D[1]*, Begg, G[1], Petursdottir, G[2], Mapstone, B[3]

1. CRC Reef Research Centre, James Cook University, Townsille, Australia
2. Hafrannsknastofnunin, Marine Research Institute, Reykjavk, Iceland
3. Antarctic Climate and Ecosystems CRC, Tasmania, Australia

Fisheries research and management of exploited fish species in temperate waters mainly rely on the use of whole or sectioned otoliths for fish age determination. Ageing tropical fishes has been less used, however, because of a suspected lack of a discernible or interpretable pattern in otolith structure attributed to the lack of strong seasonality in the tropics. Research over the last decade has indicated that otolith annuli occur more frequently in tropical taxa than previously thought. This study compares otoliths and processing techniques between tropical and temperate marine fishes. Fish otoliths from the families Bothidae and Clupeidae in both temperate and tropical waters, the cod, Gadus morhua, from the temperate Northern Atlantic and coral trout, Plectropomus leopardus, from the tropical Great Barrier Reef were exchanged between the CRC Reef Research Centre in tropical Australia and the Marine Research Institute in Iceland. Otoliths were examined, processed and interpreted independently by the methods commonly used in each institute to investigate differences in the structure of otolith increments between tropical and temperate marine fishes and to compare otolith processing techniques. The study provides important information about the large-scale environmental mechanisms of otolith increment deposition and their implications for fish age determination. It also provides significant guidance for cross-latitude standardisation of otolith processing methods.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 4.15pm – 4.30pm

Age and Growth of Polysteganus coeruleopunctatus (cachucho or blueskin) Caught By Traps In Southern Mozambique

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1. Instituto Nacional de Investigation Pesqueira, Maputo, Mozambique
2. Oceanographic Research Institute, Durban, South Africa

Mozambique, with its 2500 km coastline, has valuable marine resource that contributes for the socio economy of this developing nation. The threat to over fishing has been recognized upon demersal fishes, mainly Polysteganus coeruleopunctatus, caught by line and trap fishing especially in southern of Mozambique. Age and growth of P. coeruleopunctatus were determined using sectioned sagittal otoliths. Specimens were collected from trap off southern Mozambique during one year. Females ranged in age from 1 to 17 years and males from 4 to 16 years, and the bisexual fish were 5 and 6 years old. The species were found to be relatively slow growing and the logistic growth parameters were for females k=0.153 year^{-1}, L_{∞}=327.9 year^{-1} and for males k=0.189 year^{-1} and L_{∞}=398.4 year-1. Due to difficult to age this species more attention should be addressed with inclusion of smaller and larger fishes to improve the estimation of growth parameters.

Theme 1 – Structure and Function
Room: Ballrooms 2 & 3
Time: 3.30pm – 3.45pm

Organic Components in Endolymph: Role in Otolith Growth

Mayer-Gostan N[1]*, Borelli G[1], Guibbolini M[1], Priouzeau F[1], De Pontual H[2], Payan P[1]

1. Laboratoire Réponse des Organismes aux Stress Environnementaux, Université de Nice-Sophia Antipolis, Faculté des Sciences, Nice, France
2. Laboratoire de Sclérochronologie des Animaux Aquatiques, IFREMER, Plouzané, France

The aim of the work was to determine which of the organic components present in endolymph are precursors of the otolith organic matrix and contribute to the regulation of the otolith growth. The approach chosen was to examine the trout (Oncorhynchus mykiss) endolymph composition under 3 environmental situations known to modify the otolith growth in different ways (night/day, starvation/control, stress/control). Methods used for comparison were: gel electrophoresis, Western blot with an antibody raised against the trout otolith organic matrix (OM), measurement of a factor retarding, in vitro , CaCO3 crystallization (FCalc). After ethanol or acetone treatment of endolymph, the FCalc co-precipitated with proteins. Measurements of the activities recovered in fractions after gel electrophoresis elution, showed that fraction with molecular weights around 18kDa displayed the highest activity. The electrophoresis patterns of proximal endolymph samples appeared different in the 3 situations when compared with that of day control. Although the protein concentration decreased (30%) during the night, the volumetric activity of FCalc was unchanged. Following starvation, the protein concentration was unchanged whereas a decrease of 50% of FCalc was observed. Protein concentration increased by 55% after stress whereas FCalc decreased by 50%. The antibody raised against the OM recognized bands around 60-80 kDa in the proximal endolymph. The Western blot clearly showed differences in the amount of otolith protein precursors present in proximal endolymph. They decreased during the night (50%) and increased after starvation (factor 3) or stress (factor 2). The results will be discussed in relation to the otolith growth.

Theme 1 – Structure and Function
Room: Ballrooms 2 & 3
Time: 3.45pm – 4.00pm

Factors Determining Otolith Microstructure During Metamorphosis In Plaice Pleuronectes platessa L.

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1. Port Erin Marine Laboratory, University of Liverpool, Isle of Man, British Isles
2. University of Bergen, Bergen, Norway

The microstructure of plaice (Pleuronectes platessa) otoliths was investigated during the period of metamorphosis with respect to age, size and developmental stage. Otoliths were marked by immersion of the larvae in alizarin complexone to provide reference increments at known ages. Sagittal otoliths were examined by light microscopy. Increment deposition during metamorphosis was found to occur on a daily basis. The developmental stage of the fish was the factor that determined the timing of accessory growth centre formation with the first growth centre forming when the left eye begins to cross the midplain of the head. The total number of growth centres formed differed significantly between ages ($p=0.047$). The size of the otolith prior to metamorphosis was significantly different between the development stages ranging from an average of 72.54µm in early stage fish to 116.86µm in late stage fish. There was a good relationship between otolith size and somatic size once metamorphosis was complete.

Theme 1 – Structure and Function
Room: Ballrooms 2 & 3
Time: 4.00pm – 4.15pm

Does Fluctuating Asymmetry In Larval Otoliths Reflect Temporal Replenishment Patterns?

Lemberget, T*, McCormick, M I
School of Marine Biology and Aquaculture, James Cook University, Townsville, Australia

In bilaterally symmetrical organisms, developmental instability is defined as deviations from a perfect form due to environmentally or genetically induced factors. Fluctuating asymmetry (FA) between left and right otolith is believed to reflect developmental instability in fish. In this study, otolith asymmetry was investigated in a tropical reef associated fish, Saurida suspicio (family Synodontidae). Larvae were collected in light traps over a period of 18 consecutive lunar months in the San Blas Archipelago, Panama. Digital images were obtained of whole otoliths, and an estimate of asymmetry between left and right otolith (L&R) was calculated from the length (longest axis), width (shortest axis), perimeter and area of the otolith outline. The left and right otolith shape was also described and compared using Fourier harmonics. The following questions were addressed: 1) How does FA correlate with magnitude of lunar replenishment patterns? 2) Is there a relationship between otolith asymmetry and morphological and histological derived condition indices? 3) How does otolith asymmetry correlate with environmental parameters? Results and implications are discussed.

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Theme 1 – Structure and Function
Room: Ballrooms 2 & 3
Time: 4.15pm – 4.30pm

Feeding History Influences Otolith Shape in Tropical Fish

Gagliano, M*, McCormick, M
School of Marine Biology and Aquaculture, James Cook University, Townsville, Australia

The influence of feeding history on otolith shape was examined in juveniles of two species of coral reef fish, Amphiprion akyndynos and Pomacentrus amboinensis. Fast Fourier analysis was used to describe the shape of otoliths of fish from a variety of experimental feeding treatments, ranging from starvation, through pulse feeding, to fed ad libitum. The resulting harmonics from both the left and right otolith of each individual fish were used as the basis for multivariate analysis to investigate shape differences between feeding treatments in the two species. When left and right otoliths were analyzed separately, otolith shape analysis did not reveal significant differences between feeding treatments for either species. In contrast, when left and right from individuals were analysed together, clear separations among feeding groups were observed in both species. Differences among treatments were largely due to differences in the finer details of the otolith shape, represented by middle level harmonics. Fish that had been starved had significantly different otolith shape than fish from all of the other fed treatments. Differences in otolith shape could not simply be attributed to differences in fish size among treatments. We conclude that differences in otoliths shape are influenced by feeding history, but processes that influence otolith shape are complex and most likely species-specific. This study presents new evidence that otolith shape in tropical fish may directly reflect body condition of individuals in a non-size and non-age related manner.

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Section Four

Oral Abstracts

Tuesday 13 July 2004



Keynote Address, Theme 7 – Stock Assessment and Fisheries Management
Room: Ballroom 1
Time: 8.30am – 9.00am

Otoliths, Recruitment, and Stock Assessment

Ralston, S
National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, USA

Since a population modeling framework was first used to assess the status of fish stocks, the most difficult problem to overcome has been to develop a general theory to account for recruitment variability. From the time Hjort first postulated the critical period hypothesis, researchers have attempted, with quite mixed success, to develop an understanding of the relative importance and interplay of spawning stock size and environmental factors as they affect annual reproductive success. Progress towards this elusive goal has been generated largely through application of demographic methods to the study of fish populations (e.g., cohort analysis, separable age-based modeling, etc.), which are based upon the analysis of temporal variability in population age structure and evaluating the effects of fishing. Estimating population age structure by examination of otoliths has been the cornerstone of this approach.

Here I illustrate and discuss the use of certain information on fisheries catch age composition data in stock assessments. In particular, I briefly describe: (1) ageing error statistics and how those can be used to better estimate population age structure in likelihood-based models (e.g., the Stock Synthesis model), (2) recruitment variability and its relationship to population demography, (3) the effect of length-based fishing mortality on length-at-age, both in the catch and in the population, and (4) how information on longevity can be used to estimate the natural mortality rate, a key demographic parameter.

Keynote Address, Theme 5 – Climate, Ecology, and Population Biology
Room: Ballroom 1
Time: 9.00am – 9.30am

Estimating Population Connectivity in Marine and Anadromous Fishes using Geochemical Signatures in Otoliths: State-of-the-art and Future Directions

Thorrold, S
Biology Department, Woods Hole Oceanographic Institution, Woods Hole, USA

Quantifying population connectivity through larval dispersal and/or adult straying remains a significant hurdle in fisheries management, the design of marine reserves, and the assessment of essential fish habitat. Identifying natal origins of fish is, however, challenging because of difficulties in conducting mark-recapture studies in aquatic systems. We are developing techniques that use stable isotope and trace element signatures in otoliths as tags of natal origins in marine and anadromous fishes. In one application, we are using natural geochemical signatures in otoliths to determine patterns of natal homing in a weakfish (Cynoscion regalis) metapopulation from the east coast of the U.S. In coral reef systems, fish population connectivity is more commonly mediated by larval dispersal. We are investigating dispersal pathways of gray snapper (Lutjanus griseus) along the SE coast of the U.S. by constructing high resolution elemental profiles across the otoliths of recently settled juveniles. Finally, we are developing artificial marking techniques that will potentially allow large numbers of embryos to be indelibly tagged in situ by introducing unique isotopic combinations of naturally occurring elements into the otolith core of dispersing larvae. Together, these approaches are providing estimates of population connectivity for spatially-explicit models of fish populations. These models are, in turn, critical to the application of spatial management strategies in aquatic environments.

Theme 5 – Climate, Ecology, and Population Biology
Room: Ballroom 1
Time: 9.30am – 9.45am

High-Resolution Stable Isotope Records from Otoliths: Past, Present and Future

Patterson, W
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Carbon and oxygen stable isotope values provide a record of life history that reflects environmental conditions experienced by fish throughout life. As environmental conditions change through time, so does the isotopic record stored in a sequence of otoliths that spans the period of interest. Isotopic analysis of a suite of otoliths can therefore provide high-resolution records of climatic and oceanographic change over geological timescales. These secular records of environmental conditions can in turn provide answers to questions regarding mass extinction, variations in metabolic rate, evolution of thermal tolerance, migration, reproduction, and future global change. Significantly, such records can be recovered for both extant and extinct species. Because otoliths are the only material needed for such studies, we can develop records of life history for ancient, often extinct, species of fish that rival our data on the behavior of modern fishes. High-resolution records from otoliths offer significant advantages over many traditional proxies of environmental change because they store information throughout the year for multiple consecutive years. Examples presented will include migration of Jurassic fishes, mass extinctions at the Cretaceous-Tertiary, and the Eocene-Oligocene boundaries, and records of hurricanes in mid-Holocene North America. Importantly, the possibilities are not limited to geologic timescales, but extend as well to archeological studies. We can readily derive characteristics of human behavior for societies that relied on fishing for sustenance. Fishing techniques, seasonality of fishing and site occupation, as well as trade and transportation of goods can all be evaluated using high-resolution records of stable isotope values.

Theme 5 – Climate, Ecology, and Population Biology
Room: Ballroom 1
Time: 9.45am – 10.00am

Isotopic Indicators of Climate Regime Shifts from Marine Fish Otoliths

Gao, Y W
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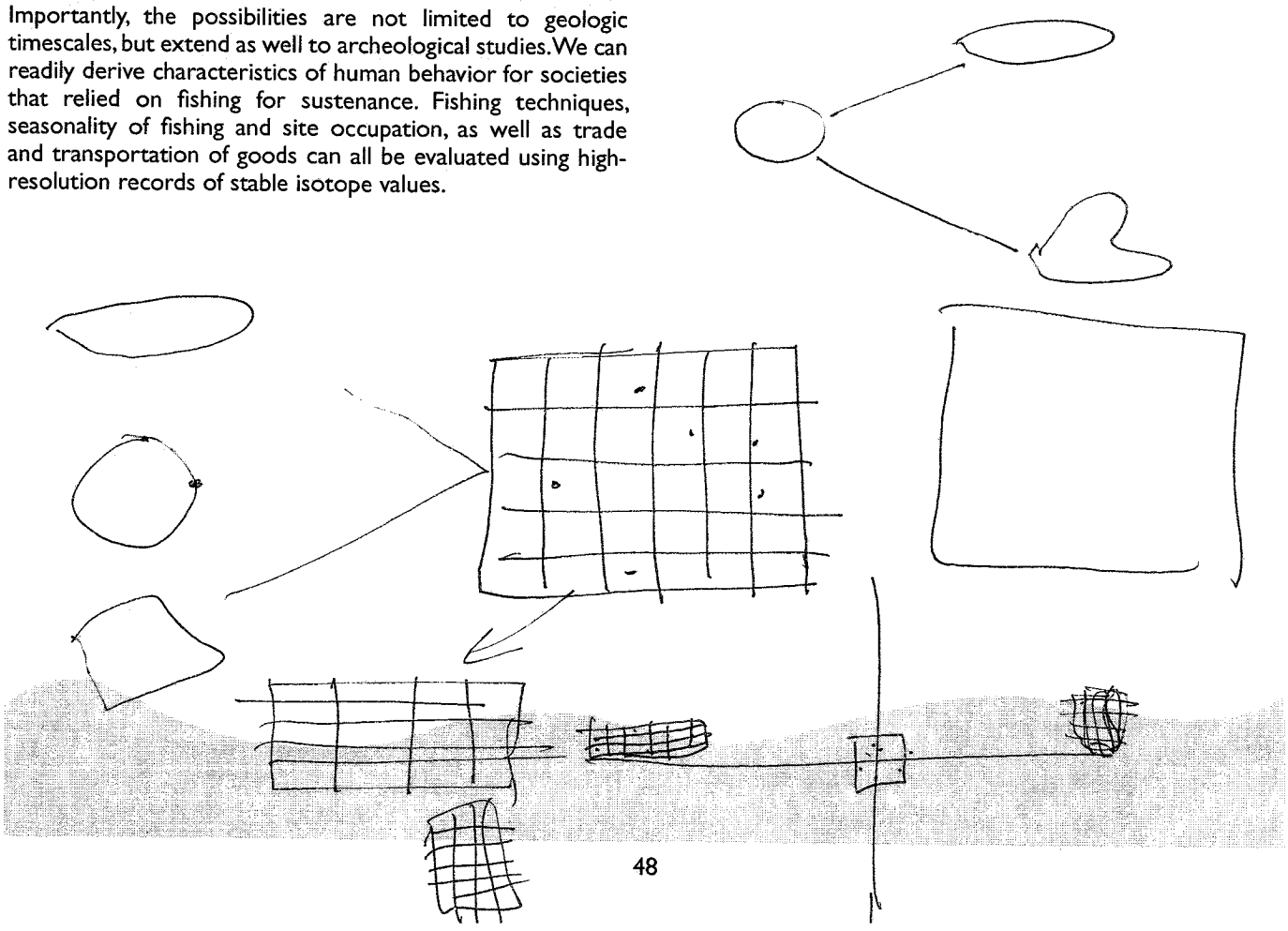
Using fish otoliths as a proxy material to detect marine ecosystem changes is a new approach in fisheries and ocean sciences. Recent studies have shown that stable oxygen and carbon isotopic variations in otoliths can be used as indicators of decadal-scale climate regime shifts in fisheries management. For example, stable isotopic analyses in otoliths of Atlantic cod (Gadus morhua) suggested that the well-documented 1977 and 1990 regime shifts did occur in Atlantic Canada, during which the cod experienced a drastic decline and the fishery was collapsed. Comparison of isotopic variations between Pacific halibut (Hippoglossus stenolepis) and yelloweye rockfish (Sebastes ruberrimus) indicated that the intensity of regime shifts might vary with different fish species and life styles. The impact of the 1977 warming regime shift and the 1990 cooling regime shift has clearly shown in Pacific halibut stocks; however, the driving force for yelloweye rockfish population dynamics was the trophic changes along the Washington and Oregon coast. Thus, the connection between stable isotopic variations of otoliths and the climate regime shifts is potentially useful in studying the fish population dynamics and the long-term (e.g., the last 20-30 years) ocean bottom environmental changes.



Theme 7 – Stock Assessment and Fisheries Management
Room: Ballrooms 2 & 3
Time: 9.30am – 9.45am

Age-Based Assessments in Tropical Developing Countries – An Expensive Folly or Worth Every Penny?

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2. RRAG, Imperial College, London, United Kingdom

The number of successful annual increment validations from the otoliths of tropical fish species has increased dramatically in recent years. Despite the resulting opportunity to apply age-based estimation methods, the costs involved are generally thought prohibitive for tropical developing states. However, are the costs outweighed by the benefits obtained in terms of improved management? Using management strategy simulations, this study examines the results of employing length- and age-based parameter estimation methods within simple stock assessments. Populations based on the biological characteristics of the tropical emperor Lethrinus mahsena are simulated and catches from these populations sampled. Growth parameter estimates are developed using age- and length-based methods. In each year, growth parameter estimates are used within length-based approaches for total mortality estimation, and compared with the results from age-based total mortality estimation methods. Stock assessments are performed by comparing fishing mortality, obtained using the estimates of total mortality, to a management target ($F_{0.1}$). Management rules define actions in the following year based upon the results of these stock assessments. The performance of management based on each assessment approach over a set period is compared using indicators which include stock status and fishing yield. A cost-benefit analysis is performed to examine the costs involved in using each assessment approach in the light of benefits resulting from their management performance in terms of fishing catch revenue. Conclusions are drawn on the appropriateness of using age or length-based methods for relatively long-lived slow growing tropical fish species.

Theme 7 – Stock Assessment and Fisheries Management
Room: Ballrooms 2 & 3
Time: 9.45am – 10.00am

Size-Selective Mortality in the Fast Growing Tropical Sprat, Spratelloides gracilis

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2. Secretariat of the Pacific Community Reef Fisheries Observatory, Noumea, New Caledonia

A cohort of tropical sprats was sampled at larval, juvenile and adult life history phases using light traps at NW Cape in Western Australia during the summer of 1997/98. Growth rate and size at age was back calculated from otoliths and the growth characteristics of those individuals that survived to become adults compared with those of the population from which they originated. Using nonlinear mixed model analyses, we found evidence of size selective mortality in the larval and juvenile phase of this species. Those fish that were relatively large at hatching underwent lower mortality than fish that were relatively small during the larval phase. We examine the relative contributions of selective mortality due to size (bigger-is-better) and growth (stage duration) processes in the cohort.

Theme 5 – Climate, Ecology, and Population Biology
Room: Ballroom 1
Time: 10.30am – 10.45am

Plaice Settlement Patterns Over a Five-year Period Identified from Otolith Increments

Nash, R[1]*, Harwood, A[1], Dau, K[1,2], Geffen, A[1,3]

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2. *Bioconsult Schuchardt and Scholle GbR, Bremen, Germany*
3. *Department of Fisheries and Marine Biology, University of Bergen, Norway*

Otoliths of 0-group plaice sampled during summer on the sandy nursery ground of Port Erin Bay were examined to identify settlement sub-cohorts. Three settlement cohorts were consistently identified over the study period, which comprised the summer of 1993 and five summers 1996 ? 2000. The timing of settlement was assumed to correspond to the end of metamorphosis, identified from the position of secondary growth centres in the otoliths. Although there was interannual variability in the timing of settlement, a tidal influence on settlement dates was easy to discern. There was significant variation in growth and mortality between cohorts and between years. These differences could be attributed to both predation and density-dependent processes.

Theme 5 – Climate, Ecology, and Population Biology
Room: Ballroom 1
Time: 10.45am – 11.00am

Diversity of Migration in Diadromous Fishes, as Revealed by Otolith Microchemistry

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Recent findings about the migration, life history, and habitat use of several species of diadromous fishes that have been examined using analysis of otolith strontium (Sr) and calcium (Ca) concentrations are overviewed. The Sr concentration or Sr:Ca ratios along life history transects in the otoliths of these fishes fluctuated greatly in accordance with their migration patterns between freshwater and marine habitats, enabling each migration pattern to be distinguished. In Anguilla, the mean Sr:Ca ratios indicated that there were eels with several general categories of migratory history, that included sea eels that never entered freshwater and estuarine eels that had entered freshwater for brief periods, but returned to the estuary or bay. The life cycle of Anguilla that migrate between the ocean and freshwater has been generally accepted without question, while the discovery of sea and estuarine eels has greatly changed the understanding of Anguilla life history. Although Gasterosteus has been classified into anadromous and freshwater resident forms based on its life-style and morphology, continuous high Sr:Ca ratios from the core to the edge of the otolith were found in both forms. Therefore, besides the two representative migration forms of Gasterosteus, some individuals appear to spend their entire lives in brackish and/or seawater as estuarine residents. Salangichthys and Cottus showed a similar diversity of movements between freshwater and seawater as was seen in Anguilla and Gasterosteus. These findings suggest that many diadromous fishes may have flexible migration strategies and an ability to adapt to various habitats and salinities. Thus, migrations of diadromous fishes into freshwater and/or seawater via brackish water are facultative and not obligatory.

Theme 5 – Climate, Ecology, and Population Biology
Room: Ballroom 1
Time: 11.00am – 11.15am

Connectivity Between Juvenile Fish in Estuaries and Adult Populations on Open Coasts

Gillanders, B

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A promising method to determine connectivity among populations is to use chemical elements in calcified tissues (e.g. otoliths) as a natural tag. The objective of this study was to determine the estuary that adult snapper (Pagrus auratus, Sparidae) from the fishery had originally recruited from as juveniles. Juvenile elemental signatures in otoliths, varied among estuaries and years suggesting that to determine the recruitment estuary of adult fish caught offshore they must be matched to recruits from their respective year class. Using this approach, multiple year classes and age classes of adults caught as part of the snapper fishery from three regions along the coast of New South Wales, Australia were assigned to their recruitment estuaries. Fish from estuaries in only one region (Sydney) contributed greatly to 2 year old adult populations right along the coast and this result was found for multiple year classes of 2 year olds. The pattern of replenishment varied for 3 and 4 year olds. All estuaries do not contribute equally to maintaining adult populations and this has implications for conservation and management, including predicting what the effects of degradation of estuarine habitats may be on adult populations.

Theme 5 – Climate, Ecology, and Population Biology
Room: Ballroom 1
Time: 11.15am – 11.30am

Flexible Life History Strategies in Two New Zealand Diadromous Fish Species; Giant Kokopu and Common Bully

Barry, B[1]*, Closs, G[2], Markwitz, A[1], Chadderton, L[3], David, B[4]

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2. University of Otago, Department of Zoology, Dunedin, New Zealand
3. Department of Conservation, Hamilton, New Zealand
4. Department of Conservation, Whangarei, New Zealand

Diadromy (migration between marine and freshwater) is a common strategy in many species of coastal freshwater fish. In New Zealand, over half the fish are considered diadromous, including species of Galaxiidae and Eleotridae. Giant kokopu (Galaxias argenteus) and common bully (Gobiomorphus cotidianus) are believed to exhibit an amphidromous life-histories, typical of many New Zealand fish. However, the occurrence of isolated coastal populations, often associated with either coastal freshwater wetlands or estuaries, suggests diadromy may be facultative in these species, even where access to marine habitats is continuously available.

Fish were collected from coastal streams with varying geomorphologies in Southern New Zealand. Otolith microchemistry of giant kokopu and common bully was examined from various locations using particle induced X-ray emission (PIXE). For both species, many otoliths exhibited relatively uniform and low Sr:Ca ratios throughout the otoliths, indicative of life-cycles completed wholly in freshwater, even in systems where marine access was continuously available. However, some fish exhibited evidence of juvenile rearing within estuarine habitats, and a limited number of fish clearly reared in marine habitats. Within the coastal region studied, either non-diadromous freshwater or estuarine recruitment appeared to dominate in any particular system suggesting that large scale processes influence recruitment. Diadromy did not appear to drive population dynamics, although it may be an important dispersal mechanism. Ongoing research will aim to identify factors determining recruitment dynamics across large spatial scales.

Theme 5 – Climate, Ecology, and Population Biology
Room: Ballroom 1
Time: 11.30am – 11.45am

From Hatching to Catching: Reconstructing the Lifetime Movements of Plaice by Linking Natural and Electronic Data Records

Darnaude, A*, Hunter, E
CEFAS Laboratory, Suffolk, United Kingdom

In order to describe the lifetime movements of plaice, Pleuronectes platessa (L) in the North Sea, we compared migration routes, reconstructed from data gathered by electronic data storage tag records, with chemical signals simultaneously laid down in the otoliths of the same individuals. By linking these two state of the art techniques, our goal was to provide information on the species population dynamics, which would be otherwise unattainable using conventional methods. The tags allowed continuous records to be made of ambient conditions experienced by free-swimming fish in their natural environment between the times of release and recapture. To date, we have used tidal (depth) data to reconstruct the geographical movements of 165 free-swimming plaice for periods of up to two repeat migration seasons. The same fish independently recorded their environmental history throughout their lifetime on their otoliths by the daily accretion of various chemical elements. Otoliths were returned with around 80 tags. By matching the tag data with otolith microchemistry, we hope to establish the retrospective positioning of the fish in space and time throughout their lives. This process should for the first time allow interpretation of the migration history of the plaice prior to tagging, and determination of the time and source of recruitment, thereby linking studies of pre- and post recruitment fish behaviour.

Theme 5 – Climate, Ecology, and Population Biology
Room: Ballroom 1
Time: 11.45am – 12.00pm

Tests of the Potential use of Concentrations of Trace and Minor Elements in Barramundi (Lates calcarifer) Scales as Indicators of Nursery Salinity Regimes

Cappo, M[1]*, Boyle, S[1], Aumend, J[1,2], Hoedt, F[1,2], Perna, C[2]
1. Australian Institute of Marine Science, Townsville, Australia
2. James Cook University, Townsville, Australia

The barramundi (Lates calcarifer) is a catadromous, protandrous hermaphrodite that exhibits seasonal and ontogenetic movements between freshwater, estuarine and saltwater habitats during its complex life history. To better identify the roles of declining freshwater nursery habitats, and restocking, in sustaining barramundi production it is desirable to develop a signature of freshwater residence that can be identified in the coastal fishery for older fish.

This paper describes the search for an elemental "fingerprint" of freshwater residency in scales, reports the results of an experiment to determine the dynamics of this signature, and compares and contrasts the changes in elemental concentrations across scales and otoliths of adult fish across a salinity gradient.

Stocked fish of known life-history were transferred from a freshwater weir to salt water environments and sections of their scales were analysed with ICP-AES at regular intervals. At the end of the experiment, "life history scans" of Calcium, Strontium, Barium, Magnesium and Manganese (in ratios to Calcium) were made across otoliths from the experimental and control fish using Laser Ablation ICPMS. The experiment showed that the "freshwater fingerprint" was conservative, and not lost from inner scale sections, whereas the scale and otolith material newly deposited in the saltwater environment had elevated Sr/Ca and depressed Ba/Ca ratios. There was no change in the same ratios for the "control" fish. The LA-ICPMS analyses showed patterns within otoliths of experimental, stocked and wild fish that could not be readily explained in terms of chemistry of the surrounding waters.

Theme 5 – Climate, Ecology, and Population Biology
Room: Ballroom 1
Time: 12.00pm – 12.15pm

Otolith Growth of Fishes in Relation to Thermal Requirements, Environment, and Climate

Casselman, J[1]*, Leggett, W[2], Johnston, T[3], Casselman, S[2], Herra, T[2]

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2. Department of Biology, Queen's University, Kingston, Canada
3. Department of Fisheries and Oceans, Bayfield Institute, Burlington, Canada

To understand the importance of parental growth on recruitment, otoliths of warm-water (summer-spawning), cool-water (spring), and cold-water (fall) species were examined from temperate waters of the Great Lakes Basin. Quantitative and qualitative growth history was examined in relation to thermal requirements, environment, and climate. Cross-sectional area was more precise than radial measurements for describing otolith growth. Growth history of spawning stocks collected from 2000 to 2003 was examined in relation to temperature and changes in prey abundance for species typical of the three thermal guilds. Otolith growth of both male and female walleye, a cool-water fish best adapted to this temperate thermal environment (midsummer 23.3C), was highly significantly correlated (P=0.004, r2=0.48) with spring and summer temperatures that followed global climate. Growth was significantly less in the cold Pinatubo and La Nia years (1992, 1997, and 1994) and greater in El Nio years (1998, 1987, and 1991). For warm-water fish, otolith growth was uniformly high in warm years but significantly lower in cold years; the opposite was true for cold-water fish, which also formed prominent discontinuities in increments deposited during warm years. Otolith growth was correlated with body and breeding condition and was significantly influenced by age (P<0.001, r2=0.45) in the year before spawning. Otolith growth is conservative when compared with other structures (e.g., opercula) and is particularly useful because it is less variable and more precise when quantifying growth history and correlating reproductive status.

Theme 7 – Stock Assessment and Fisheries Management
Room: Ballrooms 2 & 3
Time: 10.30am – 10.45am

Discrimination of Hatchery and Wild Chinook Salmon Using Otolith Microstructure

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1. National Marine Fisheries Service, Santa Cruz, USA
2. University of California, Santa Cruz, USA

To determine the contribution of hatchery and natural production sources to ocean fisheries, and to assist in evaluating the effects of hatchery produced fish on threatened and endangered stocks we developed a procedure to distinguish individuals of hatchery and natural origin. We collected juveniles in 1999 and 2003 from 5 hatcheries and 11 natal tributaries, which represent fish from all potential spawning sources. We measured a suite of otolith metrics including mean increment width, standard error of the mean, distance to hatch, distance to exogenous feeding, and circularity. Data from 48 juveniles collected in 1999 were used to develop a discriminant rule that correctly classified 100% of hatchery fish and 95% natural origin individuals using a jacknife procedure. In general, hatchery fish were characterized by otoliths with wider increment width, less variable increment widths, shorter distance to hatch and longer distance to exogenous feeding. The differences in otolith metrics are likely due to the differences in temperature and feeding regimes between hatcheries and natural tributaries. Results evaluating the robustness of the model across years and validating the model using adults of known origin will be presented.

Theme 7 – Stock Assessment and Fisheries Management
Room: Ballrooms 2 & 3
Time: 10.45am – 11.00am

The Effect of Ageing Errors on the Management Advice of the Namibian Horse Mackerel, Trachurus capensis

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1. Ministry of Fisheries and Marine Resources, Swakopmund, Namibia

2. Marine and Coastal Management, Cape Town, South Africa

With most stock assessment models, annual age-length keys (ALKs) are needed to obtain sensible results. These are usually difficult, time-consuming and expensive to obtain. Currently, the Namibian horse mackerel stock is assessed using an age-structured production model (ASPM) that uses catch-at-age (CAA) data. Information concerning maturity-at-length, weight-at-length and catch-at-length are converted to maturity-at-age, weight-at-age and catch-at-age respectively by using a single ALK.

This paper describes a study where various errors arising from the age estimation process are tested within the ASPM to evaluate the effect that these errors have on the advice to management. These errors include 1) among-reader and between-reader precision estimates and 2) bias plots. Further, historical age-length keys are used to test whether differences in these ALKs influence the management advice to any significant extent. A Bulgarian as well as Russian ALK are compared to the Namibian ALK.

Historical CAA data, based on annual ALKs (different for every year) are available, and the stock assessment results based on this historical CAA data are compared with that based on CAA data resulting from a single ALK (the same for all years). The results are then evaluated to establish 1) whether it is feasible to implement a horse mackerel ageing programme that provides management with annual ALK, 2) what precision levels the ageing programme should aim for and 3) which of the two, greater precision or annual ALK is more important in affecting management advice of horse mackerel within the Namibian fisheries institute.

Theme 7 – Stock Assessment and Fisheries Management
Room: Ballrooms 2 & 3
Time: 11.00am – 11.15am

Stock Discrimination of Central Valley, California Chinook Salmon Using Otolith Microstructure

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2. Department of Biological Sciences, California State University, Sacremento, USA

The Central Valley, California watershed supports a diverse population of Chinook salmon, with fall-run fish produced in numerous tributaries of the system. Juveniles migrating from these tributaries to the Pacific Ocean commingle in the lower rivers and the Sacramento-San Joaquin Delta, coincident with the focus of water management activities and where tracking of individual stocks is important. We examined the utility of otolith microstructure analysis as a means of discriminating between five populations of fall-run Chinook. Otolith samples were collected from five geographically discrete locations over two years and the following attributes were measured: hatching check width, first-feeding check width, transect lengths from primordia to hatching check, hatching check to first feeding check, and daily growth increments between the first-feeding check and the otolith edge. These measurements, in addition to counts of primordia, and the coefficient of variation of post-emergent growth increments and average of daily growth increments, were dependent variables in a two-factor analysis of variance (ANOVA), with location and year as factors. In five of seven cases, location contributed significantly to the ANOVA model. In contrast, year was a significant factor in only two of the seven cases. Variance between the five locations was significant more often than between the two years, supporting the utility of otolith microstructure as a tool for discriminating between populations where the influence of inter annual variation was conservative. Discriminate function and cluster analysis were used to generate a dendogram depicting relationships between these salmon populations based on otolith microstructure characteristics.

Theme 7 – Stock Assessment and Fisheries Management
Room: Ballrooms 2 & 3
Time: 11.15am – 11.30am

Age Reading Through 50 Years of History and Quality of Long-Term Stored Northeast Arctic Cod Otoliths. Might it Cause Time Trends in Biological Parameters?

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Observed temporal trends in maturity-at-age and weight-at-age of the northeast Arctic cod stock require further study to determine their cause(s). Norwegian and Russian marine research institutes have therefore investigated the possibility that biases in age reading may contribute to the long-term trends observed in changes in stock productivity (growth, maturation rate, fecundity), reduction in age diversity , shifts towards early-maturation and loss of large and repeated spawners of the northeast Arctic cod stock in the Barents Sea. Norway has a collection of cod otoliths dating back to the 1930's. To assess whether changes in age reading are influencing the time series, historic material from every 10th year since 1946, with some extra focus on the years 1965–1968 and 1980–1985, have been re-aged by both IMR (Norway) and PINRO (Russia). In addition to see if present ages are biased relative to historic ages (or vice versa), the current work also discuss the quality of the historic otoliths which have been stored dry in paper envelopes for up to more than 50 years, and the comparative reading between Norwegian and Russian readers.

Theme 7 – Stock Assessment and Fisheries Management
Room: Ballrooms 2 & 3
Time: 11.30am – 11.45am

Patterns of Aging Error Among Some Gulf of Mexico Fishes

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In sub-temperate regions such as the Gulf of Mexico, fishes commonly show large variation in size-at-age but still show notable annual growth patterns in otoliths. Thus there have been increased calls for regular and direct aging of the catch for stock assessments. However, aging error can result in a 'smearing' of age proportions and tends to obscure recruitment trends. Statistical correction can be used to 'un-smear' proportions but the ability to do so depends on how well aging error can be characterized. We made inferences about aging error based on multiple reader comparisons for three species typical of short, moderate and long-lived life histories (gulf flounder-Paralichthys albigutta, gag-Mycteroperca microlepis, and red snapper-Lutjanus campechanus, respectively). Overall aging precision for these species would be considered high enough for production aging programs with average percent error (APE) ranging from 4 to 4.9%. For gulf flounder and for the youngest ages (<10) of the two longer-lived species, standard deviation at age was relatively constant. Thereafter, standard deviation at age increased across ages, and for red snapper, reader bias was noted and increased after age-20. Taking into account the species differences, models assuming normal distributions of aging error maybe useful to correct age proportions. Gag is a good candidate for evaluation because strong year class progression has been noted across years and between fishing gears based on depth.

Theme 7 – Stock Assessment and Fisheries Management
Room: Ballrooms 2 & 3
Time: 11.45am – 12.00pm

Mixing of Spawning Stocks or Year Class Twinning in Norwegian Spring Spawning Herring?

Husebø, Å[1]*, Slotte, A[1], Clausen L[2], Mosegaard, H[2]

1. Institute of Marine Research (IMR), Bergen, Norway
2. Danish Institute for Fisheries Research, Copenhagen, Denmark

The Norwegian spring spawning herring (Clupea harengus L.) is treated as a single stock in the assessment and management. However, maturation data on this stock wintering in fjords of northern Norway indicate that 1–2% of the adult herring actually are autumn spawners. Recordings of individuals with highly developed gonads already during summer feeding also indicate such a mixture. The objective of the present study is to test whether the observed group of autumn spawners really is a result of year class twinning, i.e. that they were hatched in spring but ended up spawning in autumn. The autumn spawners can be distinguished from the spring spawners by a slower otolith growth after hatching. Based in this we will analyse the daily growth increments after hatching in otoliths from 300 adult individuals; 100 autumn spawners collected in the offshore feeding area in July–August 2001, 100 spring spawners and 100autumn spawners collected in the wintering area in January 2002. Our null hypothesis is that all autumn spawning herring show autumn hatched larval otolith microstructure. Maturation characteristics in relation to back-calculated annual growth pattern of material from the IMR database and the300 herring will be discussed in the context of life-history strategies.

Theme 7 – Stock Assessment and Fisheries Management
Room: Ballrooms 2 & 3
Time: 12.00pm – 12.15pm

Stock Discrimination of Cod (Gadus morhua) in Icelandic Waters Using Otolith Shape Analysis

Jónsdóttir, I[1]* Campana, S[2], Marteinsdóttir, G[3]

1. The Marine Research Institute, Reykjavik, Iceland
2. Bedford Institute of Oceanography, Dartmouth, Canada
3. University of Iceland, Reykjavik, Iceland

Recent research indicates that the Icelandic cod (Gadus morhua) stock may consist of many populations or management units whose relative contribution to the fishable stock as well as to recruitment is unknown. The main spawning area is located southwest of Iceland, but cod have been shown to spawn as well at numerous other locations all around the country. Results from tagging studies, 0-group surveys and genetic studies all indicate that more than one cod stock exists in the Icelandic waters. Results from tagging studies do furthermore indicate that cod from different spawning grounds do maintain spatial segregation while on the feeding grounds. Further knowledge regarding the population structure of cod in Icelandic waters is needed in order to improve the stock assessment work as well as to facilitate our understanding of the recruitment variability. To study the discrimination of spawning groups of the Icelandic cod, otoliths were collected from mature cod at different spawning areas around Iceland during spawning season in spring 2002 and 2003. To study the composition of the mixed feeding grounds, otoliths from cod at the main feeding grounds were collected in autumn 2002 and 2003. Otolith shape analysis (Fourier Analysis) was used to discriminate between the spawning areas. Discriminant analysis was used to classify the different spawning groups and maximum likelihood based analysis used to estimate the population proportions of each spawning group in the mixed population.

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Keynote Address, Theme 2 – Chemistry and Composition
Room: Ballroom 1
Time: 1.30pm – 2.00pm

Endolymph Chemistry and Otolith Growth

Payan, P
University of Nice Sophia Antipolis, Nice, France

Otolith growth is an acellular process carried out far from the saccular epithelium implying that the calcification process is strictly dependent on endolymph fluid chemistry. This morphological peculiarity provides a unique opportunity to sample and analyze calcifying fluid in order to establish relationships between its composition and the mineralization process. Endolymph is a very complex compartment which shows a lack of uniformity in the spatial distribution of ionic and organic compounds involved in the otolith formation (totCa, totCO2, HCO3-, pH, proteins, collagens, proteoglycans). The origin of the endolymph heterogeneity will be discussed with special reference to the presence of ionocytes in the saccular epithelium. Furthermore, the concentration of most of these calcification parameters vary during the day-night cycle, the ionic and the organic parameters varying in antiphase and probably involved in the cyclic deposition of CaCO3 onto the otolith. Numerous physiological situations (temperature and salinity changes, fasting, stress) result in various otolith growths and were assessed to relate the endolymph chemistry to the otolith calcification. We paid special attention to the relationships between plasma and endolymph changes to separate direct from indirect effects on endolymph chemistry. Finally, we compare the organic composition of the otolith and endolymph in order to target the organic precursors present in the endolymph and involved in the formation of the organic matrix of the otolith. A synthetic view of the functioning of the saccular epithelium-otolith complex will be presented.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 2.00pm – 2.15pm

Age-Validation and Otolith Growth of Sprat (Sprattus sprattus) in the Skagerrakand Kattegatt, Eastern North Sea

Casini, M*, Cardinale, M, Krischansson, B, Johansson, M, Vitale, F, Arrhenius, F
Institute of Marine Research, National Board of Fisheries, Lysekil, Sweden

Stock assessment procedures require an accurate and efficient determination offish age for the management of exploited fish populations. Routine techniques determine the age of an individual fish through the count of annuli on hard structures such as otoliths. However, validation of age estimates from otoliths is crucial for reducing bias derived by erroneous interpretation of annuli patterns. This has never been done for sprat, a commercially important pelagic species in the North Sea. Accordingly, we performed sprat age-validation employing three different techniques on individuals collected in the Skagerrakand Kattegatt between September 2002–September 2003. The results from otolith weight frequency distribution (Bhattacharya method) showed that the modes identified corresponded to the ages determined counting the annual rings. Aprogression of the modes between February and September samples was also observed. Marginal increment analysis pointed out as the otolith hyaline and opaque zones were laid down once during the year analysed. Furthermore, we attempted to validate the annual ageing by grinding the otoliths and counting the daily rings for the estimated 0, 1 and 2 year-classes. Preliminary results seemed to indicate a high correspondence between the ages based on annual rings counting and those determined by counting the daily increments. Otolith weight was a better proxy for age compared to fish length. Differences in otoliths growth between Skagerrak and Kattegatt as well as between males and females and their implications on age-validation techniques were discussed.

Size distribution

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 2.15pm – 2.30pm

Evidence for Growth and Mortality Trade-Offs in Simulated "Match-Mismatch" Environments and Those Consequences for Fitness in Atlantic Cod (Gadus morhua)

Buehler, V

Institute for Marine Sciences, Universität Kiel, Kiel, Germany

Atlantic cod exhibit pronounced individual growth rate differences, which are often attributed to environmental influences or lately, to maternal effects.

In this study, newly-hatched larvae from the same female, batch and hatching date were submitted to different zooplankton treatments during a period of fifty days, in $6m^3$ enclosures. The larvae were divided in three groups. Initially, the first group found a situation of mismatch, while the second one had a match situation. After four weeks, the zooplankton density was altered, and larvae that suffered a "mismatch" experienced high feeding conditions, while the second group that until then grew under a "match" was submitted to low feeding conditions. Additionally, a third group was kept as starving group.

At the end of the experiment, mortality between both groups was exactly the same. However, the individual growth rates within the groups were very variable. Based on the otolith microstructure analysis, individual growth trajectories and the characteristics of survivors at the end of the experiment could be determined, indicating that survival was not random.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 2.30pm – 2.45pm

Validation of Daily Increment and Age Estimation of Juvenile Skipjack Tuna (Katsuwonus pelamis) in the Western Pacific

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1. National Research Institute of Far Seas Fisheries, Shizuoka, Japan

2. Ocean Research Institute, The University of Tokyo, Tokyo, Japan

Daily increment formation within sagittal otoliths of juvenile skipjack tuna (Katsuwonus pelamis) was validated by the marginal increment analysis. Specimens were collected by midwater trawl in the tropical western Pacific from November to December 1995 and in February 1999. The index of completion of the marginal increment increased with time of day, approximately 40% at 07.00–10.00h, 66% at 13.00–16.00h and 80% at 19.00–23.00h. Therefore, growth of the marginal increment progressed from morning to evening and was completed during the night. Otoliths of 1008 larvae and juvenile for the daily increment analysis were collected from 1994 to 1997. The relationship between number of daily increments and standard length was used for the growth estimation in the early life history of skipjack tuna in the tropical western Pacific. The daily growth rate was 0.55mm at larval stage, but rapidly increased to about 3 mm after metamorphosis to juvenile. The different growth rate between the north equatorial current area and the north equatorial counter current area was appeared. The difference was also observed with the fluctuation of vertical water temperature from 1994 to 1996.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 2.45pm – 3.00pm

Variation in the Periodicity and Timing of Increment Formation in Red Throat Emperor Otoliths

Williams, A J
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It is often assumed in ageing studies that the periodicity and timing of increment formation in otoliths is homogeneous across age classes, years and locations. Failure to account for spatial and temporal variation in the periodicity and timing of increment formation in otoliths may lead to inaccurate age estimates and biased stock assessments. In this study marginal increment analysis (MIA) was used to test the validity of these assumptions for otoliths from populations of red throat emperor (Lethrinus miniatus) on the Great Barrier Reef. Monthly samples of L. miniatus were collected for two consecutive years from the northern and southern regions of the GBR. MIA indicated a clear annual pattern in increment formation for all age classes in the southern region but amore ambiguous pattern for most age classes in the northern region. Furthermore, significant regional and temporal variation in the timing of increment formation in L. miniatus otoliths was observed. Opaque increments appeared to form one month earlier in the southern region than in the northern region. In the southern region opaque increments appeared to form two months earlier in 1999than in 2000. No significant variation in the timing of increment formation between age classes was observed. This study highlighted the importance of determining the periodicity and timing of increment formation across age classes, years and locations in order to obtain reliable estimates of age.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 2.00pm – 2.15pm

Relationships Between Anadromous and Non-anadromous Rainbow Trout (Oncorhynchus mykiss) in California Rivers

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National Marine Fisheries Service, Santa Cruz, USA

Rainbow trout (Oncorhynchus mykiss) exhibit both anadromous and non-anadromous (resident) life history forms, but the reproductive relationships between forms are not well studied. Otolith Sr/Ca ratios have been used to infer the life history form of an individual and its mother, and then to estimate the proportion of fish descended from females of the alternate form. However this approach has only been applied to populations in a few streams. We examined otolith Sr/Ca ratios of 400 adult O. mykiss from 9 California rivers and 400 juvenile progeny of anadromous and non-anadromous brood stock, including 4 hatchery strains commonly stocked in streams. The goals of the study were to 1) document and verify differences in Sr/Ca signatures among the two forms over a broad geographic range, and 2) determine the migratory history and maternal life history form of natural and hatchery-produced O. mykiss in each system. Preliminary results suggest that Sr/Ca ratios in otolith primordia can discriminate among progeny of anadromous and non-anadromous females from all rivers, despite significant differences among rivers. Otolith Sr/Ca ratios in the freshwater region differed among rivers, making interpretation of migrations difficult for some. Adults from most rivers were anadromous and the progeny of anadromous females, but a large portion of adults from the Klamath River appear to be either non-anadromous or the anadromous progeny of non-anadromous females.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 2.15pm – 2.30pm

The Use of Natural Chemical Tags in Otoliths to Investigate Nursery Origins and Population Mixing of Snapper, Pagrus auratus, in Victorian Waters

Hamer, P[1,2], Jenkins, G[1]*, Gillanders, B[3]

1. PIRVic Marine and Freshwater Systems, Queenscliff, Australia
2. University of Melbourne, Melbourne, Australia
3. Southern Seas Ecology Laboratories, Adelaide, Australia

Understanding the relative contributions of different juvenile habitats to populations of marine fish is critical to their long-term management and preservation. In recent years natural chemical tags identified in the otoliths of juveniles have been used to retrospectively determine the origins of older fish. This methodology can provide unprecedented quantitative information on the contributions of different juvenile areas to adult populations. Obtaining this type of information from samples of fish of different ages can also provide insights into age related changes in population mixing or migration rates. Snapper, Pagrus auratus, are one of the most important recreational and commercially exploited finfish species in Victoria, south-eastern Australia. This presentation discusses the use of chemical tags previously characterised in the otoliths of 0+-age snapper to determine the contributions of different juvenile sources to populations of sub-adult and adult snapper in Victorian waters. Particular emphasis is placed on understanding the degree of replenishment from local sources for the major Victorian fishery, Port Phillip Bay, and whether the contribution of different sources changes with age. Results will be presented for two different year classes of snapper sampled before and after the age of recruitment to the fishery.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 2.30pm – 2.45pm

Tracing the Diadromous Migrations of Australian Grayling Using Otolith Chemical Analyses

Crook, D A

Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg, Australia

The Australian grayling Protoctroctes maraena is the only extant member of the Family Prototroctidae, with its New Zealand cousin Protoctroctes oxyrhynchus, believed to have been extinct since the early part of last century. The species is thought have a marine larval and juvenile phase and it has been suggested that adults spawn and spend their entire lives in freshwater. Whilst there is evidence of a juvenile marine phase in the life cycle of the species, we currently have no information regarding the proportion of the population that undertakes diadromous migrations (ie. is diadromy obligatory?), or whether adultfish are entirely restricted to freshwater. In this study, otolith chemical analyses are used to trace the diadromous migrations of Australian grayling collected from three coastal rivers in Victoria, south-eastern Australia. Proton Induced X-ray Emission (PIXE) analysis is used to examine Sr:Ca ratios in the juvenile and adult portions of the otolith. Transects across the otolith surface using Laser Ablation Inductively Coupled Plasma Mass Spectrometry(LA-ICP-MS) are also used to examine the multi-elemental composition of the otolith during the juvenile and adult phases. The chemical composition of the otoliths is then compared with water chemistry in the rivers, estuaries and sea in an attempt to identify the existence of diadromous migrations during the various life history stages. The results of the study suggest that diadromy is obligatory during the larval/juvenile phase, but provide little evidence of marine or estuarine habitation by adults.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 2.45pm – 3.00pm

Model Analysis and Numeric Simulation of Fish Otolith Accretion

Mosegaard, H*, Thygesen, H*, Hassy, K*, Beyer, J*, Asbjarn, C*, Clausen, L*, Askgaard, W*
Danish Institute for Fisheries Research, Copenhagen, Denmark

The growth of fish otoliths is the result of genetically controlled biomineralisation of calcium carbonate leading to a characteristic morphologyvital for balance and auditory senses. Variation in 3D otolith shape among individuals in a population is typically smaller than corresponding variation in volume specific weight and the latter never reach the limits of solid aragonite. It is the working hypothesis for our model that otolith formation is analogous among different fish species. Poorly known combinations of biochemical and physical crystallisation mechanisms locally control accretion rate. Finally the overall structure and composition of the otoliths is therefore the result of an environmentally mediated physiological control to retain specific shape characters during the ontogenetic development to ensure their optimal functioning. The fundamental building stones in our model are the aragonite crystals and protein matrix structure, enhancing as well as inhibiting the accretion process. Rates are related to cellular synthesis and secretion as well as extra cellular catalytically mediated precipitation on mineral as well as organic template surfaces. Otolith physical and chemical characteristics are predicted. Models of increasing complexity are analysed and simulations compared to basic observations of otolith composition and physical characteristics.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 3.30pm – 3.45pm

Is it Necessary to Validate the Otoliths of Every Species we Study?

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2. Central Ageing Facility, Marine and Fresh Water Systems, Primary Industries Research, Queenscliff, Australia
3. Department of Biology, University of Windsor, Windsor, Canada

Should we validate the annual periodicity of increments observed in the otoliths for every species of fish that we study? Much of the earlier work on age-based demography of fishes was focussed on northern hemisphere populations (gadids, pleuronectids and clupeids) of commercial importance. Underestimation of ages in these populations could have resulted in substantial problems in calculating there silience of stocks to different harvesting regimes. A large number of validations have been accomplished, the great majority of which confirm that increments observed in otoliths reflect annual periodicities. The initiation of age-based demographic research on coral reef species has confirmed that most taxa lay down well-defined increments in their sagittae. Validation experiments have demonstrated their annual nature. However tropical fishes usually occur in complexes of locally rare closely related species. This is especially true of groupers a group that are overfished over most of their ranges. Validation of each member of this complex will be an extended and expensive procedure. Is it appropriate to carry out and publish the results of such validations before the age-based demographic information vital for management is made available through the published record? Moreover what are the probabilities of misreading ages in non-validated species and the management consequences of different types of errors? We address these issues with a survey of the demography of 4 major groups of exploited reef fishes and include an analysis of the costs associated with each course of action.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 3.45pm – 4.00pm

Translucent Zones Form Annually in Otoliths of Antartic Toothfish (Dissostichus mawsoni)

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1. *National Institute of Water and Atmospheric Research Ltd (NIWA), Wellington, New Zealand*
2. *Department of Animal Biology, University of Illinois, Urbana, USA*

Antarctic toothfish (Dissostichus mawsoni) from the Ross Sea have been aged assuming that one translucent zone is formed annually in their otoliths. However, no evidence to validate this assumption has previously been presented. In the current work, otoliths from four distinct juvenile length-frequency modes were examined, and the translucent zones counted. Zone counts were consistent within modes, and increased by one in each consecutive mode. This indicates that the modes represented year classes and that one translucent zone is formed annually in otoliths of juvenile D. mawsoni. In addition, sagittal otoliths were examined from D. mawsoni that had been injected with oxytetracycline some years before recapture. The six recaptured fish were large (129–145 cm TL at tagging) and had been at liberty from 1 to 7 years. The number of zones between the fluorescent oxytetracycline line and the otolith margin indicates that one translucent zone is formed annually in otoliths of post-mature D. mawsoni. This indicates that counting translucent zones in the otoliths of D. mawsoni appears to be a valid method for determining the age of this species.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 4.00pm – 4.15pm

Validation of Age Estimates from a Temperate Wrasse Including a Robust Approach to the Use of Marginal Increment Analysis

Ewing, G

Tasmanian Aquaculture and Fisheries Institute, University of Tasmania, Taroona, Australia

The age of Notolabrus fucicola from the east coast of Tasmania, Australia, was estimated from counts of opaque growth zones in thin transverse sections of sagittal otoliths. The age of juveniles was determined through cohort analysis of young-of-the-year. The radii of the otoliths from these known-age juveniles were used to validate the position of the first annulus in adult otolith sections. The increment structure at the growing edge of the otolith sections was examined at a higher magnification than was used to enumerate annuli and displayed a high degree of clarity, facilitating the use of edge analysis for the validation of the periodicity and timing of increment formation. Marginal increment analysis confirmed that opaque zones were formed annually on the growing edge of the otoliths of every age class from two years to ten years over the two-year period sampled. Edge analysis at higher magnification also revealed that opaque zones were consistently deposited from late September to early December, which was coincident with an annual increase in somatic growth and water temperature. A criterion was developed to adjust for the lag in detection of opaque material on the otolith growing edge experienced at the lower magnification used for the enumeration of annuli. This validation protocol addressed contemporary concerns regarding the use of marginal increment analysis through the adoption of measures to maximise the interpretability of the otolith growing edge and through the collection of samples of sufficient size and frequency to robustly represent every age class over more than one annual cycle.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 4.15pm – 4.30pm

Validation of Otolith Daily Increments for Yellowfin and Bigeye Tunas by Injection of Fluorescent Substances

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2. Japan NUS Co, Ltd, Tokyo, Japan
3. Kagoshima Prefecture Fisheries Experiment Station, Kagoshima, Japan

Direct validation of sagittal otolith daily increments of two tuna species, yellowfin tuna (Thunnus albacares) and bigeye tuna (T. obesus) was examined by injecting oxytetracycline (OTC) or alizarin complexion (ALC) and rearing in acage (maximum 55 days). The experiments were conducted four times from August 2000 to June 2002 at two places of Kagoshima Prefecture, Japan. Fluorescent substances were injected once or twice in one fish. As for yellowfin tuna, 149 individuals (23.4-54.0 cm fork length) were reared and otoliths for 78 individuals were analysed. As for bigeye tuna, 72 individuals (48.0-59.0 cm fork length) were reared and otoliths for 23 individuals were analysed. The concentration of fluorescent substance for single injection (calculated value in the fish body) was 4.4-160.1ppm for OTC and 12.0-100.9ppm for ALC. Otoliths were examined under fluorescent and lightning microscope and increments outside the fluorescent band or between two fluorescent bands were counted if these could be observed or counted. Fluorescent band(s) could be observed and also increments could be counted as for 54 individuals (48 yellowfin tuna (62%) and 6 bigeye tuna (26%)), although only one pair of otoliths from ALC injected fish could be successfully analysed. There was no relationship between clarity of fluorescent bands and concentration of OTC injection, but increments on otolith of smaller fish were easier to count than those of larger fish. The number of increments during rearing was utterly or almost equal to the elapsed days as for both species (especially yellowfin tuna), suggesting that the increments were formed daily.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 3.30pm – 3.45pm

Comparison of Genetic and Chemical Signatures in Northeast Atlantic Cod (Gadus morhua) Populations

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2. University of Goteborg, Kristineberg Marine Research Station, Fiskebackskil, Sweden
3. Marine Research Institute of Iceland, Reykjavik, Iceland

As part of a larger project to establish traceability for cod in EU waters (CODTRACE: QLRT-2000-01697) we were able to test the hypothesis that there is a major genetic component to the determination of otolith shape, compared to otolith composition. We compared the results of population discrimination based on different methods: micro satellite, otolith morphology, and otolith composition. Although each method employs multivariate analysis to identify subsets and groupings, the inputs are qualitatively different. Genetics data is categorical bi-variate (presence-absence, 2 alleles), morphology data can contain complex numbers, and composition data is continuous data, but with an uneven error structure. We compared the number of populations identified by the different methods, and examined the similarities in classification and mis-classification. This procedure also allowed us to examine evidence for migration by looking for discrepancies between genetic and composition methods. To this end, we also evaluated the use of otolith morphology and composition to examine population structure in groups where gene flow is too high to support complete separation of biological stocks as opposed to management stocks.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 3.45pm – 4.00pm

Use of Geochemical Tracers to Elucidate Life History Trajectories of Gray Snapper (Lutjanidae: Lutjanus griseus) within South Florida's Marine Ecosystems

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1. Cooperative Institute of Marine and Atmospheric Studies/ University of Miami, Miami, USA
2. University of Miami, Miami, USA
3. National Oceanic and Atmospheric Administration (NOAA) Southeast Fisheries Science Center, Florida, USA
4. Old Dominion University, Norfolk, USA

The snappers inhabiting the estuarine and coastal coral reef marine ecosystems of South Florida USA are a commercially, recreationally, and ecologically important group of higher trophic level carnivores. The larvae of a number of species are believed to settle in seagrass and mangrove habitats of Florida Bay where they spend their juvenile phase before migrating to the reef tract as young adults. The elemental compositions of otoliths, extracted from juvenile gray snapper, were examined using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) in order to determine the existence of a unique 'Florida Bay Signature'. We have now defined an elemental signature for fishes that have resided in Florida Bay. This Florida Bay signature is a complex composite of elements including a number of rare earth elements. This study was the first in which rare earth elements have been included in an otolith chemical signature. This 'Bay signature' allows high-resolution spatial separation of collection sites, on the order of 10 km, with additional, significant variation attributed to habitat type. Our ultimate goal is to employ multivariate pattern matching techniques comparing the juvenile portion of adult otoliths from the reef tract to our 'Bay signature' in order to assess the proportion of adults on the Reef that used the Bay as a nursery habitat. These results are believed to offer new tools to fisheries managers and may have important implications regarding connectivity, establishment of marine protected areas, and designation of essential fish habitat.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 4.00pm – 4.15pm

Tracing the Life History of Barramundi using LA-MC-ICP-MS Strontium Isotopic and Trace Element Compositions of Otoliths

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1. Research School of Earth Sciences, Australian National University, Canberra, Australia
2. Australian Institute of Marine Science, Townsville, Australia

High resolution (subannual), high precision (±0.007%) Sr isotopic compositions and trace element concentrations have been determined on barramundi Latescalcarifer otoliths collected from the Townsville region of northern Queensland. Unlike trace element concentrations, which can be modulated by physiological controls, the Sr isotopic composition of otoliths provides a direct record of the water masses in which fish have lived. As the Sr isotopic composition of seawater is constant, the utility of the technique requires that fish spend part of their life history in freshwater, and that isotopic variations exist among river systems. Sectioned otoliths of barramundi from freshwater reaches of the Ross (BlacksWeir) and Burdekin (Anabranch) Rivers have been analysed using UV laser ablation multicollector ICP-MS methods developed at RSES. The central cores of otoliths from both sites have 87Sr/86Sr ratios (0.70918±3), indicating early residency in the estuarine/coastal waters in which barramundi breed prior to an upstream movement of juveniles. This marine Sr isotopic signature was supported by high Sr concentrations in the otolith cores. Outside the core, otoliths of the Burdekin River fish generally had systematically higher 87Sr/86Sr ratios (0.7098 to 0.7108) compared to those from the Ross River (0.7097). The Burdekin Riverfish also show pulses of lower Sr isotope ratios, indicative of periods spent in the more saline lower parts of the estuaries, and possibly reflecting downstream spawning migrations. This Sr isotope approach, together with trace element signatures should enable better characterisation of the provenance of barramundi and provide further insights into their life history.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 4.15pm – 4.30pm

Otolith Microchemistry and DNA Microsatellites in Black Rockfish (Sebastes melanops)

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Black rockfish (Sebastes melanops) is a long-lived, viviparous species with an extended pelagic larval duration (3-5 mos.) and a broad continental distribution along the NE Pacific Ocean. Marine species with extended larval durations are assumed to have widespread dispersal and little population structure. To assess the potential of otolith microchemistry to provide information on relative dispersal distances and population structure, we examined otolith elements in juveniles and adults collected from 3 locations (120-460 km apart). Elements in juveniles were examined at 3 otolith regions, representing the: 1) egg and early larval; 2) pelagic larval; and 3) late larval and early juvenile periods. For adults, trace elements were examined at the 1) otolith core, representing the1st year, and 2) otolith edge, representing collection year. Significant differences in Mg, Mn, Zn, Sr, and Ba were consistently found among collection location and otolith region. Discriminant function analyses based on geochemical signatures consistently group >80% of juveniles and >70% of adults to collection location throughout their life history suggesting the majority of individuals from these geographic locations did not mix. We also examined DNA microsatellites and found significant population structure among sites >400 km apart (FST=0.019) and weak evidence for isolation by distance (p=0.05). The genetic work identified population structure at scales <500 km. The otolith microchemistry indicated, given the high rate of classification accuracy, the majority of larvae may have dispersed distances <120 km. Combined, these techniques provide corroborative information on population structure as well as potential isolating mechanisms.

Section Five

Oral Abstracts

Thursday 15 July 2004



Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 8.30am – 8.45am

Historical Review of Cephalopod Growth

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In ancient times cephalopod growth was perceived (researched?) as 'fast' and longevity as 'short'. This assessment was based on fishermen's experiences, observation, description and reasoning. However, as far as can be inferred, first basic measurements were done in 1908 on Octopus vulgaris kept at Stazione Zoologica di Napoli by Lo Bianco, who was a technician at SZN. Quantification of various scattered observations was done 1940-1970, which resulted in the 2-4years longevity perceived for cephalopods. True breakthrough was made by R.Hanlon & Won Tack Yang and their team in 1975-1980, when 'short' life-span of cephalopods was determined to be generally one year. This was corroborated by the statolith analysis (J.Z. Young, M.R. Clarke, J. Spratt, M.R. Lipinski) in1978-1981. Next developments included gladius analysis by Bizikov in 1988 and theoretical concepts of growth, published by van Heukelem, O'Dor, Forsythe, Pauly and Lipinski (1976-2002). These developments highlighted the importance of correctly determining the relationship between growth and development. There is no problem when they are a part of continuous, measurable process (as in muscle fibre dynamics). However, when mode (=development) drastically changes the tempo, growth cannot be described by one specific function. This leads to the conflict between unitary concepts of growth, sought after by the fisheries science (Pauly) and experiment- or field-based multifunctional models.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 8.45am – 9.00am

Batoid Age and Growth: A Review of Ageing Structures, Techniques, and Interpretation

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The majority of age and growth research on elasmobranchs has focused on sharks, due mainly to their commercial importance. The batoids (skates and rays),however, have received relatively little attention despite the fact that the group represents ~62% of living elasmobranchs. To date there are only 25species of batoids for which published information is available, and we are aware of an additional 9 species with studies currently underway. We will review and summarize what age and growth information is available on batoids. We will discuss the various ageing structures that have been utilized for batoids (e.g. vertebrae, spines, caudal thorns), as well as the various techniques applied (sectioning, whole, staining), and discuss the merits/problems with each approach. Additionally, we will examine what verification/validation methods have been applied for batoids (e.g. captive growth, OTC, tagging), and review the success of each technique. Finally, we will discuss some of the band interpretation issues with ageing batoids, and compare those with the ageing of shark species, using several ray and shark species as examples. Although many skate and ray species are not currently the focus of directed fisheries, this situation is rapidly changing. In a study conducted in the Gulf of California, batoids made up more than 50% of the landed elasmobranch catch. Additionally, the issue of batoid by catch is gaining increased attention. Age and growth information for these presently underrepresented species will become increasingly necessary as other fish stocks become depleted and the world looks for additional fishery resources.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 9.30am – 9.45am

Growth and Life History Characteristics of North Queensland Reef Sharks

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2. CRC Reef Research Centre, James Cook University, Townsville, Australia

Reef sharks are a globally distributed group of fishes, characteristically associated with shallow water environments. They share with other elasmobranches very low reproductive and population turnover rates, and limited capacities for short-term dispersal. This combination of characteristics makes them particularly vulnerable to line-based fisheries. This study assessed age and demographic parameters for two species of reef shark in order to assess risks associated with fishing pressures. Two species – the Whitetip reef shark (Triaenodon obesus) and the Grey reef shark (Carcharhinus amblyrhynchos) were sampled from the central and northern GBR. Ages were determined by counting periodic band formation of vertebral thin sections. Maximum life spans were estimated at 19 and 22 years for the Whitetip and Grey reef shark respectively. A field-based validation with oxytetracycline subsequently confirmed these ages. Reef shark reproductive data showed that both male and female Whitetip reef sharks reach maturity at one third of their lifespan. The data also suggests that the oldest decade of age classes of Grey reef sharks may have been removed through fishing mortality, markedly limiting their reproductive output. Preliminary examination of age-based demography suggests that both of these species may already be under unsustainable fishing pressure.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 9.45am – 10.00am

Complex Steps to Ageing Deep-sea Corals in New Zealand Waters

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Many stony corals and octocorals occur on seamounts, as well as areas of comparatively flat deep-sea reef. The majority of such corals exist at water depths in excess of 100 m, with many living well below 1000 m. Coral ages can extend from decades to hundreds of years and relatively rapid changes in the environment e.g. fishing practices, climate and associated oceanic patterns can effect growth. An understanding of deep-sea coral systematics, biology, longevity, and growth rates is essential in order to appreciate the nature and extent of any impacts, and to mitigate them.

The diversity in coral systematic and skeletal composition, and in morphology is vast, with many corals depositing their calcite skeleton in different ways. Understanding the carbonate source and what proportion comes from the ocean and metabolism, as well as the effects of climatic events on the laying down of coral matrix is complex, as is interpreting growth zones. All make for a complex study and indicate that no single method can be applied to obtain measures of age or growth rate for all coral varieties.

This paper summarises coral ageing work that has been carried out in the New Zealand region, including the application of several methods to age and validate ages of some deep-sea coral species. Methods include counting radial growth zones, radio-isotopic dating, radiocarbon (^{14}C) dating, stable isotopes and climatic records. It is clear from the present study that coral ageing methods need to be combined to successfully confirm and validate age and growth.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 9.00am – 9.15am

Statoliths as 'Black Boxes' (Life Recorders) in Squid and Cuttlefish

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This study presents an overview of recent developments in investigations of statoliths, small calcareous structures located in the equilibrium organs of squid and cuttlefish. They primarily serve to detect both linear and angular accelerations of the body during cephalopod movement in water. Statoliths grow throughout the animal life with daily periodicity. Statoliths are perfect 'black boxes', recording a lot of information about different events in squid and cuttlefish lives. Analysing the statolith microstructure, it is possible to reveal hatchling size and temperature of embryonic development, to estimate age and growth rates of the animal with daily precision, to date its life transitions (for example, from paralarva to juvenile), to analyse its possible migratory routes and population structure by trace element analysis, and even to reveal how many spawning events had a given animal. As the paralarval statolithis embedded completely into the adult statolith, its features can be used to identify cephalopod paralarvae which are sometimes very different from adult animals. The shape of statoliths is physiologically specific, which enable to distinguish the movement pattern and possible life style of the animal (do they, for example, live in a water column or near the bottom, and what type of movement was characteristic to them). Statoliths are usually one of the few remains of squid in fossil records, and their features can be used to have anidea about the life styles of extinct species.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 9.15am – 9.30am

Investigations of Radiocarbon in the White Shark (Carcharodon carcharias) from the Eastern Pacific

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2. *Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratories, Livermore, USA*

Age and growth estimates of the white shark (Carcharodon carcharias) from the eastern Pacific Ocean indicate the life span may be long with a low growth rate; however, these estimates have not been validated. To obtain reliable age, growth, and longevity estimates useful for stock assessment and fishery models, validation of age estimation is essential. By counting vertebral growth zones, age can be estimated; however, not all sharks deposit annual growth zones, nor are they easily discernable in all species. It is necessary to validate the periodicity of growth zones in vertebrae by an independent method. Radiocarbon age validation uses the discrete radiocarbon signal produced from thermonuclear testing in the 1950s and 1960s retained in skeletal structures as a time-specific marker. The goal of this study was to further develop methods for assessment of radiocarbon in white shark vertebrae and to investigate the validation of age estimation procedures. We have prepared vertebrae for radiocarbon analysis incorporating a collagen extraction technique maximizing carbon yield from vertebrae. Annual growth bands spanning the 1950s to the early 1970s were cored from white shark vertebrae and analyzed for radiocarbon. The results were compared to regional radiocarbon time series with the goal of assessing the accuracy of age estimation and the influence of movement and diet on the radiocarbon signal. This work was performed, in part, under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 9.00am – 9.15am

Tracking Continental Habitat Shifts of Eels Using Otolith Sr:Ca Ratios: Validation and Application to the Coastal, Estuarine and Riverine Eels of the Gironde-Garonne-Dordogne Watershed

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In order to be able to give relevant interpretation of otolith Strontium:Calciumvariations in terms of habitat shifts of young eels, a validation of the Sr:Ca-salinity relationship in eel otoliths was undertaken. Downstream and upstream migrations of young eels were reproduced by transferring groups of fish every two months between aquariums filled with water coming from the Garonne river (0 psu), the upper Gironde estuary (5 psu), the lower Gironde estuary (25psu) and the coast (30 psu) representing the salinity gradient observed in the Gironde Garonne Dordogne watershed. Ontogenetic changes in otolith Sr:Ca were assessed in control fishes that were kept in the same water type during the 8-months long experiment. Baseline Sr:Caratios in the water were monitored monthly to assess their variation between aquaria. WDS analyses of Sr:Ca ratios showed that the change of aquarium was recorded in the otoliths as a Sr:Ca increase (downriver migration) or a Sr:Ca decrease(upriver migration). The WDS analysis of the Sr:Ca life transects in a hundred otoliths of eels caught in the lower and coastal part of the Gironde Garonne Dordogne watershed showed that 30% of them were nomadic eels which had experienced one major habitat shift during their continental life. The habitat shift, identified as a major variation in the otolith Sr:Ca pattern, generally occurred within the first or second year of continental life. The ecological implications of habitat shifts are discussed.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 9.15am – 9.30am

Proximal Causes for Variable Otolith Strontium and Manganese Levels in Juvenile Gag Along Florida's Gulf Coast

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2. Florida State University, Tallahassee, USA
3. NOAA Fisheries, Highlands, USA

Regular variation in the otolith composition of juvenile gag (Mycteroperca microlepis) from three year-classes collected at four nursery sites along the west coast of Florida allowed accurate classification of fish to their nursery site. Classification success rates exceeded 92% within a single year-class and across all year-classes at regional scales of site separation (>300km). Strontium and manganese, the principal discriminating elements in these otoliths, show regular coastwise gradients with latitude, Sr negative and Mn positive. The relative temporal stability of otolith Sr and Mn across year-classes and the spatial pattern of misclassified fish, suggest that the existence of broad regional geochemical gradients in Sr and Mn drive otolith composition. Regional gradients are discovered for Sr in groundwater discharged to coastal shelf waters and for Mn in coastal sediments in proximity to juvenile seagrass habitats. Sr levels in otoliths correlate ($r=0.98, p=0.0198$) with those in groundwater from coastal wells and submarine springs and seeps. Mn levels in otoliths correlate($r=0.94$, $p=0.061$) with those in surficial sediments. Water Sr/Ca and Mn/Ca are estimated at nursery sites using linear mixing models of freshwater and seawater end-members. Observed otolith Sr/Ca and Mn/Ca values are compared with expected values computed from experimentally derived otolith/water partition coefficients and existing data where the relationship between otolith and water concentrations are known or inferred.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 8.30am – 8.45am

Unravelling Life Histories of Bluenose and Rubyfish using Otolith Stable Isotope Chemistry

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Bluenose (Hyperoglyphe antarctica) and rubyfish (Plagiogeneion rubiginosum) have otoliths with complex growth zones. The analysis of stable isotopes (18O & 13C) within these otoliths has provided insights into the environment that has influenced the fish during their life history. Otolith stable oxygen isotope values are considered to represent equilibrium precipitation with respect to ambient seawater, while stable carbon isotope values are more controversial and often associated with metabolic rate, trophic level, and diet.

Samples were obtained across five otoliths of each species to complement the bomb chronometer procedure of radiocarbon (14C) dating which was used to determine the reliability of maximum ages derived from zone counts. Oxygen isotopes indicated that both bluenose and rubyfish undergo shifts in distribution during their life history with movement from surface water as juveniles to 500–1000 m as adults recorded. With increasing age, the carbon isotopic signature reveals changes in metabolic rate, trophic level, and diet, as well as suggesting the age of sexual maturity.

When integrated with other biological and oceanographic information, the inferred life history suggests an explanation for the observed complexity in otolith zone formation. With greater micro-sampling precision, there is scope for clarifying the life histories of these and other deepwater fish species whose biology is still poorly known.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 8.45am – 9.00am

Resolution of Early Life History Using Otolith Chemistry: What Are Reef Fish Doing Before They Settle?

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2. School of Marine Biology and Aquaculture, James Cook University, Townville, Australia
3. Research School of Earth Sciences, Australian National University, Canberra, Australia

Our knowledge of what reef fish experience prior to settlement has been limited largely by a lack of appropriate tools. We used laser ablation inductively coupled mass spectrometry (LA-ICP-MS) to examine the pre-settlement otolith chemistry of Pomacentrus coelestis collected from multiple reefs in both the northern and southern Great Barrier Reef (GBR). The results suggested that fish collected in the southern GBR originated from multiple sources, while fish in the northern GBR appeared to have either originated primarily from the same source, or were advected to the same water mass for their pelagic larval duration (PLD) irrespective of source. Elemental signatures from the otolith core itself have demonstrated that the core is an unreliable environmental recorder, at least for some elements. Thus, we assessed the utility of "near-natal" signatures as a means of determining origin. We determined that 67% of fish collected from reefs in the northern GBR had near-natal signatures matching signatures established for Lizard Island. This could indicate that Lizard Island is a major source reef. Alternatively, the majority of fish in the area may have been advected to Lizard Island waters for their PLD, resulting in similar pre-settlement elemental signatures. In addition, examining the otolith chemistry of reef fish as they made the transition from pelagic environments to reef environments revealed that ~65% of the fish examined settled on the reef the same day they encountered it, while some fish spent up to four days near the reef prior to settlement.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 10.30am – 10.45am

Influence of Reproduction on Otolith Microincrement Deposition

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The effects of reproduction on otolith growth were studied on a common tilapia species, Oreochromis niloticus (Cichlidae) during a two months experiment. Females were kept after tetracycline labelling and oestradiol dosages in experimental tanks. Gonadectomised females, incapable of reproducing (sham group), were compared to groups of intact females that either mouth brooded their eggs or not. Gonadectomised females displayed a better somatic and otolith growths whereas the growth deceleration observed in the marginal zone of the otolith coincided with the timing of the gonad regeneration. The group of intact females presented varied responses that seemed to follow mostly individual reactions. In these females, otolith growth was smaller and checks(discontinuities) appeared inside the otolith structure. Results thus showed that reproduction has an influence on both fish and otolith growths, leading to a significant underestimation of the number of primary daily increments during this period of life. Special attention should be taken when using the semicroincrements from fish caught in their natural environment because of a possible cessation in otolith accretion.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 10.45am – 11.00am

Otolith Size Trends in Different Depth Marine Communities

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660 sagitta otoliths from 132 species belonging to 7 demersal communities or sub communities of different depth and bottom structure and one pelagic community from North Western Mediterranean were compared in order to study otolith relative size and morpho-functional trends. In every community was selected the most characteristic species. Sagitta otoliths were digitised from their medial side (sulcus acusticus side). The relationship between area of medial side of otolith sagitta and total length of the fish was calculated to determine otolith relative size. The otoliths were divided in three groups (small, medium and large) and was calculated the percentage of every otolith size group in eachcommunity. The species from pelagic community were characterised by otolith of small and medium relative size. When compare demersal communities, the proportion of large and small otolith increase with depth (below 600-m depth). Instead, in the continental shelf and upper slope communities the relative medium sized otoliths were clearly most abundant than small and large otolith. A morpho-functional interpretation suggests an increase the relative importance of acoustic communication (related with large otolith size) in depth waters in order to compensate the limited visual field.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 9.30am – 9.45am

Stock Identification and Life History Interpretation Using Trace Element Signatures in Fish Otoliths

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2. *School of Earth and Ocean Sciences, University of Victoria, Canada*
3. *Ocean Sciences & Productivity Division, Pacific Biological Station, Department of Fisheries & Oceans, Nanaimo, Canada*
4. *Polar Research Center, Korea Ocean Research and Development Institute, Korea*

Laser ablation ICP-MS technology has rapidly established itself in geology, mineralogy and biology for determining trace elements and isotopic contents. Chemical components of otolith were examined by line scanning method and spot analysis for stock identification and environmental characteristics of North Pacific chum salmon, Oncorhynchus keta. Otoliths were collected from Canada, Japan, Korea, and the USA during the 1997-1999 spawning seasons. The results from the line scanning method showed that Sr/Ca ratios, known as an indicator of salinity, were elevated in the nucleus of the otoliths, decreased during the freshwater stage, increased suddenly at a certain point, and oscillated periodically to the margin corresponding to the year-ring. Peaks of Sr/Ca at the nucleus may indicate the marine-origin Sr contribution to the egg and the oscillations of the marginal part might reflect salinity gradients between onshore/offshore or north/south migrations. The zinc profiles oscillated and corresponded to the annual ring of the otolith. However, the profiles of Sr and Zn oscillated oppositely after salmon migrated to saline water and the zinc uptake declined toward the rim of the otolith. The result of discriminant analysis with 23 elements (Li, Mn, Cu, Zn, Sr, Y, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Pb, and U) on otolith nuclei separated distinctly in accordance with the natality of the stocks. Also, the same method using data sets from the last opaque zone in the otoliths, which formed during the summer of the final marine year, differentiated salmon from Canada and USA.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 9.45am – 10.00am

Stable Isotope Analyses of Cod Otoliths to Examine the Timing of Otolith Macrostructure Formation

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Otolith samples of pen reared cod with well-defined temperature history were obtained using high resolution sampling technique, and the samples were analyzed for stable oxygen (δ18O) and carbon (δ13C) isotope values. Samples from different aged cod (4 and 6 yrs) were collected in otolith yearly increments corresponding to the same calendar years. Otolith δ18O values showed a clear response to the annual temperature cycle, and otolith material deposited the same calendar year of different aged fish had similar δ18O values. The otolith δ13C showed a cyclic pattern roughly in phase with the δ18O values, and age specific δ13C values was observed. Significant correlations between otolith opacity and the estimated temperature(by using otolith δ18O values) were found. The translucent zones were formed at the highest seasonal temperature, and the opaque zones were formed at the lowest seasonal temperatures. There were also significant correlations between otolith δ13C values and otolith opacity. The otolith opacity changed with fish age suggesting that the translucent and opaque zones are only defined relative to the neighbouring zones. Our results show that stable isotope composition of otoliths can be used to examine the temporal significance of otolith zone formation relative to a seasonal temperature cycle, and that information about the environmental influence on otolith zone formation can be obtained.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 11.30am – 11.45am

Age and Growth of Juvenile Goliath Grouper (Epinephelus itajara) including a Comparison of Ageing Methods

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Otoliths are traditionally the most useful structure for age determination in teleost fishes, requiring the sacrificing of the fish to remove each otolith. However, because of the goliath grouper's protected status, researchers explored whether other hard parts, such as scales, dorsal fin-rays, or dorsal spines could be used instead. Juvenile goliath grouper were captured and released from 1997 through 2002 during an ongoing mark-recapture experiment. At each capture, fish were weighed and measured and tagged, and scales, dorsal spines, and dorsal soft-rays were removed for non-lethal age analysis. Ray and spine samples from successively recaptured fish were taken from hard parts adjacent to ones that had been previously taken. A subset of fish (N=152) was injected intramuscularly with OTC (oxytetracycline) prior to release. Another small subset of goliath grouper was sacrificed to validate the scale and spine/ray methodology. The extremely high recapture rate (>40%), has resulted in a highly useful time series of age and growth data. We have shown a close relationship between spine and otolith readings for these fish, and have therefore used spines as our primary method for ageing juvenile goliath grouper between the ages of 0–6. Annuli are represented by transparent rings in spines as opposed to opaque rings in otoliths. It appears that annuli are laid down at different times of the year in spines versus otoliths. Researchers validated ages using the high recapture rate, oxytetracycline (OTC) injections, and edge analysis. This study illustrates the usefulness of nonlethal methodologies for determining the age of these protected species. Applications of this methodology for sub adult and adult goliath grouper and other grouper species may also be possible. Data collected from this study will be used to inform the current stock assessment exercise underway for this species.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 11.45am – 12.00pm

Patterns of Growth, Mortality and Size of a Tropical Damselfish Acanthochromis polyacanthus Across and Along the Great Barrier Reef

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It was hypothesized that demographic patterns of Acanthochromis polyacanthus (Pomacentridae) would vary across the continental shelf (inner, mid and outer-shelf) of the Great Barrier Reef and among latitudes (scales of hundreds to thousands of kilometres). A. polyacanthus was collected at four latitudes and one to three distance strata (depending on local geography) across the continental shelf of the central Great Barrier Reef. Collections were made at three reefs per distance strata and 3 sites per reef. Greatest variation in Land growth was found with latitude and distance across the shelf. Cross shelf differences were often as great as latitudinal differences. Fish generally had significantly greater maximum lengths with increasing distance from shore, but fish from all distances reached approximately the same maximum age indicating that growth is more rapid for fish found on outer-shelf reefs. Mortality schedules (M and S) were generally similar irrespective of shelf position (e.g. off Townsville: inner-shelf: 0.51 and 60.0%; mid-shelf: 0.48 and 61.8%;outer-shelf: 0.43 and 65.1% respectively). Age validation of captive fish indicated that increments are deposited annually. The observed cross-shelf patterns in adult sizes and growth are likely to be due to variation in quality and quantity of food as well as turbidity. Our study cautions the pooling of demographic parameters on broad spatial scales without considering the potential for long-shore and cross-shelf variability.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 11.00am – 11.15am

Otolith Shape Analysis of Cod (Gadus morhua) in the NE Atlantic

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The integrity of cod stocks in the NE Atlantic was tested using otolith shape analysis by Fourier transforms. Sagitta otoliths from 380 mature fishes were collected from 5 wild stocks and 2 aquaculture sites during spring 2001. Otolith2-D contours was obtained from digitised images by standard image software and transformed into equally angular spaced coordinates. The transformed otolith shape coordinates was then analysed by Elliptic Fourier transformation with a set-up of 68 complex harmonics. The harmonics were expressed as four trigonometric values representing the amplitude and angle of the Fourier transformations. Data were normalised as the logarithmic transformed sum of squares. Discriminant analyses were applied for cross-validation and to classify fish origin. Results suggest that the optimal solution was obtained with a quadratic discriminant function analysis of the first seven Fourier harmonics. The overall misplacement rate was 54% with individual stock estimates varying from 45% to 73%. Misplacement error for the farmed cod was in the lower range. The study suggests that otolith shape has a strong genetic influence but also that biology (e.g. age, somatic size, growth rate) and environmental factors can modify individual shapes. The results are compared to similar results from other regions and species.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 11.15am – 11.30am

Age and Growth of Broadbill Swordfish (Xiphias gladius) from Australian Waters

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We determined the age and growth of broadbill swordfish, Xiphias gladius, from 1589 fish collected from the longline fishing grounds off eastern Australia between 1998 and 2002. Although otoliths were useful for determining the age (in days) of young fish the second anal fin ray was found to be the most convenient hard part for counting presumed annual increments. Two measures of marginal increment formation provided indirect validation of an annual cycle of ring deposition. There was a significant relationship between fin ray radius and orbital fork length. The Von Bertalanffy Curve fitted to age at length for each sex showed growth parameters of L8, K and to of 296.0, 0.08, and –3.7 respectively for females and 224.2, 0.13 and –3.0 for males. The oldest female we sampled was 19 years old; the oldest male was 16 years old. The resulting sex-separated growth curves overlapped those from similar studies from the Atlantic, Pacific and Indian Oceans and were only noticeably different from that provided for Mediterranean Sea swordfish. However, further refinement of our understanding of swordfish age and growth will be limited until direct age validation through marked recaptures of swordfish is achieved.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 10.45am – 11.00am

Using ICP-MS Analysis of Coral Reef Fish Otoliths to Examine Connectivity Between Islands of French Polynesia

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3. Ecole Pratique des Hautes Etudes and Centre National de la Recherche Scientifique, Perpignan, France

An estimate of connectivity within metapopulations of marine fish is essential information for anyone intending to design and implement effective marine protected areas. Our work in French Polynesia examines the degree to which populations of a territorial damselfish, Stegastes nigricans, are open or closed at the scale of whole islands by Inductively Coupled Plasma Mass Spectrometer (ICP-MS) analysis of otoliths. Using this technique, we compare the composition and concentration of elements in the otoliths of adult, juvenile and newly recruited fish collected in polluted harbours and in several other non-polluted sites around the islands of Tahiti and Moorea. This comparison will allow us to determine the importance and the scale of self-recruitment to these islands.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 11.00am – 11.15am

Determining Essential-Fish Habitat with Otolith-Geochemical Tags: Fine-Scale Habitat Use by Spotted Seatrout (Cynoscion nebulosus)

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3. Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, USA

Spotted seatrout live in estuaries along the US East Coast, with a range from the Gulf of Mexico to Chesapeake Bay. In the main portion of their range, fish move less than 50km while in the northern end of the range in the Bay, they are forced to migrate with cooling waters in the fall. The first step in our study of coastwide movement was to determine if otolith-geochemical signatures could be used to verify fine-scale habitat use in juveniles over three years. In this study we did one of the first long-term field tests of water and otolith chemistry. During the three-year study, one year was normal, one a 100-year drought, and another an abnormally wet year. We found that habitats could be differentiated to 15km based on otolith chemistry. Arguably, habitat waters were responsible for these differences, and we tested this hypothesis and the relation between environmental water versus otolith chemistry. We found that salinity and rare-earth elements in surface waters provided a good predictor of otolith chemistry. However, water chemistry over the seagrass beds differed annually and so then did fish-otolith chemistry. This necessitates annual groundtruthing from juvenile otoliths to establish cohort geochemical signatures.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 12.00pm – 12.15pm

Migratory Behaviour Between Brackish Lagoons and the Mediterranean Sea for the Gilthead Sea Bream Sparus aurata

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The gilthead sea bream (Sparus aurata) is an important species in Languedoc-Roussillon region (North-Western Mediterranean Sea) be it for its economic value, its patrimonial interest (sport fishing) or its impact of shellfish culture (predation on mussels). In the Herault department which is part of Languedoc-Roussillon region, mussel's culture provides 2500 jobs and the production of 100 farms is around 8000 tons by year. Surprisingly, little is known about migratory behaviour of the gilthead sea bream between lagoons and the Sea. Through chemical otolith analysis we are aiming at learning more about this species, i.e. variations in their diet and their exploitation of the lagoons ecosystems for reproduction, winter breeding etc. For this, we sampled wild gilthead sea bream in the Thau lagoon and along with individuals from aquaculture in the Mediterranean Sea and in Thau lagoon. Otoliths were analysed with ICP-MS. Thus, comparison between wild individuals and cultivated ones (under controlled conditions) allows assessing the migratory behaviour of wild gilthead sea bream and the change in diet. With the ratio Sr/Ca and Pb isotope we were able to differentiate wild fish from specimens caught in the lagoons or in the Sea. Some gilthead sea bream moved out the Thau lagoon in winter whereas some others seem to stay most of the year in the Thau lagoon, around mussel's farms. Thus, human activities such as aquaculture could explain that gilthead sea breams, which is well known as a migratory fish, is also sedentary and remains in the lagoons where a great amount of prey is available.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 10.30am – 10.45am

Spatial Variation in Otolith Chemistry at a Range Of Scales: Implications for the Design of Sampling Programs Aimed at the Identification of Natural Tags in Otoliths

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3. Southern Seas Ecology Laboratories, Adelaide, Australia

The development of laser ablation technology has enabled multi-elemental sampling within otoliths at fine scales of spatial and temporal resolution. The use of this technology to characterise and identify natural tags in the otoliths of juvenile and adult fish has enabled quantification of connectivity between juvenile areas and adult populations. It is clear from earlier studies that the potential for temporal variation in otolith chemistry at a range of scales should be a major consideration when designing sampling programs aimed at characterising natural otolith tags. While otolith composition will vary temporally, otoliths are also likely to show heterogeneity in their composition among parts of the otolith deposited over the same time period. Spatial differences in endolymph and otolith chemistry have been observed for some elements. Despite the few studies that have now utilised laser ablation to characterise juvenile otolith chemical tags, there is a lack of information describing variation in otolith chemistry down to the level of within a growth period. If variation in chemistry between areas of otolith deposited over the same time period can exceed spatial variation at higher levels this will have implications for the design of sampling protocols aimed at characterising natural otolith tags. Numerous questions related to sampling protocols come to mind. For example, should sampling locations within otoliths be standardised, oris it fine to randomly sample within a growth period, and how many ablations might be required? Does variation between areas within a growth period depend on the individual element? This presentation will address these issues by investigating spatial variation in otolith chemistry at scales ranging from among inlets to among different ablations around the otolith margin, for two species with differing characteristics of otolith growth and morphology.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 11.45am – 12.00pm

The Use of Strantium Isotopes and Trace Elements to Determine Natal Origins for Delta Smelt (Hypomesus transpacificus) in the San Francisco Estuary

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The delta smelt (hypomesus transpacificus) is a small osmerid fish, endemic to the San Francisco Estuary, USA. Since the early 1980's the delta smelt population has experienced dramatic declines. In 1992 the USFWS listed the delta smelt as a threatened species under the Federal Endangered Species Act. Recent investigations into the population declines has revealed a multitude of factors that may be associated with poor recruitment success, many of which operate in a spatial context. Recently the use of otolith chemistry to determine natal origins has been very successful. However many of these studies require intensive water sampling and rely on the assumption that fish take up trace elements in equal proportions to water chemistry. In this study we quantified the Sr/Ca ratios near the core of the larval otoliths using Laser Ablation-Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) from natal sloughs were delta smelt are hypothesized to spawn and Sr/Ca ratios near the core of the adult otoliths collected from the estuary, to determine the natal origin of delta smelt (Hypomesus transpacificus) adults. We found that of the five possible spawning areas, only three contributed to the adult population. Of the three surviving cohorts, one cohort made up 77% of the adult population. This suggests considerable mortality exists in a spatial context in this population and that several of the spawning areas for delta smelt may act as sinks to the population dynamics. Understanding the spatial variability in recruitment success has proved paramount in guiding conservation and restoration efforts in the San Francisco Estuary.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 12.00pm – 12.15pm

The Use of Otolith Microchemistry and Morphology for Stock Identification of an Exploited Tropical Reef Fish

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2. Antarctica Climate and Ecosystems CRC, Hobart, Australia

Consideration of stock structure is important for the sustainable management of fisheries resources. Fish stocks, or groups of individuals with similar life history characteristics, may respond differently to fishing pressure and failure to take such variation into account may result in sub-optimal, and possibly unsustainable, harvest strategies. Many techniques have been used to identify structure in temperate marine stocks but equivalent studies on tropical reef fish populations are rare. In this study we investigated the use of otolith chemistry and morphology to identify the stock structure of a tropical reef fish, common coral trout (Plectropomus leopardus), which is the major target species in the Great Barrier Reef Line Fishery. Chemical and morphological signatures of otoliths were compared on a broad regional and finer reef scale. The temporal stability in these signals was also examined by comparing two cohorts at all spatial scales. Results showed differences in both otolith morphology and chemistry at various spatial scales and between cohorts, indicating potential stock spatial structure but also showing that stock structure markers were temporally variable. The results highlight the need to incorporate data from several years in studies using these techniques, to discriminate temporary and possibly misleading signals from signals that indicate persistent spatial structure in stocks. The difficulties in identifying stocks in species with such complex spatial structure are discussed, as is the need for complementary analyses of life history characteristics to determine biologically and logistically appropriate management units.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 11.15am – 11.30am

Otolith Microchemistry as Indicator of Anthropogenetic Stress

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Otoliths have the potential to contain many elements that reflect the water composition the fish is exposed to. This property has been exploited for stock identification and environmental reconstruction. In the present study, we address the issue of whether or not otolith microchemistry could be relevant indicators of anthrogenetic pressure. Therefore, our study took place in a multipolluted environment (old mine), which has been surveyed for its water and sediment pollution for years. Fish (Leuciscus cephalus) were collected in the impacted site and in a reference site, upstream. Heavy metal (Mn, Co, Ni, Cu, Zn, As, Cd, Tl, Pb) and arsenic concentrations were measured on fish muscle and otolith, as well as in the water and sediment samples on both sites (using ICP-MS). Site effect and fish size effect on metal concentrations were tested using an analyse of covariance (ANCOVA). Significant higher contaminations in the impacted site were observed for As and Pb in the muscle and Cd, Tl and Pb in the otolith (ANCOVA, $p<0.05$). In the exposed fish, metal concentrations decrease with the size of otolith which would indicate that metal deposition decrease with age except for thallium which showed an inverse tendency. Bioaccumulation factors (concentration in tissue/concentration in water) were calculated and showed that Zn, Cu, Pb and As were more accumulated in muscles whereas Tl was more accumulated in otoliths. The effects of the different trace elements on the biology of fish are discussed.

Theme 2 – Chemistry and Composition
Room: Ballrooms 2 & 3
Time: 11.30am – 11.45am

Microchemistry of Atlantic Redfish Otoliths: Geographic Variation, Migration and Temporal Stability

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The elemental composition of fish otoliths enables natural tagging on an individual basis that may reflect geographic differences in the chemical and physical environment of the fish during a certain period of the fish's life. To quantify otolith chemistry of golden redfish (Sebastes marinus) and deep-seared fish (S. mentella), laser-ablation inductively coupled plasma mass spectrometry (LA-ICPMS) was applied. The concentrations of a suite of trace elements were measured in certain growth structures (nucleus, juvenile zones, edge) on otolith cross-sections of samples from the entire distribution area of these species. Since the population structure of redfish in the North Atlantic is highly uncertain, especially for S. mentella, otolith elemental signatures were investigated for their feasibility of using these as stock-specific markers. Geographic variation in otolith microchemistry revealed consistent differences between sampling areas. In addition, possible physiological effects were observed for some elements. The migration of recruiting S. mentella from the East Greenland shelf into the pelagic occurrences in the Irminger Sea was reconstructed by elemental assays of the nucleus and edge region of the otolith cross-sections. To test temporal stability of otolith micro constituents within a small area, samples taken from juvenile redfish on the Heimland Ridge (an important nursery area off East Greenland) for five consecutive years were analysed. Given persistent otolith trace element signatures, their use in differentiating nurseries provides a promising tool for stock discrimination of Atlantic redfish.

Theme 5 – Climate, Ecology, and Population Biology
Room: Ballroom 1
Time: 2.15pm – 2.30pm

Using Otolith Microchemistry to Gauge Dispersal Scales and Connectivity Among Marine Populations

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We lack knowledge of the mechanisms by which marine populations are replenished and sustained. This knowledge is essential in developing a scientific basis for marine resource management, including the placement and expected function of marine reserves. We are using otolith microchemistry to explore the extent of self-seeding of local marine populations, the degree of connectivity among coastal communities, and the dispersal scale of several marine species. Natal trace-element signatures in the core of growth-recording hard parts (otoliths and statoliths) can be compared with field samples of settled juveniles in fish and invertebrates. Otoliths and statoliths of larvae captured prior to leaving their birthplace show clearly distinct natal signatures over surprisingly short distances, and we are now characterizing the spatial and temporal scale of variation in natal signatures for open-coast species. Through analysis of otolith cores, newly recruited fishes can already be assigned to birthplace on large geographic scales, and sites appear to differ in the degree to which recruits are the result of retention, of dispersal from a limited array of sources, or of more general mixing and accumulation.

Theme 5 – Climate, Ecology, and Population Biology
Room: Ballroom 1
Time: 2.30pm – 2.45pm

Determining Production Sources and Spatial Structure of Chinook Salmon Using Geochemical Markers

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1. University of California, Santa Cruz, USA
2. National Marine Fisheries Service, Santa Cruz, USA

Identifying the relative contribution of larval and juvenile sources to adult stocks is a central problem in fisheries ecology. Juvenile sources provide acritical link to the long-term persistence of harvested adult populations. Determining the differential contribution of juvenile chinook salmon from the California Central Valley rivers and hatcheries to the fishery would identify important production sources critical to the maintenance of the stock. Current tagging methods, which tag a small proportion of hatchery fish, provide limited information on recruitment of hatchery fish into the fishery and no information on wild fish. Potential impacts of hatcheries on wild populations, or changes in the fishery composition, have been difficult to monitor and quantify, due to limited tools for identifying hatchery and natural individuals in mixed populations. This study examines the use of strontium isotopes incorporated into salmon otoliths as natural population markers. We used new analytical techniques and instrumentation (LA-MC-ICPMS) to spatially measure strontium isotopes in otoliths. Differences in geochemical signatures among production sources may serve to identify fish by specific river or hatchery of origin in a common marine environment. Data linking adults along the Central California Coast to their natal rivers and hatcheries and spatial distribution of adults with respect to their river/hatchery of origin will be discussed.

Keynote Address, Theme 8 – Quality Control in Ageing Facilities and Data Processing
Room: Ballroom 1
Time: 1.30pm – 2.00pm

Quality Control an Ageing Facilities and Data Processing

Morison, A
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The estimation of fish age is a process that is subject to error, and some errors have potentially serious consequences for fisheries. Yet, until recently there were few descriptions of key quality control aspects of the age estimation process, and quality control procedures are still not implemented in many laboratories that routinely undertake this work. The adoption of working procedures that include quality assurance and quality control mechanisms would unquestionably improve the reliability of fishery assessments and other analyses that are based on age estimates. So what has inhibited the establishment of globally recognised standards for age estimation? The frequent absence of reference standards that are important features of other forms of mensuration is a common and significant limitation, but one that can be overcome with reference collections. There are many other issues to be considered such as defining acceptable levels of precision and accuracy, establishing effective training programs, making use of the opportunities provided by advances in computer technology, applying appropriate statistical analyses, and undertaking regular quality control checks. These issues will be explored drawing on past and current work in this area, to provide a framework for the application of quality assurance and quality control mechanisms to protocols for the determination of fish age from hard tissues.

Theme 5 – Climate, Ecology, and Population Biology
Room: Ballroom 1
Time: 2.00pm – 2.15pm

Relationship Between Elemental Concentration and Age from Adult Snapper Otoliths – Implications for Movement and Stock Structure

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2. *School of Earth and Environmental Sciences, University of Adelaide, Australia*

Management of the South Australian snapper (Pagrus auratus) fishery is currently limited by a poor understanding of the adult movement patterns and the stock structure. This project assessed the tractability of determining the movement patterns of adult fish through the analysis of otolith chemistry. Nine-year old fish were collected from six geographic regions and a transverse section was prepared from one sagittal otolith from each. Multi-elemental laser ablation ICP-MS analysis was done along a continuous transect from the core to the outside edge, crossing the annual increments along a set axis. The elemental profiles were matched to the optical macrostructure using digital image analysis software, allowing the chemistry to be related to fish age. Profiles for strontium and barium showed considerable annual variation for individual fish. This variation was interpreted in relation to possible movement patterns between different regions. To compare amongst regions, average concentrations of barium and strontium were determined for each annual increment and the trends compared between individuals and regions via repeated-measures ANOVAs and MANOVAs. Although there was considerable within-region variation, there was also significant between-region variation, indicating that fish from different regions had spent considerable parts of their lives in different water masses. Thus stock structure was apparent at a finer spatial scale than is currently incorporated in stock assessment models.

Theme 8 – Quality Control in Ageing Facilities and Data Processing
Room: Ballrooms 2 & 3
Time: 2.15pm – 2.30pm

Quality Control of Age Estimations for a Long-Lived Reef Fish

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2. Antarctic Climate and Ecosystems CRC, Hobart, Australia

Quality Control procedures for aging generally require the repetition of age estimations in order to detect imprecision and bias in estimates. A decision then has to be made as to whether the age data are sufficiently precise and unbiased to assign a final age to the fish. In most cases an acceptable overall index of precision, which is defined in various ways, is used to justify using age data in subsequent analysis. If the likelihood of ageing errors changes with putative fish age, however, the eventual discrepancies between replicate age estimates for some age classes could be disproportionately large. Depending on the definition of precision used, this might mean that large numbers of age estimates are discarded from some age classes or the precision of the data set improperly presented. We investigated 3 theoretical models for changes in magnitude of discrepancies between replicate age estimations with increasing putative fish age for along-lived reef fish, Lutjanus bohar. We found evidence of a positive linear trend in discrepancies among repeated age estimates with putative age, indicating that errors in aging were unlikely to be restricted to interpretations of only specific features, such as the first or last increment. Further, samples from different locations demonstrated significant differences in slope, indicating that inter-read discrepancies became larger with increasing putative fish age for L. bohar sampled from the lower-latitudes. Four different methods of otolith section preparation were also investigated for their influence on trends of inter-read discrepancy with age and overall precision. For L. bohar, we chose an agreement procedure by which to accept or reject age estimates from each otolith based on an a priori critical level of precision (5%APE). This arbitrary criterion is appropriate for all replicate age readings because it effectively weights inter-read discrepancies to the putative fish age. We argue that the choice of criterion by which to accept age estimates should be based on formalisation of a model for the error-generating process for each aging application, rather than the untested adoption of convention.

Theme 8 – Quality Control in Ageing Facilities and Data Processing
Room: Ballrooms 2 & 3
Time: 2.30pm – 2.45pm

Quality Control Mechanisms at the Alaska Fisheries Science Center

Kimura, D K

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The Alaska Fisheries Science Center operates a fourteen-person Age and Growth Program which specializes in, but is not limited to, the ageing of various groundfish species using otoliths. In 1983, a quality control program was established whereby a random sub sample of 20 percent of aged samples is re-aged by a second age reader. Generally this second age reader, or tester, is a reader who is well experienced with the species in question. This age data is entered into a database where it can be easily corrected and analyzed. Two custom data analysis computer programs AGREE and RANGES are routinely run on age data before data can be released to end-users. AGREE is run on all reader/tester data and calculates precision statistics and cross-tabulations. These statistics can be compared with historic data to gauge sample difficulty and reader performance. Significant discrepancies between reader and tester are reconciled while viewing the problematic otoliths using a dual-headed microscope, and reconciled ages are assigned. When necessary, all questionable otoliths in a troublesome sample may re-aged. The RANGES program is used to screen for outliers in terms of fish size and weight at age and may help distinguish fast or slow growing fish from collection errors. The 20% overhead for quality control may seem high, but has allowed the Age and Growth Program to provide ages based on relatively consistent ageing criteria over the years.

Theme 5 – Climate, Ecology, and Population Biology
Room: Ballroom 1
Time: 2.45pm – 3.00pm

Annual Growth of Pacific Hake (Merluccius productus) in Response to Oceanographic Conditions

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Annual as well as decadal changes in oceanographic conditions have been shown to affect the growth of various fish stocks in the Northeast Pacific Ocean. Understanding past environmental variations and their effect on growth can provide predictive power about ecological conditions, contributing information to accurately estimate biomass for improved management decision-making. We used sagitta otoliths of Pacific hake, Merluccius productus, and measurements between successive annuli to construct a time series of annual mean growth. A general linear model (GLM) was used to assess the variation in growth increments due to age, sex, the region or area where sample specimens were obtained and potential interactions. There was no significant region effect or interactions. While there is a statistically significant difference between sexes, this is extremely small relative to other factors. A non-linear growth-at-age trend function was fit to these data and the residuals were then transformed to minimize the heterogeneity of variance. After accounting for age differences using these two methods, the year-to-year variability was related to various time series of oceanographic conditions. The results from the two methods are presented and differences are discussed. These results indicate that annual growth in Pacifichake is not constant but rather can be influenced by environmental and/or oceanographic conditions. Once recognized, these changes in growth can be used as benchmarks to help determine the age of the fish, as well as hind cast possible historic growth trends of the population.

Theme 8 – Quality Control in Ageing Facilities and Data Processing
Room: Ballrooms 2 & 3
Time: 2.00pm – 2.15pm

Optimising Fish Ageing Using Otolith Weight and Shape – Confirmation With Known Age Cod

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3. Image Science Software GmbH, Berlin, Germany
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Otolith shape, size and morphometric variables were combined to develop a simple, fast, objective and cost-effective method for age determination of Atlantic cod using known age individuals. The sources were farmed and wild cod from two Faroe populations. The results were compared with those obtained by traditional age reading among different laboratories. Ageing by readers that routinely age the stocks obtained around 95-100% of correct ageing against 80-90% of the measurable variables' method, whereas readers unfamiliar with the stocks performed more variable with 50-70% correct assignment depending on learning phase. Models were calibrated and validated on known age otoliths from one population applied on the other populations and vice versa to test the generality of the method. The result indicated that a reasonable good age assignment of 70-75% could be obtained. We also analysed the performance of traditional age reading for calibration and validation of the model for each specific population. The correct assignment of ages varied between 45 and 85%depending on reader experience. Therefore only if the age readings are done with a high accuracy (95-100%), traditional reading would be better than the application of a general model based on known age material from one cod population to other cod populations.

Theme 5 – Climate, Ecology and Population Biology
Room: Ballroom 1
Time: 3.45pm – 4.00pm

Reconstructing Environmental Occupancy of Bream Using Otolith Chemistry

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Understanding movements of individual fish is central to the management of stocks and conservation of important habitats. While methods of determining fish movements are often traditionally based (e.g., capture-recapture), the use of chemical elements within fish otoliths to infer movements may be plausible where differences in elemental concentration are related to environmental variables such as water temperature. Our experiments have shown that the otolith chemistry of juvenile bream (Acanthopagrus butcheri) is influenced by environmental variables of temperature, salinity and ambient water chemistry, with the effect of ambient chemistry outweighing that of the other variables. Using a combination of laboratory experiments and field collected fish we have been able to identify the environmental occupancy of bream in estuarine systems that have vastly different environmental characteristics to that of marine waters. Our results further highlight the need for research investigating the effect of environmental variables on otolith chemistry if we are to use otolith chemistry to accurately track environments that fish have occupied.

Theme 5 – Climate, Ecology, and Population Biology
Room: Ballroom 1
Time: 4.00pm – 4.15pm

The Relationship Between Juvenile Habitat Use and Adult Population Structure of White Perch in the Patuxent River Estuary, Maryland USA

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Understanding the functions of diverse habitats in the life history of migratory fishes is of paramount importance to management and conservation efforts. Here we present a case study to elucidate the population consequences of protracted use of both tidal freshwater and estuarine habitats by juvenile white perch (Morone americana) in the Patuxent River estuary, Maryland. Micro-scale analysis of Sr/Ca variability in otoliths revealed that, upon metamorphosis to juveniles, white perch either remain in freshwater during the first year of life(freshwater contingent) or migrate to brackish habitats and establish residency there (brackish contingent). Daily ageing and length back-calculation analysis indicated that the freshwater contingent experienced accelerated growth prior to juvenile metamorphosis. Annual ageing and micro-scale analysis of adult otoliths revealed that the population was dominated by the brackish contingent (93% of samples). Overall, this result demonstrates that the population dynamics of white perch in the Patuxent River estuary are driven almost entirely by larvae that recruit to brackish environments. Interestingly, in two recent cohorts, the brackish contingent was conspicuously absent, whereas some individuals of the freshwater contingent were observed in all but the oldest cohorts. Because the freshwater contingent provides a more stable (albeit small) component of the population, we speculate that freshwater habitats may provide resiliency to the population during inevitable periods of low recruitment. Thus, retrospective chemical and structural otolith analyses revealed unique roles of freshwater and brackish habitats in the life history of this species.

Theme 8 – Quality Control in Ageing Facilities and Data Processing
Room: Ballrooms 2 & 3
Time: 2.45pm – 3.00pm

Increasing Precision in Age Estimation of Cod (Gadus morhua) and Hake (Merluccius merluccius) Otoliths Using Image Analysis Computational Technology

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Individual and population age structure are essential points for proper management of commercial fisheries. Despite the important advances made in age determination there is still a need for improving both precision and accuracy. In addition, age estimation is very expensive. Here we present some advances achieved by the European Union funded IBACS project in increasing precision and automatism (i.e., cost reduction).Conventional procedures of image analysis got poor results due to 1) the poor definition of the rings in some radial sectors (i.e., incomplete rings), 2) the existence of extensive non age-related noise as radial marks or inconsistencies in background luminance. Automatic edge detectors (e.g., autonomous agents and 'snakes') seem to be interesting alternatives but we have obtained poor results with cod and European hake otoliths. We are developing the following alternative procedure: 1. Alignment, enhancement, filtering, and other conventional imagepre-treatments.2. Creation of intermediate binary images with the points that plausibly belong to a ring. Wavelet decomposition of radial signal seems to be the most powerful alternative but other approaches have shown promising results.3. Ring reconstruction.Among other alternatives, we are developing a procedure that finds a solution based on minimizing a statistic that measures the shape differences between consecutive rings. Our aim is to develop an automatic detection system of the rings considered has annual growth increments using the knowledge developed in other fields of research to improve the actual systems that incorporate an important component of human interaction.

Theme 5 – Climate, Ecology, and Population Biology
Room: Ballroom 1
Time: 3.30pm – 3.45pm

Otolith Elemental Signatures in Endemic Species: What Exactly Does a Self-Recruitment Signature Look Like?

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Identifying sources of recruitment in marine populations is central to understanding the extent to which local population dynamics are influenced by larger-scale demographic processes (e.g. meta population structure). However, attempts to determine such information have long been hindered by the difficulties in tracking planktonic larval stages capable of lengthy dispersal in the open ocean. Otolith chemistry has proven to be a useful tool in examining life history aspects of marine fishes that have been difficult to address using more conventional methods. We examined the otolith elemental signatures of six pairs of endemic and wide-ranging non-endemic species at Lord Howe Island, Australia to compare their environmental histories. As endemic species must be self-recruiting by definition, this provided a means by which natural self-recruitment signatures could be ground-truthed and then compared to species with the potential for long-distance dispersal from other sources. We also collected the non-endemic species from potential source regions along the Queensland and New South Wales coasts to assess if mainland larvae were contributing to Lord Howe Island populations.

Theme 8 – Quality Control in Ageing Facilities and Data Processing
Room: Ballrooms 2 & 3
Time: 3.45pm – 4.00pm

Difficulty of Age Determination Between Pacific Hake (Merluccius productus), Pacific Ocean Perch (Sebastes alutus) and Sablefish (Anoplopoma fimbria)

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Finfish age determination using sagitta otoliths is a learned skill. Furthermore, learning how to determine age varies in difficulty from species to species. Pacific hake (Merluccius productus) are short-lived species and less difficult to learn to age because of the distinct pattern of annuli on the otolith. Pacific ocean perch (Sebastes alutus) are long-lived, increasing the level of difficulty when determining ages. Sablefish (Anoplopoma fimbria) are more difficult to learn to age because multiple rings comprise an annulus, and the longevity of the fish. We took advantage of a unique opportunity to track the progress of learning of age readers with no previous experience. Age determinations were obtained by using a burnt cross-section of a sagitta otolith, which exposes growth zones, or annuli. To assess the ability of the inexperienced readers (readers) to reproduce an age estimate, a 20% sub-sample of the otoliths is re-read independently by an experienced age reader (tester) (i.e. double-read). Percent agreement and coefficient of variation were used to compare the difficulty between species with differing life histories. As the life span of the species increased the more difficult it was for the testers and the readers to agree on a single age. Readers reached an asymptote in their "learning curve" after 350 otoliths for Pacific hake, 500 otoliths for Pacific ocean perch, and 100 for sablefish. Due to the changes in morphology in the long-lived species, Pacific ocean perch and sablefish, these otoliths have a greater variability associated with them than that of the Pacific hake.

Theme 8 – Quality Control in Ageing Facilities and Data Processing
Room: Ballrooms 2 & 3
Time: 4.00pm – 4.15pm

Comparison of Otolith Readings, Image Analysis and Genetics in Stock Separation of Atlantic Cod

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Atlantic cod (Gadus morhua) in Norwegian fjords and coastal areas are traditionally classified into two types: Northeast Arctic cod and Norwegian coastal cod. The distinction between these two types of cod is an important management issue. Today this separation is done subjectively by visual inspection of the otoliths in a binocular using the shape of the growth zones as a distinguisher. The accuracy and precision of this method have not been scientifically documented. In this contribution the precision of this separation technique is estimated by use of parallel otolith readings by several independent readers, and the accuracy is estimated by comparing otolith readings with genetic investigations. In addition, an objective classification method based on automatic image analysis is outlined applying the readings and the genetic analyses as a reference. To validate the method, the set of analysed images is divided in two parts, where one part is used to develop and tune the classification criterion. Then the method is applied to the other images for validation.

Theme 5 – Climate, Ecology and Population Biology
Room: Ballroom 1
Time: 4.15pm – 4.30pm

From Desert Heat to Ice-Age Cool – Climate Signals in Australian Golden Perch Otoliths

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Climate change is amongst the most powerful of forces shaping an organisms life history evolution. However, direct measurements of its impact have proven elusive requiring biological data that tracks climate change over thousands of years. This research takes advantage of a unique system whereby otolith data from an extant fish species is compared with similar data from Pleistocene remains of the same species to investigate response to climate change over a truly evolutionary timescale. Ageing data and annual-increment widths of modern and fossil otoliths of golden perch (Percichthyidae, Macquaria ambigua) are compared to summarise life history variation over 25,000 years of climate change. Golden perch are currently widespread in Australia and growth chronology results will be presented for populations from the regulated rivers of SE Australia and the deserts of central Australia. Data from both of these populations demonstrate that otoliths are faithful recorders of somatic growth. Furthermore, growth-chronologies from these populations were found to be synchronous in years of strong ENSO events over large regional scales. The Pleistocene ancestors of golden perch were equally common and thousands of otoliths have been uncovered from aboriginal middens in the Willandra Lakes region. These middens date between 25,000 15,000 years BP and span from the Last Glacial Maximum 20,000 years ago when the Willandra Lakes were full and permanent through to when the monsoonal climate failed and the lakes became ephemeral, eventually drying out 15,000 years ago. Golden perch during the last ice-age were significantly slower growing but had much greater longevities.

Theme 8 – Quality Control in Ageing Facilities and Data Processing
Room: Ballrooms 2 & 3
Time: 3.30pm – 3.45pm

Using Digitised Pictures and Otolith Size and Shape Information to Improve Precision in Routine Age Determinations of Greenland Halibut (Reinhardtiushi poglossoides) Otoliths

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Age determinations of Greenland halibut otoliths are believed to be highly uncertain, and this has for long been considered a major obstacle for reliable stock assessments. Still very little has been done to improve the procedures, and in order to keep consistency, routine readings of otoliths from the North-East Arctic stock are still made in an assumed sub-optimal way. This paper compares the existing reading technique with the use of digitised pictures and an improved reading protocol. The comparisons are based on measures of precision in repeated age-reading sessions for multiple individual readers. Previous analyses show that size and shape measures of the otolith may give information on age that is independent of fish length. Thus for a given age-determination and estimated reading precision, such measures may be used to estimate age with higher precision. This paper outlines an automatic image analysis technique that provides optimal size and shape measures of the otolith in order to minimise age uncertainty. Half of the otolith readings are used to find these optimal measures, and the other half is applied to validate the technique. The resulting series of corrected age readings thus incorporates both a documented reading protocol and post-reading improvement procedure and may serve as reference series for future experiments with otoliths of this species.

Theme 8 – Quality Control in Ageing Facilities and Data Processing
Room: Ballrooms 2 & 3
Time: 4.15pm – 4.30pm

EFAN & TACADAR: A Cooperative Effort to Exchange Experience and Protocols Between Fish Institutes

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4. *Fed. Research Center for Fisheries, Institute for Baltic Sea Fisheries, Germany*
5. *Department of Agriculture and Rural Development for Northern Ireland, Belfast, United Kingdom*
6. *Institute of Marine Research Department of Coastal Zone, His, Norway*
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TACADAR is a Concerted Action (European Commission, Q5CA-2002-01891) with the overall objective to increase reliability of age estimation procedures in the European Community, compatible with the possibility of the future establishment of European wide international fisheries laboratories. TACADAR aims to increase the adoption of procedures that include quality assurance and quality control mechanisms, for the improvement of stock assessment and environmental management techniques. The ultimate objective is to stimulate the achievement of a higher level of quality within and integration between the member institutions of TACADAR, concerning fish age determination. The Institute of Marine Research, Norway, serves as the coordinating body for the Concerted Action (2002 – 2005) by maintaining the TACADAR Internet homepage, including databases, publishing TACADAR Newsletters and organising annual plenary meetings and workshops. TACADAR will : 1) Define the framework for the application of quality assurance and quality control mechanisms, to protocols for the determination of fish ages from hard tissues. 2) Discuss the levels of precision and accuracy to be used as qualifiers in statistical terms. 3) Discuss the evaluation of individual methods of age determination in cases where several methods are used to provide data input for the same stock assessment or environmental management model. 4) Develop guidelines for the creation and application of quality assurance and quality control mechanisms to protocols for the determination of the ages of fish from hard tissues. 5) Investigate legal aspects of accreditation and certification, including advice from externally invited specialists. 6) Submit a quality assurance manual including an evaluation of legal aspects and implications to the EU. Through a network of excellence, TACADAR will strengthen the competitive position of European institutions involved in fish ageing, through institutional synergy and international co-operation.

Section Six

Oral Abstracts

Friday 16 July 2004



Keynote Address, Theme 9 – Technological Developments
Room: Ballroom 1
Time: 8.30am – 9.00am

Otolith Research Techniques: Improving the Old and Embracing the New

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The diverse use of otoliths in fields such as age and growth modeling, trophic interrelationships and systematics is briefly reviewed. Developments of techniques in age and growth studies have focussed on the periodicity of daily, lunar, seasonal or annual marks. In long-lived fishes, novel approaches have been developed using isotopes for radiometric age determination. Sectioning of otoliths has allowed for the aging of fish in the tropics, which negates the use of inaccurate length frequency methods, particularly for long-lived fishes. Studies of the otolith microchemistry (particularly calcium and strontium ratios) have contributed to understanding the migration of fishes. The unique species-specific nature of otoliths has contributed immensely to ichthyo-palaeontological and trophic studies for decades. More recently otoliths have been used in systematic studies as an additional taxonomic character and to illustrate phylogenetic relationships and stock identification. The use of scanning electron micrographs has helped to illustrate otolith structure, but several problems remain. These include museological difficulties in labeling and preserving of otoliths, and the frequent neglect of preserving whole fish voucher material. One shortcoming in otolith studies is the difficulty in illustrating small 3-dimensional objects in a 2-dimensional manner. Computer software offers an exciting opportunity to overcome these limitations. Finally, benefits and disadvantages of paper-based versus electronic publication of images and results are briefly reviewed to show that an irrevocable shift to electronic media may be premature.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 9.00am – 9.15am

Age and Growth in a Euryhaline Subantarctic notothenid, Eleginops Maclovinus (Cuv & Val., 1830)

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The age and growth of E. maclovinus, a protanderous hermaphrodite, from around the Falklands' archipelago was determined by counting rings on otoliths for the first time. Scales were also used as a comparison and showed good agreement. The growth rate of E. maclovinus was found to be similar to a study conducted in Argentina using scales. Eleginops maclovinus was found to have a relatively fast growth rate and was best described by the von Bertalanffy function of the form: $LT = 196$ cm TL $(1-e[-0.07/\text{yrs}\ (t-0.14\ \text{yrs})]$. Two methods of validation were used to determine the first annual increment. The diameter of the first annulus was determined by using the mode corresponding to the young of the year in a length frequency distribution collected around the time of the expected first annulus formation, the annulus diameter was then predicted on the bases of a fish-length otolith-length regression. In some specimens the otolith microstructure was clearly discernible and this enabled daily increment counts to confirm the identity of the first annulus. The validation of the annual rings was conducted using recaptured OTC marked fish and marginal increment analysis. The effect and timing of sex reversal was also examined by identifying stress marks in female otoliths at different ages.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 9.15am – 9.30am

Seasonal Variation of Larval Growth Rate of Stelophorus insularis and Its Connection to Survivorship

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The tropical anchovy has a prolonged spawning season. To understand the diversified life history strategies of the fish hatched in different seasons, daily growth increments in otoliths of flexion and post flexion larvae, juvenile and young of Stolephorus insularis, collected monthly from an estuary of western Taiwan in 1997~1998, were examined and their daily growth rates were estimated subsequently. The growth performance of the fish was different among seasons. Life stage transition of the fish was faster in spring cohort than in autumn cohort, but growth rate of the post flexion larvae was faster in autumn cohort than in spring cohort. This may be related to seasonal variation of water temperature and productivity. We also found that most of the juvenile took advantage from the faster growth rate in the early stage. Such superiority was found from the very first day and throughout their early stages in spring cohort, but not obvious till post flexion stage in autumn cohorts. The sephenomena suggested that there is a selective mortality existed in this species, and their adaptations to the environmental selection pressure were different between spring and autumn cohorts.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 9.30am – 9.45am

Hatchdate Distributions and Mortality of Cape Anchovy, Engraulis encrasicolus, in the Southern Benguela Ecosystem

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4. CEFAS, Lowesoft, Suffolk, England, UK.

Otoliths of larval and juvenile Engraulis encrasicolus of the strong 1999/2000 year-class were collected during two routine surveys off South Africa, in Marchand May 2000 respectively. Sub-samples were selected proportional to the length-frequency distributions. From readings of daily increments, hatchdate distributions were back-calculated from each period. Differences between the two apparent hatchdate distributions were investigated to draw possible correlations between the prevailing temperatures and these differences. Instantaneous daily mortality coefficients (Z) calculated from log-transformed catch-at-age curves were 0.035 for March larvae and 0.020 for May juveniles. These correspond to daily mortality rates of 1.98 % and 3.44 % respectively, and were used to back-calculate hatchdate distributions. Hatchdate distributions of both periods showed two modes, September/October 1999 and December/January 2000 for March larvae and a month earlier respectively for May juveniles. Thus, it appears that mortality of larvae hatched after mid-December 1999 was heavier than for those hatched earlier. Large areas of >19°C sea surface temperatures (SST) on the Agulhas Bank from August 1999 to March 2000 indicated reduced offshore losses, and thus conditions conducive to spawning and good survival of eggs and yolk-sac larvae. A period of strong up welling (anomalously low SST) followed from March to May 2000. This is likely to have increased availability of planktonic food for older larvae and juveniles. Also, up welling may have caused offshore dispersal of food patches needed by younger larvae, which may have lead to age-selective mortality by starvation. Hjort's critical period thus appears to be later than at first-feeding.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 9.45am – 10.00am

Otolith Microstructure Analysis Reveals Selective Survival of Young-of-the-Year (YoY) Sprat, Sprattus sprattus, from the Central Baltic Sea

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The sprat is a small, short-lived, zooplanktivorous clupeid that plays a key role in the trophodynamics of the Baltic Sea. During the extended spawning season (typically March-July in the Central Baltic Sea), environmental conditions conducive for larval growth vary considerably, suggesting that a "time-window" of optimal conditions may exist leading to enhanced larval survival. Otolith microstructure analysis was used to determine the day of first increment formation (DFF, used as a proxy for hatch date) in YoY sprat caught in October 2002 in the Central Baltic Sea. The DFF-distribution was then compared to field measurements of larval abundance between March and November 2002 in the Bornholm Basin, one the most important spawning grounds for Baltic sprat. Mean age of survivors was 125.1 days after first increment formation (SD=12.47 days, n=90), indicating that the majority of survivors had hatched in June 2002 (mean=18.6.02). Two distinct peaks in larval abundance were observed, a main peak in spring (April) and another, smaller peak in summer (June). The latter coincided with the DFF-distribution of YoY-sprat, presenting strong evidence for a selective survival of summer born sprat compared to sprat born earlier during the 2002 spring peak in larval abundance. Mean growth trajectories were notably different between survivors that hatched during subsequent fortnightly intervals. The pattern indicated that during the larval stage (<30 days after DFF), sprat that hatched later in the season grew faster than their earlier born conspecifics, whereas individuals with lower larval growth rates showed consistently faster growth as post-metamorphic juveniles (>70 days after DFF). Our findings comprise a necessary step towards a better understanding of processes responsible for growth and recruitment variability of sprat in the Baltic Sea.

Theme 9 – Technological Developments
Room: Ballrooms 2 & 3
Time: 9.00am – 9.15am

AFORO: An Interactive Shape Analysis and Classification System for Fish Otoliths

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Sagitta otolith shape variability was related with fish environment and their genetics. Otolith shape provides information of species, their ecobiological parameters and fish geographic origin. Here we present the implementation of an interactive system to deal with shape analysis of fish otoliths and a classification system based on the mathematical properties of the one-dimensional curves describing the otolith contours. The system is connected to a database of complete morphometry information and otolith images of well identified samples. At present the database contains around 1000 high-resolution images corresponding to 200 species mainly from the Mediterranean and Antarctic Seas. Queries are based directly on the numerical descriptors of otolith contours from their images. At present three main numerical descriptors have been implemented:FFT and wavelet spectrums and curvature scale space (SCC) representation of the otolith shape. As a first approach the classification strategy is based on a weighted algorithm of cluster analysis over the indexed numerical descriptors. The user may interactively change the search strategy according to the best descriptor. The otolith database, the shape analysis and the classification system are included into a web based environment, where a server links the database with the numerical routines to perform shape analysis, written using open source technology (Java, Postgress and Scilab) to ensure portability and development control.

Theme 9 – Technological Developments
Room: Ballrooms 2 & 3
Time: 9.15am – 9.30am

A Comparison of Electron and Proton Microprobe Analyses of Strontium Distribution in Salmonid Otoliths

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The strontium (Sr) distribution in fish otoliths, as determined by several analytical instruments, has found widespread use as a means of retrospectively assessing life history traits of individual fish, in particular, migrations between fresh- and saltwater. In this study, two of these analytical instruments: the wave-length dispersive electron microprobe (WD-EM) and the scanning proton microprobe (proton-induced X-ray emission or PIXE) were used to measure the Sr distribution in 12 otoliths from four species of salmonid fishes and the results were compared. In general, the Sr distribution profiles produced by WD-EM and PIXE were similar for all otoliths analyzed, however, subtle increases and decreases in Sr, which may occur as a result of brief migrations to and from a marine or estuarine environment, were more likely to be detected by WD-EM while PIXE was more likely to collect more Sr data at the outer margins of the otoliths. Problems associated with preparation of the otoliths and applications of the methods are discussed.

Theme 9 – Technological Developments
Room: Ballrooms 2 & 3
Time: 9.30am – 9.45am

Otolith Shape Feature Extraction Oriented to Artificial Neural Network Classification

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Otolith shape classification is a common procedure in otolith related studies(morphological, taxonomical, palaeontological and food web analysis). This study reviews some of the critical pre-processing steps required for otolith shape classification in basis to Artificial Neural Networks (ANN):contouring, shape codification and shape feature extraction. ANNs are powerful tools for automatic data classification. ANNs are non-linear models that develop weighted links between network processors (hidden neurons)and both data input values and target output classes. A common procedure for optimising ANNs classification is the application of data pre-processing, in order to reduce the dimension of vector inputs. Sets of requirements for otolith image acquisitions are proposed in order to obtain a robust contouring procedure. Several codification methods (radial signature, complex contour and Freeman chain codes) are evaluated, pointing out the limitations (loss of information) and the benefits (invariance to affine transformations) associated to each method. Three different types of descriptors are presented: morphological based, statistical based and spectral based. A comparative study of the shape descriptors is developed, focused on data reduction techniques for optimising ANNs classification.

Theme 9 – Technological Developments
Room: Ballrooms 2 & 3
Time: 9.45am – 10.00am

Otolith Shape Contour Analysis Using Affine Transformation Invariant Wavelet Transforms and Curvature Scale Space Representation

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Two decades ago different methods and techniques related to image analysis began to be used in fish otolith studies (ageing, stock determination, species identification). In this paper we show the application of two recent signal processing techniques (wavelet transform and curvature scale space), which complement the information gathered using Fourier analysis methods. The motivation comes from the necessity to perform an otolith analysis capable of localizing its contour singularities, since these are very important points in automated identification tasks, very close to landmark selection done by trained human operators.

The wavelet transform (WT) is computed by expanding a signal into a family of functions that represent the dilations and translations of a unique function known as a mother wavelet. As a difference to the Fourier transform, which is defined by an integral covering the whole signal, the wavelet transform is based on an analysing function located both in space and frequency, having the ability not only to measure the irregularities of the signal but also to establish its position.

The Curvature Scale Space (CSS) representation is another technique that maps the evolution of the inflection points of a shape contour when this is smoothed at increasing scales, providing a curve analysis invariant under scale, translation and rotation image changes.

The robustness of these techniques in otolith shape studies is illustrated through a classification system based on a distance measure. We test its performance to recognize otolith images stored in a database, under affine transformations, shear and in the presence of noise.

Additionally these techniques can be used for data compression purposes, which is very important for remote retrieval and broadcasting of large databases.

Keynote Address, Theme 6 – Statistics and Modelling
Room: Ballroom 1
Time: 10.30am – 11.00am

Estimating Age from Otolith Measurements: A Review and a New Approach

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In 1985, Boehlert suggested that fish age could be estimated from otolith measurements. Since that time, a number of inferential techniques have been proposed and tested in a range of species. We review these techniques and show that all are subject to at least one of four types of bias. A new flexible method of inference based on mixture analysis is proposed which avoids these biases and makes better use of the data. We argue that the most appropriate technique for evaluating the performance of these methods is a cost-benefit analysis which compares the cost of the estimated ages with those of the traditional annulus-count method. A simulation experiment is used to illustrate both the new method and the accompanying cost-benefit analysis.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 11.00am – 11.15am

What Can the Microstructure of Otoliths Tell Us About the Early Life-History of Yellowfin Whiting?

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The fishery catches of yellowfin whiting (Sillago schomburgkii) are highly variable, most likely a consequence of variable recruitment. This will likely relate to the species' poorly understood early life-history. The aim of this study was to describe the early life-history by the retrospective analysis of otolith microstructure of juvenile fish. Preliminary investigations of the sagittae of yellowfin whiting indicated that transverse sections provided the best view of the microstructure. The microstructure of otoliths of fish collected from several sites were analysed to provide information on the somatic and otolith growth rates, the period of spawning and settlement, and estimates of pre-settlement duration.

The daily periodicity of increment formation was validated based on known-aged, reared fish. First increment formation occurred at five days. Standard length and otolith length showed a proportional relationship allowing back-calculation of individual growth trajectories. Pre-settlement growth rates increased from 0.1 to 0.5 mm.day-1, and post-settlement growth rates, although variable, occasionally exceeded 1 mm.day-1. Spawning occurred between mid November and mid February. Estimates of pre-settlement duration ranged between 23 and 28 days.

The estimates of growth rates and pre-settlement duration were more similar to those of tropical species than to other temperate species from southern Australian waters, probably a consequence of the species inhabiting highly insolated tidal sandflats, and the warm summer waters of the northern gulf regions of South Australia.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 11.15am – 11.30am

Seasonal Growth of Otoliths of White Perch, a Warm-Water Species, in Temperate Great Lakes Waters

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Understanding seasonal growth of otoliths provides insights into otolith microchemistry, thermography, qualitative and quantitative otolith deposition, and factors influencing them. Invading white perch, a typical warm-water fish(optimum 28.8C), dominate inshore fish communities of the temperate waters (midsummer 23.3C) of the Laurentide Great Lakes. Intensive sampling in eastern Lake Ontario, provided otoliths (N=867) to examine seasonal growth. Sampling throughout 1993 and 1997, thermally typical years, provided insights concerning otolith growth of a warm-water species living at temperatures below optimum. The first increment was highly significantly correlated with only peak summer temperatures (July, r=0.704) and much reduced in the cold Pinatubo year of1992. Otolith growing season was strongly influenced by temperature commencing on May 29 (15.3C) and extending over the 15C temperature range (5 months) with most rapid growth over the 20C range (3 months). Maximum otolith growth occurred July 19, 1993, and July 15, 1997. The season for otolith growth is short and rapid: 50% of growth occurs in 55 days. Body growth was much more variable. Qualitative otolith conditions are described in relation to seasonal growth cycle. From this more precise understanding of appositional growth of white perch otoliths, age and growth can be more accurately estimated and related to temperature, and the reconstruction of otolith thermal history can be validated.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 11.30am – 11.45am

The Importance of Rapid Growth for Early Life History Stages of Sablefish

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Larval and early juvenile sablefish (Anoplopoma fimbria) reside in neustonic waters of the Northeast Pacific. In laboratory experiments their growth potential, behavior, and physiology all suggest a strategy of maximizing rather than optimizing growth, in contrast to many other species. These results imply strong selection for large body size, rapid growth, or shorter stage duration for larvae during their initial neustonic period. We collected larvae and juveniles from 1993-2001, with 2–3 cruises per year at 2–3 week intervals from March-May, consistently spanning the early residence of annual cohorts in the neuston. Our objectives were to 1) Examine inter annual variability in growth patterns and link differences to variability in oceanographic factors; 2) test for size-selective mortality within each year, and 3) compare natural growth rates with the extremely rapid growth previously observed in the laboratory. We measured complete series of increment widths from lapillar otoliths for 10–20sablefish from each cruise in each year. Results will be compared with other studies to contrast life history patterns of sablefish with other species that have pelagic larvae.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 11.45am – 12.00pm

Effects of Age and Environment on the Shape of European Eel (Anguilla anguilla) Otoliths

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2. Institute of Marine Research, Lysekil, Sweden
3. Image Science Software GmbH, Berlin, Germany
4. Danish Institute for Fisheries Research, Department of Marine Fisheries, Charlottenlund, Denmark

Eels are slow growing benthic species with complex life histories and a strong phenotypic plasticity making their otoliths difficult, laborious and subjective to interpret. To find an easier, faster and more objective method for ageing eels the effects of age and environment on the shape of their otoliths were analysed. Eels were stocked as elvers in two eel-free lakes in Southern Sweden (i.e. different environment) and later sampled during different years to produce two collections of known age otoliths. The otolith shapes were acquired from digital images and analysed and described by using several Normal Fourier Descriptors (NFD) and morphometric variables. ANCOVA was used to remove the effect of otolith size on the magnitude of each morphometrics variable. To reduce the number of dependent variables, we used Principal components analysis. MANCOVA with fish age as covariate was used to test for differences in the otolith shape(both NFD and morphometric variables) between different environments. Results showed that there is no highly significant difference in the otolith shape between environments. A tree-model was used for predicting age using both NFD and morphometric variables, with the variables selected using a stepwise method. The results of the model indicated that otolith shape (defined as above)could be used to predict age of European eel with a success rate between 71 and 81% depending of the complexity of the model and the variables used.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 12.00pm – 12.15pm

Dynamics of Growth Histories in 0-age of Two Clupeid: Etrumeus teres and Sardinops melanostictus

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Individual daily growth rates (IGR) of 0-age E. teres and S. melanostictus caught in Tosa Bay (one of their primary nursery and spawning grounds),southwestern Japan, were back calculated from first feeding through 5 months of life for the 2000-2003 year classes. Hatch dates showed two distinctive groups in both species: autumn and winter, although their occurrence varied among years. Growth trajectories of juveniles spawned in a same season showed three stages irrespective of species or year class: a fast-growth period (FGP) from first feeding (0.5-0.6 mm/d) to the 20th day (0.8-1 mm/d), a variable-growth period (VGP; 20th – 70th day) and then a slow-growth period (SGP; a marked and continued decline in IGRs). For S. melanostictus, IGRs were higher in 2001(1.10) and 2002 (1.14) than in 2000 (0.88) and 2003 (0.89 mm/d) yr. classes during the VGP. The overall growth rate (TL at catching – size at hatching]/age]also varied among years, although growth rates were lower in E. teres (0.57;0.72; 0.78; 0.60 mm/d) than in sardine (0.78; 0.95; 0.95; 0.84 mm/d) for 2000, 2001, 2002 and 2003, respectively. The slower IGRs of E. teres occurred during both the VGP (0.74 mm/d) and SGP (IGRs decreased from 0.71 to 0.23 mm/d). Juveniles spawned in autumn grew faster than winter-spawned juveniles during the VGS; the opposite occurred during the SGP. Findings suggest that most the growth variability of both species occurs during the metamorphosis from larvae to juveniles, which may be critical for survival and subsequent year class strength.

Theme 6 – Statistics and Modelling
Room: Ballrooms 2 & 3
Time: 11.00am – 11.15am

How to Estimate Philopatry and Movement Using Otoliths as Natural Tags

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Scientists use applied and natural tags to determine population structure by estimating natal homing and migration rates. Estimation procedures from applied tags are well understood and scientists have developed a large statistical literature on the subject. In contrast, there is virtually no statistical foundation for the use of natural tags as estimators of natal homing and migration. Certain characteristics of natural tags, such as the uncertainty of their abundance in the population, nullify the use of established statistical procedures and force the derivation of new estimators and techniques of estimation. The burgeoning use of otolith-geochemical signatures as natural tags further motivates the derivation of correct estimators to preclude misuse of applied-tags in this developing field. I present the newly-derived estimator for natural tags and discuss how it must be used to obtain correct estimates of natal homing and movement with otolith-natural tags.

Theme 6 – Statistics and Modelling
Room: Ballrooms 2 & 3
Time: 11.15am – 11.30am

Numerical Reconstructing of Age Distribution in a Population Using Fredholm First-Kind Equation

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For many fish stocks distributions of age-dependent variables, such as length or otolith weight, remain relatively stable at any given age. Therefore size and other distributions in a population can be considered as indications of the age composition. Using known probability distributions-at-age the unknown age distribution in a sample can be obtained. As distinct from the classical age-length-key method no data on the age composition-at-size are required. Therefore individual ageing data need not be regenerated for each new sample. The development of this approach leads to a reduction of cost and time for production ageing data. This paper details reconstruction of the unknown age composition using the Fredholm first-kind equation. The methods of 'ill-posed problems' are used for numerical solving of the equation. These methods have well-known credibility in applications to noisy data. This technique was trialed on data, which we retreated as populations with known age distributions. Randomly sampled length-at-age, otolith weight-at-age and 2-dimensional length / weight-at-age frequencies were used. The results were compared to the known age distributions, and the trend of errors was plotted against sample size of aging data. The efficiency of the method was calculated as the ratio of accuracy and sample-size(cost) of the aging data. The correction of size-specific sampling bias can be incorporated into this numerical technique. Therefore data collected using fishing gears with different size selectivity can be combined to improve data utilisation. This powerful approach has the potential to be extended to many other aspects of quantitative fishery.

Theme 6 – Statistics and Modelling
Room: Ballrooms 2 & 3
Time: 11.30am – 11.45am

Testing Larval Fish Dispersal Hypotheses Using Maximum Likelihood Analysis of Otolith Microchemistry Data

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Otolith microchemistry analyses may enable researchers to follow the dispersal pathways of individual fish through time. Given that water masses have spatially or temporally variable chemical signatures (or correlates thereof, e.g., temperature) and that this variability can be modeled statistically, we have the potential to describe the dispersal history of a fish by examining a temporal transect of trace metal concentrations throughout the otolith. Typical approaches to this end include microchemical data generated from laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS). Previous statistical analyses tend to focus on the temporal trajectories of individual elements or have analyzed multiple elements at single points in time. In addition, these approaches have generally discarded potentially valuable data by using traditional statistical tools that do not fully model process uncertainty and observer error present in the data. We have developed novel statistical techniques to allow more detailed exploration of elemental signatures from microchemical transects using maximum likelihood methods. The benefit of such an approach is the ability to model the chronological series of otolith measurements for all fish and all elements simultaneously, while providing explicit treatment of variability in the data. We use data from fish populations on the island of St. Croix to compare traditional analysis techniques with this likelihood-based approach, showing the potential to better test specific hypotheses regarding the dispersal trajectories of individual fish within a population. Through the incorporation of all available microchemical data, we can explore more detailed models of fish movement than were possible using existing approaches.

Theme 6 – Statistics and Modelling
Room: Ballrooms 2 & 3
Time: 11.45am – 12.00pm

Statistical Learning Applied to Fish Age and Growth Analysis

Fablet, R*, Le Josse, N
Ifremer/LASAA, Plouzanne, France

In this presentation, we investigate the use of statistical learning techniques for fish age and growth issues. Following Morison and Robertson 1998, we first tackle the determination of fish age from otolith images using two learning strategies (Neural Networks and Support Vector machines). We particularly focus on the extraction of new relevant descriptors of the content of otolith images. We combine a semi-local template framework with an adapted growth-based filtering. Besides, a procedure based on demodulation and remodulation of fish growth patterns is used to improve the generalization properties of the trained SVM and NN classifiers. The performances of these techniques are evaluated on a database of Plaice otoliths from age class 1 to 5 using different feature sets (combining or not biological, geometric and image features). With rates of correct age estimation between 85% and 88%, these experiments validate the relevance of the proposed feature sets compared to previous work. In a second step, we aim at using statistical learning for fish growth modeling. Rather than describing fish growth patterns in terms of a mean a priori model, our goal is to build a statistical model evaluating the relevance of a given fish growth pattern. The potential applications are numerous: for instance, computer-assisted aging to help the expert in discriminating ambiguous configurations, checking the coherence of expert readings, selecting/rejecting growth patterns issued from automatic aging schemes. We discuss the training of the proposed statistical growth model and its use for the interpretation of plaice otoliths.

Theme 6 – Statistics and Modelling
Room: Ballrooms 2 & 3
Time: 12.00pm – 12.15pm

Modelling Otolith Growth: A New Approach to Age Validation in Tailor (Pomatomus saltatrix).

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1 Southern Fisheries Centre, Deception Bay, Australia
2 Animal Research Institute, Yeerongpilly, Australia

Tailor populations in Queensland are subject to a significant seasonal recreational angling fishery located mainly along the southern ocean beaches. The fishery occurs principally in winter-spring (August-November) during the period when the schooled-up fish are undertaking their annual northward spawning migration. Previous high estimates of total mortality rate for the east coast stock were based on un-validated age data from angler catch samples. In a recent study we validated the aging technique using tetracycline and calce in marking. However, because of unexpectedly poor tag recapture rates (particularly amongst fish that had been at liberty for more than a complete annual growth cycle) we were unable to rely on the classic direct fluorescence analysis techniques. Instead, we modelled otolith growth, incorporating a seasonal component, which predicted maximum growth in February and minimum in November. This is consistent with seasonal changes in coastal water temperatures in the area where this species occurs. Further modelling of predicted vs. observed otolith growth under three scenarios of growth band deposition periodicity (bi-annual, annual and biennial) clearly favoured the annual scenario, confirming our interpretation of the banding structure in tailor otoliths.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 1.30pm – 1.45pm

Contrasting Growth Rates and Stable Isotope Signatures of Larval Fish in Upwelling Regions

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2. National Research Institute of Fisheries Science (NRIFS), Kochi, Japan

Australian fisheries may well be nutrient limited. Two summer research cruises to an up welling system, driven by the East Australian Current off the northern coast of New South Wales, Australia, revealed a striking contrast in the growth rates of larval fish. Larval pilchard, Sardinops sagax had significantly reduced growth in the upwelling regions off Diamond Head (31°S), compared to those from non upwelling regions to the north. Water temperature was not a significant factor. Nevertheless, larval pilchards were significantly more abundant in the upwelling region. Parallel early life history with the pilchard in the Kuroshio extension suggests the importance of the Tasman Front well offshore. Growth rates of pilchard larvae were correlated with their stable isotope signatures (15Nitrogen and 13Carbon), on both cruises, linking the different growth rates with a different diet. In complete contrast, two larval carangids, Pseudocaranx dentex and Trachurus novaezelandiae were less abundant in the upwelling zone, but had significantly faster growth at the post-flexion stage in the upwelling compared to non-upwelling region, and with consistent changes in their isotope signatures. Preflexion carangids showed no significant difference in size-at-age among regions. All three species had different isotope ratios among regions. The complex roles of species and stage specific responses to the spawning location, growth and mortality are revealed by a combination of growth and stable isotope signatures. Upwelling of nutrient rich water and the stage duration hypothesis may not be a general mechanism underpinning year class strength variation.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 1.45pm – 2.00pm

Revealing Fitness Costs of High and Low Metabolic Rates for Larval Herring Using Otolith Microstructure

Bang, A[1]*, Grønkjær, P[1], Folkvord, A[2]

1. Department of Marine Ecology, University of Aarhus, Aarhus, Denmark
2. Department of Fisheries and Marine Biology, University of Bergen, Bergen, Norway

The study seeks to identify effects of metabolic rate on the survival and growth of individual fish larvae. The otolith size at hatch is used as a measure for metabolic rate based on the assumption that a large hatch-check reflects a high metabolic rate and vice versa. The hypotheses are; 1) Larvae with a high metabolic rate as an embryo grow faster during periods of high food availability yielding an advantage in the form of decreased stage duration and, as a consequence decreased stage-specific mortality. 2) Larvae with a low metabolic rate will have an advantage during periods of low food availability because of lower energy demands and, hence, they will be able to survive longer without food. To test these hypotheses, 450 herring larvae were reared in each of six tanks with three different food regimes; high and low food plus a starvation group. For the duration of the experiment (5 weeks), growth controls were taken each week to see whether larvae with a large hatch check grew faster than conspecifics with a small hatch check when food was plentiful. Furthermore, dead larvae were sampled each day to see if a small hatch check meant longer survival when food was scarce or absent.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 2.00pm – 2.15pm

Effects of Environment on Survival and Abundance of Larval Suckers from Upper Klamath Lake, Oregon

Terwilliger, M*, Cooperman, M, Markle, D
Department of Fisheries and Wildlife, Oregon State University, Corvallis, USA

The shortnose sucker Chasmistes brevirostris and Lost River sucker Deltistesluxatus are endemic to the Upper Klamath Basin of southern Oregon and northern California, USA. Upper Klamath Lake in south-central Oregon is the primary refuge for both species. These species were federally listed as endangered in1988 following eighteen years of apparent recruitment failure. Both species are obligate lake-dwellers except during spring, when most adults swim up lake-tributaries to spawn. Spawning for both species is protracted, temperature dependent, and the first recruits typically appear in Upper Klamath Lake in early April. Otolith-derived hatch dates of surviving fall-captured juveniles, coupled with results of annual larval surveys (1995-2001), indicated that both relatively early-hatched (early April) and late-hatched (late June-early July) larval cohorts do not recruit into the juvenile population. We used a combination of linear regression, unconstrained multivariate ordination, and discriminant function analysis to explore the relationship between habitat conditions and larval sucker abundance and survival. The three families of analyses yielded complementary results and indicated that air temperature (and its effect on larval growth rate), the proportion of high wind events, and the availability of emergent macrophyte habitat interacted to strongly influence the abundance and survival of larval suckers.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 2.15pm – 2.30pm

Growth – Mortality Hypothesis Evaluation for Atlantic Menhaden (Brevoortia tyrannus) Larvae

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1. *Sea Fisheries Institute, Department of Fisheries Oceanography and Marine Ecology,Gdynia, Poland*
2. *NOAA National Ocean Service, Center for Coastal Fisheries and Habitat Research, Beaufort, USA*

This study tests the 'growth-mortality' hypothesis for Atlantic menhaden larvae. After being spawned in offshore coastal waters, menhaden larvae are carried into estuarine nursery areas by currents, where they transform into juveniles. This 1–3 month-long larval period is characterized by high mortality and may be an important determinant in eventual year-class strength. Age and hatch dates of larval menhaden recruiting to the Beaufort estuary during 1988–1999 were estimated from daily otolith increment counts. Furthermore, growth rates of specimens classified to low and high survival periods, within and between year-classes, were analyzed. This analysis included individual somatic growth trajectory back-calculation from otolith increment widths (data from 5 years), as well as fish length at age comparison (data from 14 years). In addition, temperature effect on growth rate was evaluated for fish origin from different year-classes, and different spawning periods within one year-class. Finally, summary of the recruitment characteristics (fish size and age, arrival period) for menhaden larvae incoming to Beaufort estuary during 14 years of observations were addressed.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 2.30pm – 2.45pm

Short-Term Uncoupling of Otolith and Somatic Growth Induced by Food Level Changes in Post-Larval Baltic Sprat, Sprattus sprattus

Baumann, H*, Peck, M A, Herrmann, J
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We studied the effects of different and changing feeding regimes on otolith and somatic growth in 40 to 70 day old, post-larval Baltic sprat. Otoliths were marked using alizarin complex one (50 mg l-1 for 18 h) and fish reared for 11days under zero, low, and ad libitum feeding conditions. During a subsequent 11dperiod, feeding regimes were reversed in half of the low and ad libitum feeding treatments, and starved fish were re-fed ad libitum rations. Irrespective of experimental period or previous feeding treatment, somatic growth was rather similar in all the low (means s.d.=2.40.57 mm d^{-1}) and the ad libitum (means s.d.=6.00.67 mm d^{-1}) feeding treatments leading to significant differences in length and weight among fish in different feeding treatments. Previously starved fish, however, grew only 2.9 mm $11d^{-1}$ when re-fed ad libitum rations. Significant linear relationships were found for otolith growth and increases in length and weight across all treatments ($P=0.007$, $r=0.94$) during the first period, but not after feeding regimes were changed ($P=0.31$, $r=0.33$).Widths of increments formed directly after the food changes were least correlated with somatic growth but, after a time-lag of 9 days, increment widths were again significantly related ($P<0.05$) to length growth. Despite the existence of a generally good correspondence between otolith and fish size, we found that otoliths continued to grow during times of stagnant length growth and that slow somatic growth resulted in disproportionately large otoliths. Our findings confirm daily increment formation in post-larval sprat otoliths and provide a time course of response in otolith microstructure to changes in somatic growth. The results will aid our interpretation of otolith growth patterns of field-caught sprat within this scarcely studied life-stage.

Theme 3 – Age and Growth Estimation and Validation
Room: Ballroom 1
Time: 2.45pm – 3.00pm

Multiple Condition and Growth Measures of Individual Larvae: How do they Compare?

Folkvord, A*, Hie, H, Johannessen, A
Department of Fisheries and Marine Biology, University of Bergen, Bergen, Norway

The responsiveness and latency of several condition and growth indices were studied on herring (Clupea harengus) larvae reared under controlled conditions in the lab. Larvae were reared at to two temperatures (6 and 10C) and two food levels (low and high). Sub-populations of larvae from the main rearing groups were subject food restriction at three periods during the larval period. Individual growth and condition measures (otolith, RNA:DNA, weight: length based)were compared with observed patterns in population growth rates in respective treatments. Survival including sampling was high and averaged 90–95% in the high food level groups after the 8 week experimental period, providing a reference against which the other groups could be compared. The otolith based condition and growth measures were generally not applicable for the lowest temperature group due to low daily incremental otolith growth. In contrast, the otolith increment width pattern generally predicted individual growth history at the high temperature group. The RNA:DNA based indices correctly assessed previous feeding conditions(and starvation) in both temperature groups, with a shorter latency in the high temperature group. Weight: length based condition measures of starved groups reflected extent of starvation when contrasted against high food level groups, but this had to be done on a temperature specific basis. The benefits of using multiple condition measures and the added value of using otolith data on individual larvae are discussed.

Theme 6 – Statistics and Modelling
Room: Ballrooms 2 & 3
Time: 1.30pm – 1.45pm

Cross-Correlating Time Series of Otolith Growth Increments to Validate Ages in Long-Lived Fishes

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1. Hatfield Marine Science Center, Oregon State University, Newport, USA
2. NOAA National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, USA

Fish growth varies as a function of physical and biological variability. We use the population-level climate signals in otolith increment widths to validate age estimates. Otoliths of a Pacific rockfish species, Sebastes pinniger, were cross-sectioned along the dorsal-ventral axis. Annual growth increments in each otolith were measured along a continuous, curved transect from the focus to the dorsal distal increment margin. To isolate the high-frequency climate signal, each otolith time series was fit with a cubic spline and observed ring widths were divided by the predicted values. Next, autocorrelation was modeled and removed from each otolith time series. Using the transformed time series, the arithmetic mean of growth increment was calculated for each calendar year to generate a master, population-wide chronology. Each individual otolith time series was correlated with the master chronology. Agreement between the master chronology and otolith time series indicates a high degree of precision, which we consider to be a result of common responses to climate variability. Any time series with a low correlation was remeasured and age estimates were adjusted to determine whether the correlation improved. The population-wide master chronology was correlated with patterns of environmental variability, including the ENSO index. A significant correlation between growth and ENSO provides a measure of age-validation accuracy; years of severe El Niño events correspond with years of abnormally narrow growth increments. This cross-correlation approach is commonly used in dendrochronology and also provides a powerful tool for evaluating the precision and accuracy of otolith age estimates.

Theme 6 – Statistics and Modelling
Room: Ballrooms 2 & 3
Time: 1.45pm – 2.00pm

Using Mixed-Effects Models to Analyze Data from Otoliths: Applications in Fisheries Science

Vigliola, L

Secretariat of the Pacific Community (SPC), Noumea, New Caledonia

To provide decision-makers with the necessary information for management, the SPC is conducting a comparative assessment of reef fisheries throughout the tropical Pacific. Estimates of key demographic parameters such as age, growth, size at settlement or at sexual maturity are crucial to this assessment, and back-calculation from otoliths provides a cost-efficient means to gather such information. However, data back-calculated from otoliths presents a challenge for statistical analysis as it is typically longitudinal, unbalanced and auto-correlated. Fortunately, non-linear mixed-effects models (nlme) have recently been developed to analyse datasets with such special properties. Here I show how data derived from otoliths can be processed by nlme to estimate growth rates, develop age-length keys, compare individual growth trajectories of fish from several populations or from sequential samples (size-selection), and investigate linkage between growth processes and environmental factors.

Theme 6 – Statistics and Modelling
Room: Ballrooms 2 & 3
Time: 2.00pm – 2.15pm

Comparing Growth Curves: Statistical Significance is not the Same as Biological Significance

Manning, M J
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Estimating fish ages from counts of growth rings in otoliths then fitting statistical models of growth to length-at-age datasets is one of the most common applications of otolith-derived data in fisheries science. Unfortunately, the methods used to fit and compare growth models are often inadequate, or where adequate, inadequately specified. Furthermore, the distinction between statistical and biological significance is often not considered. The use of maximum-likelihood methods to fit growth models and the likelihood ratio test to compare competing models is emphasised as a framework that allows competing, hierarchical growth models fitted to the same dataset to be compared quantitatively. The use of quantitative stock assessment models to explore the relationship between statistically and biologically significant differences in competing growth models is discussed. An example using giant stargazer, Kathetostoma giganteum, is provided. Different on Bertalanffy growth models assuming separate growth for different groups within the same dataset are fitted using maximum likelihood methods and compared using the likelihood ratio test. Yield-per-recruit analysis is then used to explore the relationship between statistical and biological significant differences in the competing models. The implications of these results are discussed.

Theme 6 – Statistics and Modelling
Room: Ballrooms 2 & 3
Time: 2.15pm – 2.30pm

A Statistical Methodology for Otolith Ageing Validation via The Bomb Radiocarbon Chronometer

Hamel, O*, Wallace, J, Piner, K
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Atmospheric testing of nuclear weapons during the middle of the twentieth century produced an increase in radiocarbon levels in the atmosphere and oceans. Over the past decade, this bomb radiocarbon signal has been shown to be useful in ageing validation. Numerous studies have utilized this unique temporal signal in comparing the relationship of 14C levels in the otolith core to annulus-count estimates of hatch-year among species. Recently, two studies have used otoliths from known-aged fish to develop reference relationships between hatch-year and14C levels. We present a statistical methodology to rigorously compare test datasets to reference data. A single strong reference data set is produced from the two studies using known age fish from the North Pacific and North Atlantic oceans. Using this reference data, we show evidence of under-ageing for several species and discuss other possible explanations for the observed results. Data selection methods are set forth that allow testing for consistent and age-dependent ageing bias as well as for differences in the rate of change of the environmental signal among the rearing areas used by different species.

Theme 6 – Statistics and Modelling
Room: Ballrooms 2 & 3
Time: 2.30pm – 2.45pm

Determining Appropriate Sample Size to Measure Differences Between Two Age Estimates

Schirripa, M J
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Age determination of fish using counts of annual rings (annuli) laid down in hard parts, such as otoliths, is not an exact science. The uncertainty in age determination is often included in the assessment of the fish stock in the form of "ageing error". In order to characterize the uncertainty associated with age determination from fish otoliths, regular "double-reads" are performed. Several methods have been suggested to compare the precision of several age estimates on the same otolith but no where in the literature is any mention made of the appropriate sample size to use for the double-read comparison. The objective of this study is use simulation techniques to arrive at a estimate of sample size that is large enough to capture the true underlying characteristics of the paired age estimates, but not so large as to result in conclusions of bias where the bias is so small so as to make it meaningless. The number of double-reads required to determine if two sets of age estimates are in agreement was determined by such things as number of ages being considered, the statistic used to determine a difference, and the desired level of precision of that statistic being accurate. For data sets with an age range of approximately 0–20 (short-lived species) a sample size of 100 to 150 should be sufficient to get within 10% of the true diagnostic statistic. For data sets with an age range of approximately 0–20+ (long-lived species) a sample size of 200–250 should be sufficient to get within 10% of the true diagnostic statistic. Even though the number of ages being considered is often related to that particular species longevity, it is the number of ages in the data set that determines the required number of double-reads. Traditional sampling theory suggests that a certain percentage sub-sample (commonly 20%) be used to determine the necessary sample size. However, this analysis suggests that rather than relative sample size, it is better to think in terms of absolute sample size.

Theme 6 – Statistics and Modelling
Room: Ballrooms 2 & 3
Time: 2.45pm – 3.00pm

Otolith Based Analysis of Survival and Size-selective Mortality of Stocked 0+Pike (Esox lucius L.)

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2. *Danish Institute for Fisheries Research, Department of Inland Fisheries, Silkeborg, Denmark*

Several methods have been proposed in order to measure size-selection in fish using "before-after" comparisons. Here, a non-parametric spline fitting method, which yields a relative fitness curve based on a quantitative trait(e.g. otolith size) and a corresponding estimate of minimum size-selective mortality, is used to evaluate extent and source of mortality in groups of alizarin marked 0+ pike stocked at different times during the spring season in a lake (20 ha) and a drainable pond (0.5 ha). Very low survival through the first growing season (<2%) indicate that pike stocked late in season fell victim to cannibalism from larger native 0+ pike. In contrast, pike stocked early in the season exhibited significantly higher survival (>12%). Changes in the size distribution of the alizarin mark areas indicated that the major part of the mortality in these early stocked 0+ pike was size-dependent. The survival of the largest stocked pike was a factor four better than the average pike in the drainable pond and a factor three better in the lake. In both cases relative fitness increased dramatically above a threshold size. The size-selective mortality estimated for pike in the drainable pond (76.4%) and the lake (69.7%)could account for most of the mortality observed in these populations (74.0 and82.7%), which indicate that cannibalism is substantial. The close agreement between the absolute mortality calculated after draining the pond and the estimates from the otolith-based method suggests that this method yields robust estimates of the shape of the fitness curve.

Section Seven

Poster Abstracts



Variations on Otolith Microstructure of Sea-Bass (Dicentrarchus labrax L.) Larvae Under Different Food Regimes

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Sea-bass (Dicentrarchus labrax L.) larvae were reared for the first month of life under different food regimes (fed, starved, delayed) to set a condition index for this species based on the otolith microstructure. Previously, a marking experiment (with alizarine) was carried out to validate increment deposition for this species. It was observed that daily increment deposition begins the second day after hatching. It was also verified that the different food regimes applied do not affect otolith increment deposition periodicity, although they affect increment width. Non-fed larvae showed significantly smaller otoliths than fed larvae, but no variation in the number of increments was observed. Under this situation, larvae do not make use of more resources than needed for the increment deposition. When food was supplied to the delayed feeding larvae, a progressive increase of increment width was observed. After one week of feeding they reach similar values than fed larvae. A late fast experiment (2–3 days of fast) was conducted on the third week of larval life. We noticed a delay from the moment of fast until it was reflected in their otoliths. We calculated different condition indices based on the width of the outermost increments. We have found that, for D. Labrax, the most appropriate condition index among all we have used is the one based on the width of the last three complete growth increments.

The Relationship Between Metabolic Rate and Otolith Size at Hatch for Zebrafish

Bang, A.*, Grønkjær, P.

Department of Marine Ecology, University of Aarhus, Denmark

For adult fish, otolith growth has been shown to be associated with metabolic rate more than with somatic growth. Such a link has, however, never been shown for larval fish due to difficulties in measuring individual oxygen consumption rates (as a proxy for metabolic rate) of these small individuals. Using a new microsensor technique, oxygen consumption rates of individual embryos of zebrafish, Danio rerio, were measured and correlated to various traits at hatch. 39 embryos were measured every 6 hours until hatching, thus giving individual cumulated oxygen consumptions for the whole embryonic period. Significant correlations were found between egg size, cumulated oxygen consumption and sagittal area at hatch. The correlation between oxygen consumption and sagittal area was still significant when egg size was held constant and cumulated oxygen consumption during the embryo stage explained 34% of the variation in sagitta size at hatch. The otolith hatch check can, consequently, be seen to reflect the total integrated metabolism since its formation. Thus, the hatch check lends itself as a tool for studies of the effects of different metabolic rates for larval viability.

The Difference in Otolith Microstructure Between Damselfishes and Angelfishes at Early Life Stage

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Institute of Fishery Science, National Taiwan University, Taipei, Taiwan

Early life history pattern of coral reef fishes are diverse. To understand the relationship between otolith microstructure of the fishes and their life stage transition and habitat use, the young damsel fishes family Pomacentridae and angelfishes family Pomacanthidae were collected between May and September 2003 from the reef area of northeast Taiwan. Daily growth increments in otolith of the fish were examined using light microscope. It was found that growth increment width in inner part of the otoliths of damselfishes did not dramatically changed as that in angelfishes. This may imply that their early life history strategies were different. Angelfishes have a flexible pelagiclarval duration that will be extended till they meet suitable reef area for settle down. On the other hand, damselfishes, from eggs to young, live in the similar benthic environment, and thus, their otolith microstructures did not change much as angelfishes during early life stage transition. This study indicated that otolith microstructure could reflect the different early life history strategies of coral reef fishes.

Nutritional Conditions and Growth Rates in Sardine Larvae off Northern Portugal

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2.- Instituto de Investigação das Pescas e do Mar, Av. Brasília, Lisboa, Portugal

3. Laboratório Marítimo da Guia /IMAR. Faculdade de Ciências da Universidade de Lisboa, Campo Grande, Lisboa, Portugal.

We investigated the impact of winter upwelling events off Western Iberian on the survival of *Sardina pilchardus* larvae, through an analysis of nutritional conditions and growth rates among field-caught larvae, and related it to oceanographic conditions and food availability. The larvae were collected by four samples taken during a research cruise off northern Portugal, in February 2000. Environmental parameters, such as water temperature, salinity, food availability were also measured. Sardine larvae were aged using daily growth increments in sagittal otoliths. A highly sensitive fluorometric method for nucleic acid quantification was applied to larvae. Average (integrated) daily growth of sardine larvae sampled during the cruise varied from 0.384 mm/day (larvae with post-yolk absorption age up to 25 days) to 0.447 mm/day (larvae with post-yolk absorption age up to 50 days). The mean RNA/DNA ratios were relatively high, so almost all the larvae collected were generally in good condition. We consider that the present situation could support the 'stable ocean' and 'ocean triad' hypotheses.

The Relationship of the Otolithic Spatial Distribution and Morphology of Fish Heads: An Ecological Perspective

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2. Department of Biology, University of Kentucky, Lexington, USA
3. Department of Entomology, National Taiwan University, Taipei, Taiwan

The major sound and vestibular receptors of fish are the otolithic organs of the inner ears. Not only the shape and the size of otoliths are useful for taxonomical identification but also the distribution of otolith of larval fish has been proved to be species-specific. The work presented here tested hypothesis that the spatial distribution of otoliths is correlated to the morphology of the heads of various species of fish. Radiographs are used to photo dorsal and lateral view of fish head to obtain otolith and fish head landmarks in both vertical and horizontal planes. The Thin Plate Spline analysis methods (tpsDIG32, tpsRegr) are used to study the correlations among the four data matrices. The shape of fish head is likely related to their swimming and feeding behaviour. Thus, these two behaviour data matrices are also included for comparison purpose. The preliminary results show a significant correlation between otolith location and morphology of fish head. The significance of this correlation is interpreted in the light of ecological perspectives.

Crystalline Structure on Sulcus Acusticus of Some Thai Fish Sagittae from Different Habitats

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Sagittal otoliths from 3 species of bottom fish {Pristipomiodes typus(Lutjanidae), Nemipterus tambuloides (Nemipteridae) and Pardachirus pavominus (Soleidae)}, 3 species of coral reef fish {Cephalopholis miniatus, Cephalopholisargus (Serranidae) and Lutjanus decussatus (Lutjanidae)} and 2 species of inshore fish {Cephalopholis formosa (Serranidae), Alepes djeddaba (Carangidae)}were collected from coastal of Thailand. Structure of crystals on sulcusacusticus of these sagittae was studies by scanning electron microscope. The differences in shape, size, direction of crystalline arrangement and crystalline surface were found to be related to habitats. The crystals of bottom fish were separated into 2 types: type II was thin, rectangular crystals, stacked in horizontal plane, type II was thick, quadrilateral crystals, arranged invertical plane; surface of these crystals were smooth. In coral reef fish, the crystals were long, rectangular-shaped, large size, smooth surface and arranged in vertical plane. The rod-shaped, irregular surface, small size crystals were found in inshore fish and direction of crystalline arrangement was more complex than those two habitats. The structural differences of the crystals on sulcusacusticus of these sagittae might be related to the pattern of hair cell orientation of sensory epithelium in fish otolith organ which providing information that could be used in sound source localization in each habitat.

Comparative Features of Otolith Microstructure in the Young of Several Fish Species of the White Sea

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The otolith morphology was studied in the young of 16 fish species from the White Sea. The features of the sagitta and lapillus microstructure were described. The study showed that the sagitta morphology peculiarities were specific for each species, and they apparently reflected the features of early ontogeny of the species. Two groups of species were defined based on the ranges of values for sagitta nucleus radius. The first group included the species with the values of the sagitta nucleus radius less than 15 μm, and the second group included the species with these values higher than 15 μm. It was found that the size of the sagitta nucleus was associated with the features of ontogeny of the species. Inter specific differences in the otolith morphology were used to identify the young of the White Sea fishes. A key to the pelagic larvae and juveniles widely distributed in the ichthyoplankton of Velikaja Salma Strait based on the otolith microstructure analysis was developed. The key is complemented by the sagitta microphotos. The relationships between the sagitta radius and standard length of the individual were determined for some species.

Cephalopod Statolith Formation, Structure and Function

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Possible mechanisms of the cephalopod statolith formation are discussed in the light of the CORAL theory of calcium deposition. Formation of a fish otolith and a cephalopod statolith looks similar from the available evidence. Proteins, strontium and pH are all important in the dynamics of the deposition process. Proteins and Sr also serve as building materials, together with Ca. There is evidence that Sr is stabilising formation of Ca crystals, both in the initial phase of deposition and later, during the increment formation. Statolith shapes and chemical compositions are species-specific, however, this is associated with their function and ecological requirements of their specific life cycles. Therefore, physiological functions of a statolith are not limited to the linear acceleration control, but include control of complicated movements and hovering and act as a developmental archive. Can an animal access its own archive? This is an excellent research prospect, but largely unanswered question.

Otolith Atlas of the Central Atlantic Ocean and Western Mediterranean Sea

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The morphology of the sagittal otolith of 100 species of commercial interest inhabiting the eastern-central Atlantic and/or western Mediterranean is illustrated. The spatial distribution of the fishes included coastal pelagic, oceanic pelagic, coastal semi-pelagic, deep pelagic and epibenthonic species. Quantitative and qualitative features were used to identify specific trends. The most common otolith shapes were the fusiform, oblong or elliptic. Moreover, most otolith showed an opening sulcus in the ostial (rostral) region and the type of sulcus acusticus called 'spermatozoon'. The shape of the excisura ostii and the associated rostrum and antirostrum were used to describe specific features. In order to quantitative features, four basic otolith types were identified basing on the width/length rate: i) elongated, when the rate is less than 0.3;ii) rectangular, when the rate vary between 0.4 and 0.6; iii) rounded or squared, when rate ranges from 0.9 to 1.1; and iv) flattened, when the rate is higher than 1.1. Also, the relationship between otolith length/fish size provided very interesting specific information. Finally, we had observed that dorsal and ventral side could be useful to separate species; futher more, the future studies of the otolith shape should be tridimensional.

Influence of Sea Temperature and Other Factors on the Formation of Annual Growth Zones Within North Sea Cod Otoliths

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Cod (Gadus morhua) is near the limit of its distribution in the southern North Sea. This fact, combined with the relatively large sea temperature fluctuations experienced in this shallower area, might be expected to influence cod growth and development. This study will examine this by attempting to identify factors influencing the formation of increments within the otoliths of commercially caught North Sea cod. Otoliths for examination are selected from two time periods, with contrasting temperature regimes. For a range of ages, monthly measurements of the otolith marginal increment are taken. Multivariate analyses are used to relate both the timing of the onset of increment formation and the width of the increment to a number of covariates including temperature, growth rate and age (incorporating various life history factors). Identifying environmental and life-history variants that stimulate the seasonal pattern of otolith macrostructure in wild cod will improve both the ageing of this species (by reducing subjectivity) and help examine possible shifts in the onset of increment formation. The impact of changes in identified influential factors on interpretation and stock assessment can be anticipated.

Otoliths of Some Fish Species of the Irminger Sea

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PINRO, Russia

Otoliths are described for approximately 30 fish species from the Irminger Sea. These species belong to families Alepocephalidae, Searsiidae, Stomiidae, Argentinidae, Bathylagidae, Notosudidae, Evermannellidae, Paralepididae, Myctophidae, Serrivomeridae, Melamphaeidae, Anoplogasteridae and Chiasmodontidae. For some species fish size-otolith length relationships are presented.

Determining Natal Origin of Lake Ontario Chinook Salmon (Oncorhynchus tshawytscha) Using Otolith Microstructure

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The chinook salmon (Oncorhynchus tshawytscha) is an important component of the Lake Ontario sport fishery providing millions of dollars to local communities. Changes in habitat quality, specifically flow levels associated with Federal Energy Regulatory Commission reauthorization protocols, since the mid 1990s in the Salmon River, NY, may have led to increased natural reproduction in the system. Based on known-origin YOY chinook salmon from hatchery and wild sources we established a baseline for separating these two groups using otolith microstructure. A protocol was developed for determining hatchery or wild origin of adult spawners based on the daily growth characteristics in the vicinity of 300 ïm from the otolith core. These measurements were used to determine the origin of out-migrating chinook salmon smolts and returning adults sampled in and around the Salmon River. Variation in the wild proportion of returning spawners by year class provides valuable insights into the variability in recruitment of wild origin fish. The contrast between population composition at out-migration and that of surviving spawners shows that survivorship of both groups is significant, indicating that wild fish are making an important contribution to the system. While some year classes appear to contain up to 25% fish of wild origin it is unclear at this point if the changes in recruitment of naturally produced chinooks to the fishery was the result of changing flow patterns. A substantial increase in natural reproduction could have ramifications for current management aimed at maintaining a balance in predatory demand on Lake Ontario's prey supply.

Properties and Localization of Carbonic Anhydrase Involved in Otolith Calcification in Inner Ear

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Teleost otoliths are calcium carbonate concretions consisting of aragonite polycrystals with a small amount of organic matrix, and grow in the inner ear which filled with endolymph. To promote otolith calcification, CO2 level in the endolymph must be highly regulated by constant supply of bicarbonate. In this process, carbonic anhydrase (CA) is believed to be involved. However, the localization of the enzyme in inner ear is unclear. In the present study, characteristics and localization of CA in the teleost inner ear were investigated. By Western blotting using an antibody against mammalian CA II, a protein band was detected at approx. 28 kDa in the inner ear cytosol. CO2 hydration activities were also detected and inhibited by acetazolamide, an inhibitor of CA, in a concentration dependent-manner. By immunohistochemistry, the enzyme was localized in squamous and transitional cells, however, enzyme activity and immunoreaction were not detected in the mitochondria-rich cells in the transitional epithelium, which are putative ion-transporting cells. Two cDNAs encoding carbonic anhydrase (28.61 and 28.34 kDa of deduced amino acid) were cloned. RT-PCR analysis revealed that the expression levels of these mRNAs were different in some organs. Although the primary structure of these CA isoforms were similar (80% identity in amino acid), they were classified into different groups of CA II. These results suggest that the two CA isoforms are involved in otolith calcification as a bicarbonate producer and/or proton eliminator. For more insight of otolith calcification, differences of two CA isoforms should be investigated.

Otoliths of Marine Fish of the Barents Sea

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PINRO, Russia

Otoliths description of some fish species of the Barents Sea are given. Relationships between fish size and otolith length are studied. Preliminary information on age of non-target fish species from families Gadidae, Lotidae, Agonidae, Cottidae, Psychrolutidae, Liparididae, Zoarcidae and some other is presented.

Estuarine Residence, Ocean Entry and Iteroparity: What can Salmonid Otolith Microchemistry Divulge?

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Our understanding of the anadromous salmonid life cycle includes emergence from streambed, freshwater rearing, saltwater transition, ocean growth and tributary spawning. This life history involves movements of individual fish over long distances making the tracking of individuals difficult. The focus of our research is to better understand the migratory behavior of California steelhead (sea-run rainbow trout). We believe fish performance prior to ocean entry is key to survival. Our goal is to determine where successful spawning adults rear as juveniles and if certain rearing strategies result in higher percentages of iteroparous individuals. Adult steelhead otoliths were analyzed by laser ablation-inductively coupled plasma/mass spectrometry (LA-ICP/MS). This otolith microchemistry technique successfully tracked changes in elemental composition of the otolith as fish moved between freshwater, brackish and marine environments. We determined freshwater, estuary, and ocean growth periods. The temporal resolution of differences in ambient conditions was measured using a 20 m beam spanning approximately 7 daily otolith increments. Our results indicate that California steelhead utilize two early life history strategies, the traditional freshwater rearing typical of most Pacific salmonids, and rearing in the estuary. Residence time for the alternative estuary-rearing group was highly variable among individuals and appears unrelated to upstream conditions. Growth rates of individuals in the estuary are significantly greater than those rearing in upstream freshwater habitats. This study on lifetime habitat use and fish performance demonstrates that otolith microchemistry can be used to obtain information that was previously unattainable using traditional mark-recapture techniques. Preference: Oral presentation preferred/poster session acceptable.

Comparing Otolith Chemistry and Microstructure as Life History Indicators

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Otoliths have long been examined for answers to fish population dynamics. However, before one can use otolith methodology for fisheries management purposes, validation steps are necessary. The purpose of this study is to examine the utility of otolith microstructure and microchemistry in describing life history events and habitat utilization of juvenile Chinook salmon (Oncorhynchus tshawytscha). We examined otoliths of outmigrating ocean-type Chinook from the Skagit River, WA, USA to determine how structural and chemical attributes might be used in tandem to reveal age-specific habitat associations and growth during outmigration through an extensive estuary. Qualitative patterns of strontium abundance showed clear evidence of the transition between freshwater and estuarine habitats with measurable salinity. Otolith strontium concentrations suggested that more specific associations with very low salinity habitats could be distinguished from higher salinity habitats, but that finer distinctions were impossible due to highly variable salinity regimes. Detailed trajectories of otolith increment measures also revealed specific patterns associated with fish captured in different estuary and freshwater habitats. Conclusions regarding life-history representation and entry time, life stage, residence and growth rates within estuary habitats were compared using the two techniques.

Comparison of Three Age Structures as Recorders of Migration Histories in Rainbow Trout (Oncorhynchus mykiss)

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Migrations of diadromous fishes between freshwater and marine waters often induce large changes in the Sr/Ca ratios of calcified structures. In some salmonids, migrations of anadromous females can elevate Sr/Ca ratios in calcified structures of their progeny. Otoliths are usually the age structure of choice for reconstructing these migratory histories because material is not resorbed or reworked after deposition. Otolith removal is lethal however and these structures are not suitable for studies on rare, threatened, or endangered species. We evaluated the utility of two non-lethal alternative structures for reconstructing migration histories and inferring the maternal life history form of rainbow trout (Oncorhynchus mykiss). O. mykiss exhibit both anadromous and non-anadromous life history forms. Sr/Ca ratios were measured in otoliths, fin rays (pectoral, pelvic, anal, caudal), and scales of three size groups: small juveniles, large juveniles, and adults. Analyses were performed along a transect across each structure and in the core region using an electron microprobe. Preliminary results showed similar cross-structure patterns in Sr/Ca ratios in otoliths, scales, and fin rays, suggesting that all three structures can be used to reconstruct migration histories. Sr/Ca ratios in cores of otoliths and fin rays from small juveniles were generally higher in progeny of anadromous females than in progeny of non-anadromous females, and suggest that fin rays can be used to infer maternal life history form. Complete results of these analyses will be discussed.

Otolith Elemental Fingerprints of Juvenile Pacific Swordfish (Xiphias gladius)

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The trace element composition of young-of-year (YOY) juvenile swordfish (Xiphias gladius) sagittal otoliths was analyzed as a preliminary test of the value of otolith elemental fingerprints for determining swordfish nursery ground origin in the central Pacific Ocean. A suite of five elements (Mg, Zn, Ba, Sr, and Pb) was assayed with isotope dilution -inductively

coupled plasma mass spectroscopy (ID-ICPMS); all elemental concentrations were roughly comparable to those of other marine fish otoliths. None of the elemental concentrations differed significantly among sampling sites, but the concentrations of Ba and Sr varied significantly with greater latitudinal separation. The multivariate elemental fingerprints differed significantly at all spatial scales, and the magnitude of the differences increased with latitudinal separation. With more comprehensive sampling of nursery grounds, it should be possible to identify the nursery ground origin of individual adult swordfish by analyzing the YOY juvenile portion of the sagittal otolith.

Comparative Sr/Ca Electron Microprobe Analysis of 4 Species Otoliths

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Otolith Sr/Ca ratio has been widely used in stock discrimination studies or for reconstructing environmental histories of fish. Wavelength dispersive spectrometry is well known for providing accurate Sr/Ca measurements but very few studies have delt with the effect of operating conditions (accelerating voltage, beam current, beam size and acquisition time) on precision and accuracy of measurements. In this work, we analysed otoliths of four species from various environments: common sole, Atlantic hake, yellowfin, and chaetodon. Two standards were also analyzed, wollastonite which is a mineral and an otolith CRM (NIES 22). Eighteen analytical conditions were tested: accelerating voltage (10kV, 12kV, 15kV), beam current (10nA, 15nA) and spot size (3µm, 5µm, 10µm) with a beam power density ranging from 1.2 to 31.8 µW.µm -2. Acquisition time was set to 250 s and measurements were recorded at each 10s time interval. Along with Ca and Sr, Na and K were also measured. This paper presents an overview of the obtained results which are discussed in terms of data quality.

The Use of Otolith Microchemistry to Monitor and Evaluate the Movement of Coral Reef Fish in South Florida Waters

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Stable isotopic ratios of carbon and oxygen, obtained from the otoliths of teleost fish, have been well documented as useful tools for providing a wealth of information about environmental variations and stock structure of fish throughout their life history. Some of the valuable data include information about habitat temperature and salinity, migratory patterns and habitat use, diet and metabolic rates, and determination of the degree of stock mixing. The aim of this study is to investigate the size-age structure of Lutjanus griseus juveniles in Florida Bay, their growth rates and migration patterns, and explore how these relate to habitat characteristics and environmental variables such as salinity, temperature, and ontogenetic shifts in habitat. Measurements of 18O/16O and 13C/12C ratios in the sagittal otolith carbonate were obtained from juvenile gray snapper (Lutjanus griseus) collected in 2001–2004 from various locations within Florida Bay. Using a high-resolution Micromill drill, portions of the otolith formed during juvenile and adult periods were collected and analyzed in order to assess ontogenetic and environmental transitions. Additionally, age data gives an insight into the age at which ontogenetic and environmental transitions occur. We will discuss this data in light of natural variability in population parameters such as recruitment and growth and how these parameters are influenced by natural environmental variability. Ultimately, we are optimistic that we may be able to afford fisheries managers insights into the impacts of ecosystem change which will result from the effects of the Comprehensive Everglades Restoration Plan.

High Resolution Mapping of Otolith Trace Elements with Synchrotron X-Ray Fluorescence

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Micro-sampling of otoliths, either for trace elemental or isotopic analysis, has produced a myriad of results that are often difficult to cross-validate. For example, multi-laboratory assessments of trace elemental measurements, even using standardized materials (e.g., Campana et al. Can. J. Fish. Aquat. Sci 54(9):2064-2079, Zdanowicz et al. 2001, Northeast Fisheries Science Center Reference Document 01-13) show poor agreement when measuring trace elements. Part of the reason may be due to the considerable heterogeneity of otoliths, revealed by mapping of trace elements throughout otolith sections, for example by electron microprobe analysis (EMPA) or micro-PIXE (proton-induced X-ray emission spectroscopy). However, EMPA has limited sensitivity, and the sodium concentrations in otoliths produce interferences in micro-PIXE through gamma reactions, which prevent detection of many trace elements. We present new results of trace elemental mapping with high energy (5-15 keV) X-ray fluorescence, using precision glass monocapillaries to compress the beam. To date, we have produced reliable, high-resolution (20-50 micron) maps of Zn, Mn, Ba, Rb, Kr, As, and Se, in addition to the major element Ca and minor element Sr in half a dozen species from diverse ecosystems. These maps demonstrate convincingly that elements are incorporated differently over the lifetimes of fishes, often due to differences in environmental concentrations, but sometimes due to endogenous factors.

Effect of Salinity and Food on Otolith Sr/Ca Ratios of the Japanese Eel, Anguilla japonica

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Otolith Strontium (Sr)/Calcium (Ca) ratios have been widely used for reconstructing the migration history of fish, but the interactive relationships between otolith Sr/Ca ratios and environment factors are still not clear. The goal of this study is to understand the effect of salinity, food regimes and somatic growth rate on otolith Sr/Ca ratios of A. japonica. Elvers (average size 54.7 2.1mm) were immersed in 50 ppm alizarin complexone (ALC) solution for 6 hours to produce fluorescent marks for identifying the onset of the experiment. They were then reared in different conditions with 5 different salinities (15, 25, 50 and 75 ppt) and 3 feeding regimes (formulated feed, tubifex, and starvation) for 30 days. Sr and Ca concentrations in water, feed and otolith were analysed with AA and EPMA, respectively. The Sr/Ca ratio of tubifex was 7- to 24-fold higher than formulated feed, however, otolith Sr/Ca ratio did not differ significantly among feeding groups ($p>0.05$), despite significant differences in somatic growth rates among feeding groups($p < 0.01$). Sr/Ca ratio in otoliths increased significantly with salinity ([(Sr/Ca) 1000]otolith = 3.66 + 0.11SAL). These results suggest that feed regimes and somatic growth rate do not interfere with the relationship between otolith Sr/Ca ratio and salinity; therefore, otolith Sr/Ca ratios provide a reliable means of investigating the migration history of eels.

Age-Related Trends in Otolith Microchemistry of Merluccius merluccius from the Northeastern Atlantic Ocean and the Mediterranean Sea

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Fish otolith composition reflects the combined effects of endogenous processes such as development and reproduction, and external conditions associated with habitat, behavior and diet change. Metabolic rate may be a major factor influencing otolith growth, and for this reason it may also influence otolith composition through the rate of incorporation of individual elements. There is the unresolved question of whether variations in composition are directly linked to developmental events or whether the variation is a function of fish size or age. In an attempt to resolve this, we have selected otoliths of a widely distributed and relatively well-known species, hake (Merluccius merluccius). Sagittal otoliths were obtained from 52 hake coming from six areas of the Atlantic and Mediterranean. The relative concentrations of the isotopes 7Li, 24Mg, 55Mn, 66Zn, 85Rb, 86Sr, 138Ba and 208Pb were determined using laser-ablation ICP-MS analysis of transversely sectioned otoliths. A semi-quantitative approach was used, and the abundance of the different elements was expressed normalized to 43Ca. The lack of appropriate matrix-matched standards precluded the determination of actual elemental concentrations. The relative concentrations were analyzed with respect to the otolith growth increments (annulae). The results showed a clear temporal trend, irrespective of locality, in the relative concentration of Sr. The variations observed in elements were more influenced by the population source. This result further supports the model where fish growth and metabolism have a major influence on otolith composition through their influence on otolith growth rate.

Use of Elemental Analysis in Stock Discrimination of Bristol Bay Sockeye Salmon

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In recent years below average returns of sockeye salmon to the Bristol Bay region have prompted state and federal agencies to declare this an economic disaster area. Specific mechanisms related to reduced Bristol Bay sockeye salmon production are unknown due to the lack of stock-specific information on early marine residence and sparse or outdated data on the life history of immature salmon as they travel the waters of the Bering Sea and North Pacific Ocean. To assess life history characteristics of Bristol Bay sockeye salmon stocks in the North Pacific Ocean and Bering Sea researchers must be able to identify salmon, at least by their country or continent of origin and ideally by region or watershed of origin when captured in various commercial fisheries and during research sampling. In this study, we examined and compared the concentrations of nine common elements found in the otoliths of juvenile sockeye salmon in Bristol Bay, Alaska. Our objective was to use differences in concentrations of naturally occurring elements in the otoliths to discriminate between three stocks of Bristol Bay sockeye salmon. would be reflective of the concentrations of those elements in the freshwater system. ANOVA indicated that of the nine elements (Ca, K, Cl, P, S, Na, Mg, Sr, and Fe) were significantly different between the three systems ($p<0.05$). Discriminate analysis of the elemental data showed three distinct groups corresponding to the three river systems. The Kvichak river system sockeye were grouped correctly 91.3 % of the time followed by Ugashik and Egegik river fish at 70.8% and 68.0% respectively. Overall 76.4% of the samples were correctly classified to the correct river system. The use of probe-based technology for discrimination of mixed salmon stocks in Bristol Bay, Alaska would be useful to managers and researchers. Combined with isotope analysis and genetic characteristics, as well as scales and parasite analysis, elemental analysis can be an effective tool to discriminate between sockeye salmon stocks in Bristol Bay.

Evaluation of Strontium and Calcein for Marking Hatchery and Wild Juvenile Chum Salmon

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Mass marking of hatchery chum salmon has been identified as a critical need for effective management of large-scale enhancement, to assess ecological and genetic interactions of hatchery and wild stocks and assure enhanced chum production is adequately marked. Presently the accepted method of mass marking and identifying hatchery fish is otolith thermal marking. This technology is being applied in hatcheries in Alaska, Japan and Russia which release nearly 1 billion otolith marked salmon yearly. However, the practical number of unique mark codes that can be applied is limited due to various factors of embryonic otolith development such as the physical size and the relatively short time available for inducing marks. The ability of readers to visually recognize marks is also limited. As more facilities utilize this technology, mark duplication will become more common. In addition, remote enhancement projects or studies of wild salmon stocks cannot usually implement this technology as it is not feasible to install and operate the heating or chilling equipment needed to induce otolith marks. The development of alternate techniques to mass mark chum salmon are needed, either as an adjunct to thermal marking or as a main marking tool for research on remote or wild stocks. This project tests the efficacy of different immersion times or dosages of strontium and calcein under varying environmental conditions in order to develop and establish protocols for use. Use of either of these compounds provides researchers with permanently marked fish. For this project, juvenile chum salmon will be obtained from the DIPAC, Ladd Macaulay hatchery near Juneau, Alaska. These fish will be exposed to strontium and calcein of varying concentrations and immersion times. Otoliths will be examined weekly to determine the degree of strontium or calcein uptake in the various treatments. Results will be available later this year.

Improved Interpretation of Labeled Fish Otoliths: Cost-effective Tool in Sustainable Fisheries Management

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A total of 222 pairs of alizarin stained and 75 pairs of unstained sagittal otoliths from 6 hatchery-reared species Arctic charr (Salvelinus alpinus (L.)), lake trout (Salvelinus namaycush (Walbaum)), salmon (Salmo salar L.), brown trout (Salmo trutta L.), whitefish (Coregonus sp.), and pikeperch (Sander lucioperca (L.)) were used in blind tests in order to test whether sawing a 0.4 thick slice from the otolith would improve interpretation of labelled otoliths. The fish were labelled in 1995–2002. Fish age at staining varied from two weeks to three months, incubation time from three to six hours, and concentration of alizarin 50–100 ppm/l. Blind tests were arranged so that sawed slices were contrasted with entire otoliths using stereofluorescence microscopy. According to blind tests, accuracy of interpretation of alizarin stained otoliths was 97.0 % from the slices and from entire otoliths 92.3 %. Percentage of correct readings was slightly lower for whitefish and for the fish that had incubation time of six hours. In 2003, we applied alizarin staining and subsequent otolith reading with stereofluorescence microscope successfully for newly hatched peled whitefish (C. peled Gmelin), whitefish, Arctic charr, lake trout and brown trout. Stocking results for newly hatched fish have been poorly studied area due to lack of methods for reliable interpretation of labelled otoliths. Many stocks of above mentioned fish species are managed by stockings in Scandinavia, which probably makes our results very useful for future research and management.

Otolith Analysis: Key to Understanding the Ecology of a Rockfish

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Otolith microstructure analysis was used to estimate timing of extrusion, planktonic period, settlement and post-settlement patterns as well as growth history of young-of-the-year (YOY) Sebastes inermis collected in Zostera and Sargassum beds in 1998–2001 around Sendai Bay, Japan. Extrusion occurred in winter and settlement in early spring, and both events were synchronized, i.e. YOY extruded earlier in the parturition season appeared in the beds first and vice versa. YOY settled in distinctive groups synchronized mainly at new and full moons. Planktonic period ranged from 53 to 113 days, varying among settlement groups and years. Conversely, settlement groups had similar sizes (ca. 20 mm TL). Post-settlement growth rates of YOY in Sargassum and Zostera beds (0.4 to 0.8 mm/d) were higher than in the planktonic period (0.1–0.25 mm/d). Growth trajectory of settled groups in the nursery grounds followed the same trajectory irrespective of their settlement dates. YOY extruded earlier emigrated first from their beds and vice versa. In addition, YOY from the 2 nursery grounds were distinguished accurately using in parallel two approaches: the trace elements (TE: Li, Mn, Ni, Cu, Zn, and Ba measured using High Resolution-ICPMS) and the kernel measurements (KM: width and length of the opaque kernel) of otoliths. KMs were linked to the formation of the first hyaline zone, deposited earlier in YOY inhabiting Zostera bed (mean=91 days after parturition) than those in Sargassum bed (mean=120 days). Findings suggest that TEs and KMs can be used as natural tags of the nursery grounds where YOY grew.

Elemental and Isotopic Fingerprints of Juvenile Winter Flounder (Psuedopleuronectes americanus)

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Elemental fingerprinting has become a powerful tool in fisheries science for identifying fish migration patterns, seasonal changes in habitat use, and for delineating the nursery origins of adult fish populations. In this study, we investigated whether elemental and isotopic signatures in fish otoliths collected from different habitat types and locations, could be used as natal fingerprints.

We collected juvenile (50–70mm) Winter flounder (Pseudopleuronectes americanus) from nearshore habitats (unvegetated, macroalgae, and eelgrass), as well as from different locations (lower, middle, upper) in Narragansett Bay, RI (USA) and surrounding coastal lagoons. Sagittae otoliths were removed in the laboratory, cleaned under a laminar flow hood, and a single sagittal otolith was digested with high purity nitric acid using a hotblock at 100°C for 1 hour. Samples were diluted to 2.0ml and analyzed for trace metal chemistry using Inductively Coupled Plasma Mass Spectrometry (ICPMS) and or Inductively Coupled Plasma Atomic Emission Spectroscopy (ICPAES). Isotopic analysis (d13C) was conducted on the remaining sagittal otolith using an Isotope Ratio Mass Spectrometer (IRMS).

Both univariate and multivariate statistical analysis were used to analyze and describe elemental and isotopic signatures of fish otoliths. Results of our study provide insight on how habitat composition may affect natal fingerprints of juvenile Winter flounder.

The Migratory History of Pacific Tarpon, *Megalops Cyprinoides* as Revealed from Otolith Sr/ca Ratios

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Pacific tarpon *Megalops cyprinoides* are widely distributed in the tropical and subtropical areas of Indo-Pacific Ocean. They spawn in the coastal waters, and then the larvae drift with currents to inshore nursering ground approximately 25–30 days post-hatching. Young Pacific tarpons were found in variant environment, such as stream, estuary, inner bays, and mangrove. It is still unclear whether their migratory behavior is obligatory or facultative?

The strontium (Sr) concentration is approximately 100 fold higher in sea water than in freshwater, and thus Sr/Ca ratios in fish otolith were widely used to study the migratory history of the fish between seawater and freshwater. Sr/Ca ratios in otoliths of Pacific tarpon at different stages, including wild and cultivated leptocephali, young and adult were examined with Electron Probe Microanalyzer (EPMA). Sr/Ca ratios in otoliths indicated that the patterns of the fish movement beyond juvenile stage were very complicated. All of them were clearly originated from marine environment. Sr/Ca ratios in otolith were greater than 6‰ if the fish stay in the marine environment, but less than 4‰ if move to freshwater. Sr/Ca ratios in otolith of the juveniles cultured in salinity of 10‰ was from 4–7‰. This study indicated that the habitat selection of the fish beyond juvenile stage is facultative.

Origins of Red Drum Stocks: Assessing the Contribution of Different Nursery Grounds Using Chemical Signatures

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The aim of this study is to use natural markers in otoliths (trace elements and stable isotopes) to determine the nursery origin of red drum (Sciaenops ocellatus). In 2001 and 2002, age-0 red drum were sampled from nurseries in Texas: Sabine Pass, East Bay-Galveston, West Bay-Galveston, Matagorda Bay, Copano Bay, Aransas Bay, and the lower Laguna Madre. Stable isotopes (d13C, d18O) and trace elements (Mg, Ca, Mn, Cu, Sr and Ba) were quantified in the otoliths, and ratios differed significantly among estuaries and within site variability was relatively low. North to south gradients were observed for d13C and d18O, and both isotopes were enriched in otoliths of red drum from southern sites relative to northern sites. Correct assignment to a specific estuary based on stable isotopes ratios alone was greater than 80% in each year. Classification success was further improved when trace elements (e.g. Sr) were added to the model. Interannual variability in otolith chemistry was present; however, classification success was still high when year classes were pooled for 4 primary regions suggesting that signatures in the otoliths of red drum are useful indicators of nursery origin. To establish the nursery origin of sub-adult or adult red drum, stable isotope and trace element values in the core of the otolith must be determined. We have recently evaluated and developed drilling-based procedures to isolate otolith cores of red drum, and analysis of these cores is currently underway to predict the contribution of different nursery grounds to adult red drum stocks in Texas.

Effects of Handling and Storage Methods on the Concentrations of Elements in Deep-Water Fish Otoliths

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Sagittal otoliths of roundnose grenadier, bluemouth and European hake were collected using a variety of handling and

storage treatments and their elemental composition examined using inductively coupled plasma mass spectrometry. Some differences between element concentrations were identified for the control/treatment groups, most notably for the element Li. In bluemouth and hake, Li concentrations were significantly higher in the otoliths extracted with metal forceps and stored in paper envelopes (treatment), compared to those from the same fish that had been extracted using plastic forceps and stored in polyethylene vials (control). Lower concentrations of Ba and Cr were found in hake otoliths extracted from the heads of defrosted fish. No significant differences were identified in the number of samples with detectable concentrations of elements above the instrumental limits of detection for any of the treatments or species. The results are discussed in relation to otolith composition and the potential lability of some elements.

Microchemistry of Bluemouth and Hake Otoliths as an Aid to Stock Discrimination

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Bluemouth and European hake are widely distributed on the continental slopes throughout the Atlantic and Mediterranean and have quite different life history characteristics. Both are commercially exploited, although little is known about stock identity. Fish otolith composition is thought to reflect both endogenous processes and external factors, some of which relate to the surrounding environment, and this work assesses the usefulness of otolith microchemistry as a tool for stock discrimination in these species. The elemental composition of sagittal otoliths was examined using both solution-based inductively coupled plasma mass spectrometry of the whole otolith, and laser-ablation analysis of the otolith nucleus. It was possible to distinguish between groups of bluemouth whole otoliths, with Sr, Ba and Cu contributing most to group separation. No significant differences were identified between element concentrations by area for bluemouth, based on composition of the otolith nucleus. For hake, a separate analysis of the whole otolith data for the Atlantic and Mediterranean samples gave a clear distinction of the different groups within each ocean basin. Analysis of the hake laser-ablation data indicated some differences in elemental concentrations in both the Atlantic and Mediterranean samples. Mg and Pb were found to be important elements in separating the groups in the Atlantic and Ba, Sr and Pb were important in the Mediterranean. The results are discussed in relation to our understanding of the distribution and life history aspects of these species and the differing environmental conditions of the deep Atlantic and Mediterranean.

Chemical Marking Techniques for the Stock Enhancement of Mulloway (Argyrosomus japonicus)

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Marking of fish that are released to enhance natural stocks is fundamental to the monitoring of survival, growth and catchability of released fish. Chemical marking by immersion incorporates ease of bulk tagging fish, optimal detection, and retention of the mark for a suitable period of time. Mulloway (Sciaenidae: Argyrosomus japonicus) have been identified as a potential candidate for stock enhancement in New South Wales, however no information is available on efficient marking techniques for this species. This study tested immersion-marking techniques for mulloway using oxytetracycline (OTC) and alizarin complexone (ALC) for the quality of mark in otoliths, vertebrate and fin spines. Juvenile mulloway (50–100 mm total length) were immersed in a range of OTC (0-600 mg.L-1) and ALC (0–60 mg.L-1) concentrations, for 6, 12 and 24 h. No marks were detected in otoliths for OTC concentrations <200 mg.L-1, and marks were only obtained for OTC treatments of 200 and 600 mg.L-1 in diluted seawater (5 psu). Immersion marking or reduced salinity had no effect on survival relative to controls. Reduced salinity is typical of the riverine habitat where juvenile mulloway occur. Otolith marks were obtained from all alizarin treatments, however mark quality was reduced at concentrations <30 mg.L-1 for 12 hours. Vertebrae and fin spines were sectioned for the ALC and OTC treatments with the highest otolith mark quality, however they showed no discrete marks. The cost and efficiency of multiple marks and marking relative to microchemistry and genetic markers will be discussed.

Experimental Investigation of Element Incorporation in Larval and Juvenile Fish Otoliths

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Otolith elemental signatures are used for discerning fish stocks, identifying nursery habitats, locating spawning sites, tracing larval transport pathways, and quantifying the degree of population connectivity. Three laboratory experiments were conducted using late larval to early juvenile stage spot (Leiostomus xanthurus) and gray snapper (Lutjanus griseus) to validate the assumption that otolith elemental composition is a function of water elemental concentrations, test the effects of water temperature and salinity on otolith element incorporation, and assess similarities or differences between species. Sr/Ca ratios and partition coefficients (DSr) in both L. xanthurus and L. griseus were significantly influenced by water temperature and salinity. Mg/Ca ratios and DMg were influenced by temperature and otolith precipitation rates in L. xanthurus. There was no effect of temperature on Mg/Ca in L. griseus otoliths; however, the DMg was

significantly affected by salinity. Mn/Ca ratios in L. griseus otoliths were significantly affected by temperature. DMn for both species were significantly affected by both temperature and salinity. Although only Ba/Ca ratios in L. griseus otoliths were significantly affected by salinity, DBa in both L. griseus and L. xanthurus were affected by salinity. These results are independent of ontogenetic effects and diet effects, and prove that otolith element incorporation is not solely a function of water elemental composition because it is affected by both temperature and salinity and those effects varied uniquely among the elements investigated. This comparison between fish species draws attention to the necessity of validation experiments to translate species-specific elemental signatures in otoliths.

Recruitment in Experimental Releases of Brown Trout: Patterns in Dispersal and Survival Relative to Fry and Otolith Growth

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Pre-emergent brown trout fry were planted in the gravel at each of five swim-up sites in isolated sections of a natural stream to assess subsequent parr dispersal and survival as a function of fry and otolith size and growth. Each release of 210 fry was composed of individuals from two females, where progeny of one female were distinguished from those of the other female by thermally-induced marks on the sagittal otolith. Emergence times of the two female groups differed by about 4 days as determined from in-stream reference samples, and fry weights in the late-emergence group were significantly greater than fry weights in the early-emergence group. After 54 days, fry numbers in each section were reduced by 46% on average, and recruitment patterns among swim-up sites and total sections were remarkably uniform. Late emergers were recruited in proportions greater than or equal to an expected value assuming proportionate survival among female groups, and their final weights were significantly greater than those of early emergers. Size and growth were determined for individual trout that established territories at swim-up sites, and in downstream and upstream stream sections. Dispersal and growth patterns of individuals were related to their otolith size at emergence and subsequent otolith growth. We concluded (i) that the initial population regulation of brown trout fry was a highly structured process with an evident maternal influence, even at low population densities; and (ii) that otolith microstructure analysis was useful for revealing individual trout influences in the structuring of the parr population.

Elemental Composition in Otoliths of European Eel Anguilla anguilla

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This study proposes that elemental composition in otoliths of the eel (Anguilla spp.) changed with life stage and growth habitat. The elements of Cl, Na, K, Mg, Ca, Sr and P in otoliths of European eels Anguilla anguilla were examined using an Electron Probe Microanalyzer (EPMA) equipped with wavelength dispersive spectrometers (Cameca Sx -50). Yellow-stage eels were collected from coastal waters and lakes of Sweden in 1987, 1988, 1991, and 1994, with ages ranging from 5 to 18 years old. Sr map and profiles of Sr/Ca ratios in otoliths were used to classify eel life history stages as leptocephalus, and freshwater and seawater yellow eels. Canonical score plots of the otolith elemental composition of freshwater eels were completely separated from those of leptocephali and seawater eels, but the latter two partially overlapped. Sr is the primary component in determining the discrimination, but the nutrient-related components S and P, and the salinity-related ones Na and Ca, may also play an important role in the plots. These results indicate that that multiple elemental information can provide additional insight into the migratory environmental history of the diadromous eels.

The Relative Contributions of Food and Water to Otoliths

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An experiment was carried out to quantify the relative contributions of water and food sources to material accreted in otoliths. Mummichogs (Fundulus heteroclitus) were hatched and raised in filtered seawater in treatment tanks spiked with 1mg 86Sr and 50 Âµg 137Ba each. The otoliths of surviving fish were harvested after 70 days and isotope ratios were assayed with a laser ablation inductively coupled plasma mass spectrometer (ICP-MS). Because the treatment tanks were spiked significantly beyond natural isotopic ratios, the signature of the water was distinct from that of the food. A simple mixing model was applied to determine the relative contribution of each to the isotopic signature in the otolith. Our results show that 83% of Sr and 98% of Ba derived from water sources. This experiment is one of the first to examine the sources of ions in otoliths of a marine species and the results confirm the primacy of water sources in the formation of otoliths.

Geographical Variation on Chemical Composition of the Statolith of Veined Squid Loligo forbesi

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The chemical composition of statoliths of the veined squid Loligo forbesi Steenstrup (Cephalopoda: Loliginidae) was analysed by inductively coupled plasma-mass spectrometry (ICP-MS) to determine geographical differences. Statolith samples from three geographic areas, the North Sea, the Irish Sea and the Azores were collected, and samples of two consecutive years from the Irish Sea were also included in the analyses to test temporal stability of the statolith chemical composition. Eight elements were detected, including Ca, Sr, Ba, Li, Pb, Mn, Ni, Co, in the order of the concentration. Geographical variation of the elemental composition of statolith was found among three sampling areas and the sample from the Azores was significantly different from the rest. There was no difference in chemical composition between two consecutive yearly samples.

Effects of Handling on Elemental Composition of Otoliths in Age-2 Pacific Halibut

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The chemical composition of otoliths (their otolith elemental fingerprint, or OEF) holds great promise for use in a variety of environmental, ecological, and life-history studies. In particular, the OEF of early juveniles may be used to identify their origins or the water-masses in which they were reared, indicating ontogenetic migration patterns. While numerous studies demonstrate the potential use of OEFs in life-history studies, many methodological questions remain. Research has suggested that the way in which fish are handled following collection can impact otolith microchemistry. In particular, chemical composition may change over time if the otoliths are not immediately removed from the fish upon collection. In many cases this is not practical, especially in the context of extended research cruises or assessment surveys. Removal of otoliths at sea may subject them to metal contamination, and thus, at-sea freezing of fish may provide an attractive alternative. But how much variance in handling can be tolerated without compromising the chemical composition of the samples? In this experiment we examined OEFs in age-2 halibut using solution-based ICPMS, using otoliths extracted from fish that were frozen immediately upon capture, but whose otoliths were not removed until after a period of storage. We compare OEFs for fish that were frozen according to 5 treatment-lengths ranging between 5 and 18 weeks. Additionally, we examine the effects of thawing-time on OEFs by comparing otoliths removed immediately upon thawing with specimens extracted from fish that were thawed and then refrigerated for 1–3 days prior to otolith removal.

Comparative Growth of Three Larval Fish Species in the Bay of Biscay: Anchovy (Engraulis encrasicoulus), Mackerel (Scomber scombrus) and Hake (Merluccius merluccius): Ecological Implications

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The variation of larval growth rate of three species which inhabit the Bay of Biscay during different periods was evaluated. Different environmental conditions characterise each larval develop. Hake larvae are presented in the Bay of Biscay during winter an early spring and they show the lowest growth rates, mackerel larvae, abundant during early and mid spring, present intermediate growth rates and finally anchovy larvae which occur in summer the exhibit the highest growth rate. Different comparative analysis relating daily growth, mouth width and dry wet were done and differences between species were related with temperature and zooplankton abundances as two more important environmental parameter affecting the growth and survival rates of fish larvae. Species-specific strategies adapted to prevalent conditions are discussed.

Otolith Microstructure Analysis Reveals Selective Survival of Young-of-the-Year (YoY) sprat, Sprattus sprattus, from the Central Baltic Sea

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The sprat is a small, short-lived, zooplanktivorous clupeid that plays a key role in the trophodynamics of the Baltic Sea. During the extended spawning season (typically March-July in the Central Baltic Sea), environmental conditions conducive for larval growth vary considerably, suggesting that a "time-window" of optimal conditions may exist leading to enhanced larval survival. Otolith microstructure analysis was used to determine the day of first increment formation (DFF, used as a proxy for hatch date) in YoY sprat caught in October 2002 in the Central Baltic Sea. The DFF-distribution was then compared to field measurements of larval abundance between March and November 2002 in the Bornholm Basin, one the most important spawning grounds for Baltic sprat. Mean age of survivors was 125.1 days after first increment formation (SD=12.47 days, n=90), indicating that the majority of survivors had hatched in June 2002 (mean=18.6.02). Two distinct peaks in larval abundance were observed, a main peak in spring (April) and another, smaller peak in summer (June). The latter coincided with the DFF-distribution of YoY-sprat, presenting strong evidence for a selective survival of summer born sprat compared to sprat born earlier during the 2002 spring peak in larval abundance. Mean growth trajectories were notably different between survivors that hatched during subsequent fortnightly intervals. The pattern indicated that during the larval stage (<30 days after DFF), sprat that hatched later in the season grew faster than their earlier born conspecifics, whereas individuals with lower larval growth rates showed consistently faster growth as post-metamorphic juveniles (>70 days after DFF). Our findings comprise a necessary step towards a better understanding of processes responsible for growth and recruitment variability of sprat in the Baltic Sea.

Age and Growth of the Eastern Freshwater Cod (Maccullochella ikei) from the Mann-Nymboida Rivers of NSW, Australia

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The eastern freshwater cod (Maccullochella ikei) is one of Australia's most endangered freshwater fish species, restricted to one small catchment in Northern New South Wales. Despite the conservation status of M. ikei, little is known of the biology of the species. Much of the life history is assumed due to its similarity to the closely-related and well-studied Murray cod. Therefore the aim of this study was to determine the age and growth of M. ikei in the Mann-Nymboida River systems. To determine age-at-length of M. ikei; otoliths, operculum bones and dorsal spines were gathered from archival collections, supplemented by 16 samples captured throughout 2001. Operculum bones and dorsal spines were found to have no consistent annuli present. Age was determined for 52 sectioned otolith samples. Relationships were established between age and total length of fish, and otolith weight, width and diameter. Cod were aged from one year to a maximum of 13+ years. High variability was apparent in length at age, particularly in older fish. Edge increment analysis and otolith collected from known age cod were used to validate age estimates. Back-calculated mean length at age estimates were used to determine von Bertalanffy growth constants. The von Bertalanffy growth equation for M. ikei was $L_t = 864.05\{1-\exp[-0.1677(t+0.26138)]\}$. The results of this study have shown that length alone cannot be used to determine the stock structure of M. ikei in the Mann-Nymboida River system.

The Use of Back-Calculation for Ageing Sharks: Which Method is Most Appropriate?

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Due to the difficulty in obtaining adequate samples throughout the size range of a given shark species, the use of back-calculation to determine a mean-size-at-age is frequently used to increase sample size for missing ages in order to estimate population growth parameters. Among previous studies, the method used for back-calculation is often chosen arbitrarily, and has varied from the simple Dahl-Lea method to more complex procedures such as the birth-modified Fraser-Lee and modified Dahl-Lea methods.

Lee's phenomena (underestimating previous lengths-at-age) can lead to errors in population growth parameter estimates, which can cause poor management decisions. We compared several back-calculation methods using four species of sharks with varying life histories to see which method's results most closely resembled sample data. The birth-modified Fraser-Lee method provided the best results for the Atlantic sharpnose shark, Rhizoprionodon terraenovae, while a linear-modified Dahl-Lea method provided the best results for the blacknose shark, Carcharhinus acronotus, and sand tiger shark, Carcharias taurus, and a quadratic-modified Dahl-Lea method provided the best results for the salmon shark, Lamna ditropis. The simple Dahl-Lea method is the most commonly applied method in age and growth studies of elasmobranch fishes, however, Lee's phenomenon occurred in all four species when we applied the simple Dahl-Lea method. This demonstrates the need to apply several back-calculation methods to see which method's results best resemble sample data.

Geographic Variation of Early Life History Traits of Apogon doryssa in the Coastal Waters of Taiwan

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To understand the geographic variation of early life history traits of the coral reef fishes, the Apogon doryssa larvae collected in the coastal waters from the north to south of Taiwan were identified by mtDNA and then their ages, growth rate and hatching dates were estimated by otolith daily growth increments. Total lengths, somatic and otolith growth rates, seasonal occurrence and hatching dates of the larvae were all significantly different between north and south. The daily age at which the otolith daily growth rates reached the maxima, which can be taken into a sign of settlemental component, delayed from south to north. These results seem to follow the geographic variation of water temperature, suggesting that the environmental factors affect not only growth but ontogenetic development process.

Otolith Micro-Increment Periodicity of Captive Juvenile (Age 0) Sablefish, Anoplopoma fimbria, Experimentally Immersed in Strontium Chloride (SrCl2)

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Sablefish, Anoplopoma fimbria, are a long-lived species that support a valuable fishery in Alaskan waters. Our understanding of sablefish recruitment processes could be enhanced by the accurate determination of sablefish daily age during the first year of life (age 0). In this study, age 0 sablefish were captured at sea and held alive in the laboratory for up to three months. The otoliths of 20 live fish were marked with immersion in saltwater baths containing elevated levels of strontium chloride (SrCl2). Each fish was marked twice over a period of about two weeks, sacrificed about two weeks after the second marking event, and a sagittal otolith from each marked fish was processed into a thin section. Two strontium bands were identified on each otolith thin section with scanning electron microscopy, and otolith micro-increments between strontium bands were detected under transmitted light microscopy. The number of otolith micro-increments detected between strontium bands was highly variable (ranging from 10 to 25), and in general did not agree exactly with the number of days between marking events (15 to 17 days). However the average number of otolith micro-increments (16.6±se 0.7) was not significantly different (P=0.19) from the average number of days between marking events (15.5±se 0.2). These results suggest that otolith micro-increment counts from individual age 0 sablefish may vary widely from a daily periodicity, but that average otolith micro-increment counts from a sample of age 0 sablefish may provide a useful proxy for daily age.

Direct Validation of Daily Increment Deposit on Otoliths of Juvenile European Hake (Merluccius merluccius)

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Despite considerable progress in recent years, thanks in part to international otolith reading workshops, estimating the age and growth of European hake remains complex. In 2002, we carried out a pilot mark-recapture experiment on juvenile hake in the Bay of Biscay. By the end of September 2003, 35 tagged fish and 5 additional tags had been returned to the laboratory (a 3.1% return rate). Recaptured fish provide invaluable information on somatic and otolith growth which is discussed elsewhere. Besides these aspects, otoliths were also analysed to study microstructure deposit rate which has not yet been validated. Thirteen sagittal sections of marked otoliths were prepared for microstructure analysis (thin slides). Microstructures were counted from the oxytetracycline mark to the edge on an antero-dorsal prism. Only four otoliths had a complete sequence of microstructures while blind zones made this sequence discontinuous for the other ones. Hence we were required to interpolate the number of microstructures within the blind areas. Given the overall sample, ages in days were on average slightly underestimated. This is probably due to underestimation of the microincrement number within unreadable zones. However, if we considered only the four available complete sequences, the daily rate of increment deposit was established. This result is of key interest for previous and ongoing works that rely on the assumption of daily deposited microstructures in hake otoliths. It is particularly relevant for the analysis of 0-group juvenile growth which cannot be performed from tagging experiments.

Do We Underestimate Growth of European Hake (Merluccius merluccius)?

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Despite considerable progress made in recent years, thanks in part to international otolith reading workshops, estimating the age of European hake remains problematic. In 2002, we carried out a pilot experiment on hake tagging using a codend specially designed to catch fish in good condition. In all, 1307 fish were tagged with anchor T-bar tags, injected with oxytetracycline (OTC), and then released (de Pontual et al, in press). This experiment represented the first recorded mass tagging of European hake. By the end of September 2003, 35 fish and 5 tags had been returned to the laboratory (a 3.1% return rate). For combined sexes, the somatic growth rate was estimated at 0.038±0.020 cm day^{-1} (n=19). Males and females did not differ significantly in somatic growth rate, which were respectively 0.028±0.018 (n=6) and 0.039±0.016 cm day^{-1} (n=8). Otolith growth was measured on transverse sections and compared to a growth model established from previous data issued from 'usual' ageing criteria. Marked otoliths were also read (blind reading) by 2 experts and estimated ages were then compared to otolith growth after the OTC mark. The results indicate that recaptured fish grew faster than expected and show that criteria used for routine ageing may need to be revised. Although based on scarce data, this study highlights the need to carry out a large-scale tagging experiment of the European stocks in order to improve biological knowledge, assessment and subsequent management decisions.

Analysis of Otolith Microstructure for Estimation of Influence of Environmental Conditions on Hatching Date and Growth Rate of Herring and Cod Larvae

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Microstructure of sagitta and lapillus of larvae of spring spawning herring Clupea pallasi marisalbi and cod Gadus morhua from Kandalaksha Bay of White Sea was studied. It was found that correlation of larva growth with development of sagitta was more pronounced than with development of lapillus for both species. Basing on revealed correlation larva growth rate was back calculated from radiuses of daily rings of sagitta. Calculated dates of mass hatching of the larvae corresponded to real date of hatching observed in nature in 1997-1999. The latest date of mass hatching in both species were observed in 1998 then temperature in the early June was lowest among these three years. The growth rate of 6 to 26 days old cods at 1999 was 0.25 mm/day, at 1997 and 1998 was 0.19 and 0.17 mm/day, respectively. The high growth rate in 1999 was probably due to higher temperature in summer period. The growth rate of herring larvae under 25 days old was the same (0.6 mm/day) in 1997, 1998 and 1999, though the temperature regime was different. Possibly the growth rate in 1999 was not increased due to high density of the herring larvae in plankton.

Interannual Differences in Growth and Hatch Date Distributions of Age-0 Walleye Pollock (Theragra chalcogramma) from the Shumagin Islands Region of the Gulf of Alaska, 1985 – 2001

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Some evidence exists that strong year classes of walleye pollock in the Gulf of Alaska exhibited high growth rates during the juvenile period. In this study we examine interannual differences in growth and hatch date distributions of age-0 walleye pollock captured in the Shumagin Islands region from 1985–2001. A total of 659 age-0 pollock otoliths were prepared and aged. Differences in growth and hatch date distributions are compared to environmental conditions (e.g. SST) and biological factors (e.g. initial density), that may explain variability in our data and the relationship with eventual recruitment is examined using statistical models.

Effect of Otolith Type and Preparation Technique on Age Estimation of Larval and Juvenile Spot (Leiostomus xanthurus)

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The accuracy (deviation from real age) and precision (repeatability of increment counts from the same otolith) of different age estimation methods were evaluated for larval (8.8-16.1 mm LT) and early-juvenile (19.4-28.1 mm LT) laboratory-reared spot (Leiostomus xanthurus). The otolith increment number was counted from: (1) one-side polished transverse section of sagittae, (2) two-side polished transverse section of sagittae, (3) one-side polished whole sagitta in sagittal view, and (4) one-side polished lapilli in sagittal view. All the methods, except one side polished sagittal transverse section analysis, for both larvae and juveniles provided similar accuracy. The age was underestimated during the first five days of life, but beyond this period increment deposition was daily. When the precision was evaluated by comparison of the coefficients of variation (CV) calculated from three independent age readings of the same otolith, the lapilli provided the highest repeatability of age estimates. Contrary to assumptions made by a previous study, the first increment was formed just after hatching in sagitta, and six days after hatching in the lapilli.

Validation of Back-Calculation Methods for Laboratory Reared Spot (Leiostomus xanthurus)

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Growth rate back-calculation from otoliths of larval and juvenile fish is a powerful tool in the research on the ecology of early life stages of fish. Although many back-calculation methods exist, not all of them are equally accurate. In the current research, larval spot were reared individually and measured daily using computer video. Fish were scarified after 20 days and increment width were measured from lapillar otolith. The lapilli provided similar accuracy of age estimates as sagittae (increments were formed daily), but higher precision (daily increments formed on lapilli were more clearly spaced and were easer to recognition), and therefore lapilli were chosen for the analysis. Growth curves were back-calculated from otoliths using three methods: SPM, BPM, and BI. These estimated growth curves were then compared with the real somatic growth trajectories derived from daily length measurements. A back-calculation method that includes the effect of age or the otolith size-fish size relationship was developed and compared to the three other back-calculation methods.

Recruitment Processes in Norwegian Spring Spawning Herring

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The most important factors for recruitment of Norwegian Spring Spawning Herring (Clupea harengus L.) seem to be operating during the larval stage from first feeding in March/April to metamorphosis in July. Herring recruitment is studied in more than a decade from 1985–1998 in the present work. Herring larvae are sampled along the Norwegian shelf in April and again in May-June together with zooplankton and physical parameters. The number of daily increment and the widths of the individual increments in the otoliths are studied to backcalculate hatching curves and to investigate larval growth. First feeding success and growth during the larval stage is proposed as the two most important factors for recruitment success. The variable growth and feeding success seem to be dependent on large scale density independent factors that governs changes in zooplankton biomass and the environment.

Larval Herring Otoliths: Coping With Reality

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Despite two decades of field surveys and experimental work, there remains strong evidence that primary increments do not form daily during the early larval stages in herring (Clupea harengus). We have considered the experimental evidence, the data available from field studies, together with the availability of additional techniques and tried to evaluate what can accurately be determined about herring larvae from their otoliths. It may be possible to develop a model that will accomodate the uncertainty of age estimation in the first weeks of life. Alternatively, pattern-recognition techniques could be developed simply to identify otoliths as coming from good growth or poor growth areas or seasons. Otolith increment patterns and composition is still useful for population discrimination, but with this species we may be confronted with the question: How do we study herring larval growth when we can't use otolith increments for straightforward age estimation?

Is Corroborating Ages a Valid Concept for Walleye Pollock (Theragra chalcogramma) Fish Age Determination?

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Age determination researchers have long recognized the importance of validating age reading methodologies. Validation requires the acquisition of ageing structures from fish of known ages or tag recoveries from fish of known time at liberty. Often such specimens are extremely difficult to acquire so researchers have not pursued validation. In this paper we encourage the concept of corroborating fish ages. Corroboration of a fish ageing method occurs when fish ages are found to be consistent with another source of information. This other source of information may be, but is not limited to, ages from another non-validated method of age determination. Corroboration, we believe, requires two components: (1) ancillary information and (2) randomization that ensures unbiased interpretation of this information. Taken together, corroboration should increase the likelihood that the ageing methodology under study is providing correct ages. Logically then, validation can be taken to be corroboration with known-age fish. In this paper we discuss the concept of corroboration and show how ages read from vertebra can be used to corroborate ages read from otoliths of walleye pollock (Theragra chalcogramma). A new statistical F-test is proposed for testing whether vertebra ages are different from otolith ages. Although vertebra ages were found to be statistically different from otolith ages, their overall agreement was judged to be corroborative.

The Direct Validation of Otoliths for Use in the Age Estimation of Patagonian Toothfish, Disstostichus eleginoides

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The correct identification of annual increments observed in otoliths is essential to the accurate estimation of age. This is

particularly important in species in which annual increments are hard to interpret. Patagonian toothfish, Dissostichus eleginoides have been aged assuming that one translucent (fast growth) and one opaque (annulus) increment is laid down each year. There has been no published data on the direct validation of these assumed annual increments. Sagittal otoliths, chemically tagged with strontium chloride (SrCl2), were collected from 66 recaptured D. eleginoides. Of these, 98% of the samples showed a clear strontium mark on their otoliths when viewed under scanning electron backscatter microscopy. Time at liberty after tagging ranged from between 350 and 1160 days. For each year at liberty, positive otolith growth occurred and a single annual zone (fast growth and annulus) was formed. It was found that the otolith growth was almost exclusively restricted to the proximal side of the otolith. The time of tagging and the associated position of the strontium chloride mark in relation to the observed annulus laid down prior to tagging suggested that annulus formation was occurring during late spring – early summer. This current study validated the annual nature of the growth zones after SrCl2 marking for fish between the ages of 5 and 13 years. The appearances of several zones formed prior to tagging were similar to those formed after the SrCl2 mark. The protocols currently used to determine the age of Patagonian toothfish are supported by this validation study.

An Age-Based Analysis of Sexual Size Dimorphism in the Coral Reef Surgeonfish Ctenochaetus striatus

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Sexual size dimorphism is prevalent among coral reef fishes. However, the mechanisms underlying the differences in size between sexes remain largely unresolved. There are 3 general hypotheses. Males may achieve a larger size than females because they live longer and continue to grow. Alternatively, males may grow to larger size through a growth spurt following sex change. Males may also grow faster than females before sexual maturation through faster initial growth. The fundamental differences between these hypotheses lie in the age and size structure of males and females. This study investigates the mechanisms underlying larger male size using the coral reef surgeonfish Ctenochaetus striatus. Over 1000 individuals were collected in the Seychelles, along the Great Barrier Reef and in American Samoa. Age was estimated for both sexes from transversely sectioned sagittal otoliths, and the relationship between size, age and sex was analysed for distribution of sexes across ages and sex-specific growth rates. Back-calculated growth was used to distinguish the sex-specific early growth trajectories. The size-at-age analysis and back-calculation of males and females of C. striatus revealed sex-specific growth trajectories, suggesting faster initial growth as the mechanism responsible for larger male size. Males and females had intrinsic differences in demographic characteristics across geographical scales, but the mechanism driving sex-specific growth patterns remained constant, suggesting no influence of environmental factors on the growth mechanism of sexual size dimorphism. This study furthers our understanding of sex-specific life histories, and the evolution of reproductive strategies and mating systems.

Otolith Based Evidence for Sub-Stock Structure in Gulf of Mexico Red Grouper (Epinephelus morio)

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Red grouper (Epinephelus morio) otoliths were sampled from fishery independent sources throughout the Gulf of Mexico and from fishery dependent sources primarily along the West Florida Shelf (eastern Gulf of Mexico; the central area of fishery harvest in U.S. waters). Age, growth, and other life history parameters were determined. Based on geographical features, the eastern Gulf of Mexico was divided into two regions a northeastern (capture locations equal to and greater than 28o latitude) and southeastern (capture locations less than 28o latitude). Regional identification (north or south) was added to the fishery dependent age and length data, and revealed red grouper from the northeastern region were younger and smaller, whereas fish from the southeastern region were older and larger (age: single factor ANOVA, $F=116$, $p<0.0001$; length: $F=307$, $p<0.0001$). Forty-nine percent of red grouper from the south had lengths of 700mm and greater compared to only 28% of fish from the north. In addition, 37% of red grouper from the south were 10 years old and greater compared to only 13% of fish from the north. Further analysis revealed red grouper from the south had significantly heavier otoliths by length then their counterparts from the north, and fish from the northeastern region grew faster than fish from the southeastern region. Fishery independent samples, available from surveys of the eastern Gulf and southwestern Gulf (Bay of Campeche) also indicated differences in size and age structure by region. This implies a sub-stock structure that may be important for the management of this species.

Integrated Approach to the Biological Basis of Age Estimation in Commercially Important Fish Species

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The European funded project (QQLRT-2001-01610) running from October 2002 to October 2005, is a co-operative venture to improve our understanding of the biological basis of age estimation for cod (Gadus morhua) and hake (Merluccius merluccius). Our objective is to integrate modelling, laboratory and field observations to provide an objective basis for interpreting the macrostructures of otoliths used for estimation of fish age. We take a multi-disciplinary

approach, including mathematical modelling, geochemical analysis of oxygen isotope ratios, experimentation in controlled conditions with live fish, and collection of biological data from field populations, to develop generic models of otolith growth. The research activities are divided into 4 tasks: Model development; New observations from Laboratory Experiments and Field Investigations; Generic Model refinement; Development of ageing protocols and production of an accessible database and interactive web site for fisheries age estimation laboratories and fishermen's organisations. We expect to achieve a generic model of otolith formation based on existing information, including functional aspects, to obtain results from field studies of the correlation between temperature history and otolith macrostructure and from laboratory studies of the correlation between otolith micro- and macrostructure and feeding, temperature, and fish growth. From these we will obtain a refined model of otolith formation, including growth patterns and otolith shape and an improved methodology or age determination in fishes based on objective classification of otolith growth structures using trained artificial neural networks for age identification. We expect to increase confidence in fishery management due to improved reliability (and improved perception of reliability) of data.

Growth of Pomadasys argenteus from New Caledonia (West Pacific)

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Pomadasys argenteus, a tropical coastal fish, is an important artisanal fishery throughout New Caledonia. Growth rate was determined from 55 young fish of length <255mm and from 114 fish of length >255mm caught between December 1988 and December 1989 in Ouenghi Bay on the west coast of New Caledonia. Two techniques were used to get "age at length" data : microincrements were read on thin sections of sagittal otoliths and seasonal rings were read on whole sagittae. Only the microincrements of young fish are easy to observe and count. Both young and old fish otoliths present seasonal increments. Increment deposition rate was validated first using linear regression analysis between the number of, assumed daily, microincrements observed and the seasonal increment number on the same young fish. The second method employed annual marginal increment evolution. The results of both methods of validation show a seasonal increment deposition rate of between three and four increments per year. The growth parameters were estimated by fitting the von Bertalanffy growth function to both the number of seasonal increments and the number of microincrements, and the corresponding length data. The growth parameters estimated in this study are similar to estimates found for the same species in other global locations. Consideration of results takes the climate of New Caledonia into account. It is tropical and humid with four seasons, two hot and rainy and two relatively cool and dry. The number of seasonal increments per year seems to depend on the climatology of the sample year.

Age and Growth of Spotted Goatfish, Pseudupeneus maculatus (Pisces: Mullidae) off Northeastern Brazil

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From 1999 to 2002, 4973 specimens of Spotted Goatfish Pseudupeneus maculatus (4.5 to 29.2 cm TL) were collected off northeastern Brazil. Otoliths (398) were used for age and growth estimation using periodic marks and increments in the otolith microstructure. Otolith sections were polished and analyzed using a light microscope (100 to 1200 x magnification); some samples were EDTA etched and examined under scanning electron microscopy (SEM). Mean monthly marginal increment (MIR) analysis suggested that one band is formed annually (May-June). For validation of increment periodicity fifteen specimens were reared (3 to 71 days) and injected with Oxytetracycline (OTC). Ten specimens (7.5 to 16.9 cm) showed the fluorescent dye. After testing, it was accepted that one increment was formed every day. Spawning occurs from October-March and the first annual band appears in May in 60 to 180 day-old specimens. Individuals >22.6 cm (4 years) showed heavily overlaid increments on the otolith edge, hampering counts. There was agreement between annual and daily counts. The von Bertalanffy growth function best fit the data: $L\infty$=33.23 cm; K=0.265 ; t0=0.0883 year. The sample was composed of specimens of 0+ to 5.4 years. Age at first maturity was 3.6 years (20 cm), under the age of recruitment to fisheries (3.9 years). Juveniles represented about half of the catch (48.7%), which may have implications for population equilibrium.

Growth Variability and Evidence of Growth Dependent Survival of Larval Whiting (Merlangius merlangus) from the North Sea

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We investigated the temporal and spatial growth variation in a population of larval whiting (Merlangius merlangus), distributed in an area of a hydrographic front in the north-eastern North Sea. The population was surveyed twice (in April and May 2001), and sampled larvae with different dates of hatching and sites of distribution were selected for analysis. Comparison between of otolith (lapillus) and somatic sizes indicated close linkage between their respective growth rates, and the growth history of each larva was described by ring width determinations from the otolith. The whiting larvae showed great variability in their growth trajectories, and averaged trajectories differed both among groups from different periods of hatching and between sites. From both surveys we observed the same pattern in growth differences. Growth was markedly enhanced in central parts of the distribution, coinciding the area of the hydrographic front, and at comparable ages, larval growth rates in the late hatched

group were higher than growth rates in the group hatched 1–2 weeks earlier. In the off-frontal area, where larvae generally grew at a lower rate, we saw the opposite picture with respect to the influence of hatching time. Here the growth rates of the late hatched larvae were relatively higher. These growth differences were linked to changes in the prey environment of the larvae, and the findings illustrate how environmental changes, over relatively short distances in time and space, exert great influence on larval growth performance.

Otolith Diagnostic Characters Used to Reveal Older Age Range of Walleye Pollock (Theragra chalcogramma)

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Surface characters were observed in otoliths from walleye pollock *(Theragra chalcogramma)*, tested for repeatability, and compared to ages derived using unconventional growth pattern interpretation criteria for the species. Characters of "luster" (flat, semi gloss, gloss), "texture" (smooth: general, contour-wavey; not-smooth: bumpy, wrinkly, poolish), "opalescence" (absent, lightly present, strongly present), and "original crenulation" (present, absent) at their most detailed level had 49.5%, 28.3%, 33.3%, and 66.2% agreement (respectively) among four observers of varying experience. Decreased character detail (flat versus "any gloss", smooth versus not smooth, and absent versus "any present") increased agreement to 86.2%, 71.2%, and 50.4%. Within-observer agreement for two observers averaged 82.7%, 74.4%, 70.2%, and 87.5% agreement for luster, texture, opalescence, and crenulation at their greatest detail. Age-length data were compared to each character, with an added character, "foliation", observed at the time of age determination. Good recognition of these characters support their integrity, though possibly affected by observer ability. These characters suggest complexity in otolith accretion, suggested to be induced through animal growth variation and time, and support this unconventional pattern interpretation for walleye pollock that results in a more complex and older age composition for the species.

Age-based Demographic and Reproductive Ontogeny of an Angelfish (Family Pomacanthidae)

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Few studies have examined the demographic and reproductive ontogeny of angelfish. Such features are important in understanding impacts of harvesting a family that is characteristic of relatively rare and endemic species. Analysis of annual increments in sectioned sagittal otoliths and gonad histology of the larger angelfish, Pomacanthus sexstriatus, allowed an examination of its gonadal and reproductive ontogeny, and sex specific growth in relation to age of sexual maturity. Fitting pooled size at age to von Bertalanffy growth function displayed distinct 'square' growth in which 85% of growth occurred in the first 15% of its lifespan. Furthermore, when growth by sex was explored, there was sex-specific differential growth in which males were larger with age. Males reached maximum ages of 58 and females reached lower ages of 41yrs. Interestingly, P. sexstriatus is gonochoristic, with gonad development consisting of an extended period of sexual differentiation with juvenile fishes exhibiting a bisexual stage. Male recruitment was through sexual maturation of faster growing bisexuals, while slower growing bisexuals matured as females. Sexual differential growth was predicted to be a result of 'early differential growth'.

Age and Growth of the Freshwater Sawfish, Pristis microdon in the Gulf of Carpentaria Australia

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Estimating age from the vertebral centrum of the freshwater sawfish, Pristis microdon was carried out by examining growth bands on whole vertebra, sectioned vertebra and Alizarin Red S stained whole vertebra. Specimens of this sawfish were collected from both fresh and brackish water locations in the Queensland Gulf of Carpentaria. Laser ablation inductively coupled plasma mass spectrometry is a common microchemistry technique used to measure trace element concentrations in hard structures. Laser ablation was used to help interpret the pattern of growth banding within the vertebral centrum, and to verify whether this species was an obligate freshwater elasmobranch. A secondary purpose was to aid in the interpretation of the life history of the freshwater sawfish. Sawfish sizes ranged between 711 to 6000 millimetres (mm) total lengths and the number of growth bands in these animals varied between less than one and 42. The first growth band appears to be representative of birth and the annual growth rate of the first year class was calculated at 420 mm. Whole stained vertebrae gave distinct banding which corresponded well with the bands observed using polished 250 micron sectioned preparations. Comparisons between the concentration ratios of strontium and calcium revealed seasonal trends representative of a typical monsoonal wet and dry seasonal alternation. The laser ablation analysis supports annual growth banding seen under light microscopy. Other trace elements investigated included manganese, magnesium and barium, which exhibited more complex behaviour than strontium and calcium and might provide additional information about the life cycle of these animals.

Growth of 0-Group Hake (Merluccius merluccius) from the 'Southern Stock' Estimated by Otolith Microstructure Analysis

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Recent data from mark-recapture experiment have shown that European hake may grow faster than previously thought. Somatic and otolith growth of recaptured fish was higher than expected. Otolith analysis of recaptured fish permitted

to validate the hypothesis of daily increment deposition. This study is aimed at estimating growth of 0-group juvenile hake from the so-called 'southern stock' (ICES Divisions VIIIc and IXa). Otoliths were sampled on fish (<25 cm) collected during spring and autumn surveys carried out in the Spanish Atlantic waters in 2002. Age was determined by counting the number of daily increments on otolith sections. Due to their relevance in terms of routine ageing, we also checked the occurrence of false rings, which are deposited during the first year of life. Such pattern have been often reported in the literature and helped to define ageing criteria, which were agreed in international workshops. Growth results are compared with prior data and discussed in the light of recent work on 0-group juvenile growth in the so-called 'northern stock'.

Growth History and Age at Recruitment of European Glass Eels (Anguilla anguilla) as Revealed by Otolith Microstructure

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Our survey was about various aspects of the biology of the European eel (Anguilla anguilla L., 1758), in the most southern part of his area of distribution geographical, estuary of the Moulouya situated on the Mediterranean Moroccan. While being based on the presence or the absence of the transition zone on the sagittae, we could differentiate three types of otoliths: type 1, type 2 and the type 3. In beginning the otolith of elvers doesn't present all one in season, marks transition and the pigmentary stage dominating is the transparent stage. The otolith of type 3 is present at the end of season and is essentially pigmented elvers. Otherwise, we posted for the first time and every type of otolith, the total daily growths since the sea of the Sargasso until the estuary of the Moulouya. For the types 1, the transatlantic migration would come true in one record time of 170, 67 days (5 to 6 months), whereas the elvers of migration end would measure 7 to 8 months to arrive there.

Growth of Juvenile Fish from Douro Estuary, Portugal, Based in Microincrement Count

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The study of fish community of the Douro estuary only recently started. The growth of young fish in this important estuary was not studied before this work. Sampling in Douro estuary with a beach-seine collected small (20-82 mm) mullets (Chelon labrosus, Liza ramada, and Liza aurata) and sand smelt (Atherina presbyter). After cleaning and storing in plastic vials, sagitta otoliths were prepared to examination in a JEOL JSM-6301-F scanning electron microscope: mounting in Struers Specifix-20 resin, abrasion with Silicon carbide paper 1000 and 4000, polishing with Struers AP-Fin 0.3 Âµm, etching with 0.1% HCl and cathodic gold spaying. Increments were counted in 20 Chelon labrosus, 18 Liza ramada, and 16 Liza aurata and were related to total length to obtain the following growth equations (t=days; L=cm): L. aurata Lt=0.0175 t+1.0931 (r2=0.9133; p<0.05) L. ramada Lt=0.0152 t+1.682 (r2=0.9409; p<0.05) C. labrosus Lt=0.0175 t+1.0931 (r2=0.9138; p<0.05) Atherina presbyter Lt=0.0085 t+4.987 (r2=0.8911; p<0.05) Average growth rates were: L. aurata 0.222 mm/day L. ramada 0.324 mm/day C. labrosus 0.240 mm/day Atherina presbyter 0.456 mm/day During this part of the life cycle from 100 to 500 days, growth can be described by a straight line better than the von Bertalanffy growth curve.

Using Age-Structure of An Adult Barramundi Population to Investigate Relationships Between Environmental Variables and Survival of Young Fish

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A need was identified to confirm the effect of freshwater flows on the survival of juvenile barramundi (Lates calcarifer) within the Fitzroy River estuary in Northern Australia. Analysis of fisheries and environmental data showed a strong correlation between commercial catches of barramundi and summer flows. Increases in commercial landings were observed 3 to 4 years after high summer flows, suggesting that wet summers result in enhanced survival of juvenile barramundi that occur in estuaries at that time. We investigated the relationship further by using otoliths to establish the age-structure of the adult population. Although barramundi migrate between salt and freshwater habitats, they return to estuaries to spawn. Therefore we were able to sample the adult barramundi population efficiently by collecting otoliths from commercial catches from the estuary. We collected otoliths during three consecutive years and estimated year-class strength from the age-structure of the adult population. Strong year-classes occurred in 1991, 1992, 1996 and 1999, coinciding with the wettest summers and supporting the suggestion that freshwater input into the estuary during the first few months of life has a large impact on the subsequent survival of a juvenile barramundi.

Effect of Thyroid Hormone and Thiourea on Otolith Growth of Metamorphic Leptocephalus, Megalops cyprinoides

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Experiments were conducted to understand the effects of triiodothyronine (T3) and anti-thyroid hormone drug, thiourea (TU), on the otolith growth during metamorphosis of leptocephali. Fully grown leptocephali of tarpon Megalops cyprinoides collected at the river mouth were immediately treated with 10 ppb T3 and 300 ppm TU, respectively for 13 d. The newly grown otolith radii were 77.0±12.0, 91.9±7.2 and 47.9±6.3 micro meter in control, T3 and TU group, respectively. The otolith radius of T3 group was significantly

larger than control and TU groups, and control group was significantly larger than TU group. T3 treatment stimulated the growth rate of daily growth increment that increased from 8 – 9 micro meter in control group to 12 – 14 micro meter during the growth peak of metamorphosis. However, the maximum increment widths were only 6 – 8 micro meter in TU treated tarpons. After 13 rearing days, the newly deposited increments were 13.2±0.4, 13±0 and 7.1±0.8 day in control, T3 and TU groups, respectively. The otolith of the fish with T3 and TU treatment was still deposited in daily period, however the otoliths of TU treated tarpons stopped growth between day 6–9. These results suggest involvement of thyroid hormone in the unique and dramatic increase of increment width during metamorphosis of leptocephalus.

Age and Growth of New Zealand Right-Eyed Flatfish (Family Pleuronectidae)

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New Zealand has 11 largely endemic species of right-eyed flatfish (Family Pleuronectidae), eight of which are commercially important and managed as a species complex in the New Zealand Quota Management System. The remaining three species are small and poorly studied. Most flatfish ageing in New Zealand has focused on only two species; the sand flounder, Rhombosolea plebeia, and the yellowbelly flounder, R. leporina, which grow rapidly and generally only live for 3 to 4 years of age. These studies led to the widely held belief that all New Zealand's commercial flatfish species were fast-growing and short-lived. However, recent work on New Zealand brill and turbot observed maximum ages of 21 and 16 years respectively, questioning the suitability of the current flatfish management strategy. We present age estimates for a number of New Zealand flatfish and discuss the impact of these on current flatfish management.

Translucent Zones Form Annually in Otoliths of Antarctic Toothfish (Dissostichus mawsoni)

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Antarctic toothfish (Dissostichus mawsoni) from the Ross Sea have been aged assuming that one translucent zone is formed annually in their otoliths. However, no evidence to validate this assumption has previously been presented. In the current work, otoliths from four distinct juvenile length-frequency modes were examined, and the translucent zones counted. Zone counts were consistent within modes, and increased by one in each consecutive mode. This indicates that the modes represented year classes and that one translucent zone is formed annually in otoliths of juvenile D. mawsoni. In addition, sagittal otoliths were examined from D. mawsoni that had been injected with oxytetracycline some years before recapture. The six recaptured fish were large (129–145 cm TL at tagging) and had been at liberty from 1 to 7 years. The number of zones between the fluorescent oxytetracycline line and the otolith margin indicates that one translucent zone is formed annually in otoliths of post-mature D. mawsoni. This indicates that counting translucent zones in the otoliths of D. mawsoni appears to be a valid method for determining the age of this species.

Comparative Growth Between Widely Separated Populations of Striped Trumpeter (Latris lineata): Assessed via Otolith Morphometrics, Increment Analysis and Growth Modelling

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Otoliths were collected from two widely separated populations of striped trumpeter. One from Tasmania, Australia and the other from the French territories of St. Paul and Amsterdam Island. Individuals were aged by counting annuli on transverse sections of sagittal otoliths. Validation of age was facilitated via comparison of morphometrics at age and increment deposition with cultured individuals and the modal progression of a strong recruitment pulse. Comparative growth of individuals across a range of age classes was assessed. Likelihood ratio tests were employed to identify stock specific differences in individual length at age, and analyses of otolith morphometrics and increment deposition were used to assess variability in otolith structure between the two stocks. Environmental influences on growth were explored and the effects of sea surface temperature on patterns of seasonal growth are also considered and modelled.

Growth Variation of Juvenile Jack Mackerel (Trachurus japonicus) off the Pacific Coast of Western Japan

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Juvenile growth trajectories of individual Japanese jack mackerel caught off the Pacific coast of western Japan in April 2000–2002 and March 2002 were back-calculated, based on individually determined linear relationships between otolith daily increment width and fish size (standard length, SL). Estimated hatch date and age ranged from early January to late March; and from approximately 20 to 65 d after hatching, respectively. In 2002, the SLs of January-hatched group were significantly smaller than those of March-hatched one. Cumulative sea surface temperature (SST) in the possible nursery area during their life in the ocean did not differ between January and March. There was little inter-annual variation in growth among March-hatched group of each year. However, variations in recent 3-, 5-, and 10-days daily growth rates calculated from the outer increment widths on the otolith of March-hatched group among three years corresponded with in situ SSTs, but not with zooplankton wet weight as an index of prey density. These suggest that temperature certainly affects the growth of juveniles but it is not only factor affecting the growth throughout their early life stages.

Early Life History Traits of Sillaginids (Sillago spp) in the Northern Taiwan as Indicated From Otolith Daily Growth Increment

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The Sillaginids are estuarine-dependent marine fish. To understand their early life history among species traits, the larvae and juvenile of Sillaginids were examined based on the specimens collected twice a month using a set net in the Gong-Shy-Tian Creek of northern Taiwan in 1998. The three species recruited to the creek during April to November with a peak in early. Sillago sihama was the most abundant of these three species of Sillaginids, constituted of 88.5% of the total catch, followed by S. japonica (2.8%) and S. maculata (8.7%). Mean age at recruitment of S. sihama was 22.4 days, significantly older than the other two species at 19.2 and 18.2 days, respectively; while the mean daily growth rate of S. sihama was the lowest at 0.67 mm/d. The differences in growth rate in relation to environmental conditions were also discussed.

Growth Rates of Larval and Juvenile Anchovy, Engraulis encrasicolus, in the Southern Benguela Ecosystem

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Growth rates of larval and juvenile Cape anchovy Engraulis encrasicolus were investigated, based on samples of the particularly strong 1999/2000 year-class collected during two consecutive surveys in 2000 in the southern Benguela region off South Africa. Standard lengths (SL) were measured and otoliths extracted for examination. March larval (14–70 mm SL) otoliths were examined using light microscopy (n=193, 92% success rate). Scanning electron microscopy (SEM) was used for May juveniles (52–114 mm SL, n=80). Because of its low success rate (22%), SEM is only recommended for specimens >95 mm SL for its higher magnification and resolution. Three models were applied to estimate daily growth rates: a linear regression, a Laird-Gompertz curve and a von Bertalanffy growth function (VBGF). All three curves showed similar results. March larval growth rates ranged between 0.33 and 0.36 mm.day^{-1} (r^2: linear=0.90, Laird-Gompertz=0.90 and VBGF=0.89). May juvenile growth rates were estimated between 0.22 and 0.24 mm.day^{-1} (r^2=0.45, 0.48 and 0.47 for the 3 models respectively). The hypothetical larval standard length at age 0 (L0) was estimated as 8.8 mm, 11.7 mm and 5.3 mm for the 3 models respectively. Daily growth rates were slower than previously reported rates, possibly due to the high density of larvae present in 2000 and hence less per capita food availability. However, reduced food availability did not affect survival in 2000 and therefore, does not support Wareâs Growth-mortality hypothesis.

Description of a Pacific Halibut Chronology of Bomb Radiocarbon From 1944–1981 and a Validation of Ageing Methods

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Pacific halibut are important biologically to the ecosystem and commercially in the fisheries of the northeast Pacific ocean. They live on the continental shelf adjacent to the United States and Canada, and are monitored and managed by a joint commission of the two countries. Validation of the ageing methodology used in the assessment of Pacific halibut has not been completed previously. This study uses 1 y-old fish to create a reference curve of radiocarbon levels for the years 1944–1981. Pre-1960 levels of radiocarbon in halibut otoliths are among the lowest reported to date, but increase dramatically post-1960 through 1970. Subsequently, this reference curve is used to validate the ages determined using the standard break and burn and surface ageing techniques by comparing reference curve to radiocarbon levels in the cores of older fish collected at a later date but born during this period of rapidly increasing radiocarbon levels. Otolith cores were compared to the reference curve based upon the presumed birth year determined from the estimated age and year of capture. The ages derived from both break and burn and surface ageing methods were determined to be generally accurate, validating the methods used currently to age Pacific halibut.

Distinct Annuli Inside the Chondrophores of Horse Clams

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Horse clams *(Tresus nuttalli* and *Tresus capax)* are conventionally aged based on the growth pattern on the external shell surface. The ageing expertise is required to distinguish annuli from numerous disturbing checks. Aggregation of annuli in the margin of the shells of old horse clams causes additional difficulties in age determination. We developed a new method of using chondrophores to age horse clams. The cut surfaces of chondrophores exhibit distinct annuli which are much less perturbed by checks and easier to identify than those on the external shell surfaces. The chondrophore is particularly useful for ageing old horse clams. One-hundred and fifty horse clams, which had been aged using the existing method by a horse clam ageing "expert", were aged using the new method by a "beginner". The oldest horse clam was estimated to be 17 years using the external shell surface and to be 20 years using the chondrophore. In general, the ageing results from both structures are rather comparable, suggesting that the identified annuli in the chondrophores are most likely to be true annuli, as annuli on the external shell surfaces had, to some extend, been verified.

Age Estimation of Sicyopterus and Cotylopus Gobiids (Adults and Offspring) in Mascarene Islands

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The age of two amphidromous gobies (Sicyopterus lagocephalus and Cotylopus acutipinnis), sampled at La Reunion and Mauritius islands (Mascarene archipelago, south-west Indian Ocean) was estimated through sagittal otolith examination. The juveniles are heavily exploited by traditional fisheries during their recruitment and for several years the resource has been decreasing. Moreover, little is known of the complex life cycle of these fishes. Consequently, age determination is very important for applying life history knowledge to this economically important resource. The age of adults was obtained by counting the seasonal rings in otolith sections, validated through marginal zone analysis. Like other amphidromous gobies, these two species have a relatively short life span (3–4 years). Several checks were detected on the otoliths in relation to environmental river conditions. The settlement mark was well detected on adult otoliths. For juveniles of the two species, the number of daily increments was used to estimate the oceanic larval life duration. Daily deposition was validated with Alizarin (30 mg.L^{-1}). These values, in relation to the size at recruitment, showed several differences between S. lagocephalus and C. acutipinnis and with other amphidromous gobiids. The duration of larval life is compared with other taxa of exploited fishes and is discussed in terms of dispersion capacity.

An Assessment of Fish Ageing Errors From Otolith Sectioning Process

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Australia Determination of fish age from thin sections of otoliths is an important and routine procedure used in fisheries research. Despite the importance placed on age determinations and the considerable time and resources invested in aging, the outcomes can be undermined by procedural or interpretive errors. Identifying the sources of such errors and improving the reliability of age estimates is of key importance for precise and accurate age estimation. The process of embedding otoliths and sectioning and mounting thin sections of them is time consuming and may introduce several sources of error that ultimately impact on the precision and accuracy of age estimates. We compare age readings from a series of thin sections from pro-nuclear to post-nuclear position of the same otolith to investigate fish ageing error caused by variation in the otolith sectioning process. Fish otoliths were collected from three common tropical fish families (pelagic Scombridae, and demersal Serranidae and Lutjanidae) in the Great Barrier Reef off Australia. Errors in ageing were assessed for each species and multiple age groups within species. We present significant information about the importance of where on otoliths sections are taken and suggest improvements to widely used otolith processing techniques which should enhance the precision of age estimates for tropical fish.

Aspects of the Early Life, Age and Growth of Mulloidichthys flavolineatus in the Indian Ocean (Mauritius Island and Reunion Island)

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A coral reef fish, Mulloidichthys flavolineatus (Lacepède, 1801), was studied for the first time in the Indian Ocean. This species is a commercial and overfished mullidae. 179 fishes were collected in Reunion and Mauritius Islands (from november 2002 to mars 2003).

The objectives of this study were to:

1) estimate hatching date, settlement date, age on recruitment, pelagic larval life duration, as revealed by otolith studies
2) determine larval growth of Mulloidicthys flavolineatus in the two islands
3) compare a same species in the two islands

In respect to these objectives, weight, total length, standard length, body depth and eye diameters were recorded. Sagittal otoliths were extracted to provide morphometric data that were recorded using video-image analysis software (Visilog, Noesis). The daily deposition of increments was validated by use of Alizarine complexon. The otoliths daily increments were then counted to give accurate informations on the aspects of the early life of Mulloidichthys flavolineatus.

'Long-lived Fish Down Under'

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Several of the major commercial fisheries in New Zealand waters are associated with large aggregations of deepsea fish on seamounts and the nearby areas of relatively flat slope. Careful management is required for these deepwater fish due to their great longevity (and thus low productivity) and late maturation. There is growing confidence in the current age interpretations of deepwater species, and why deepwater fishes attain such a high longevity. High longevity is likely to be a resilient adaptation to the deepsea environment, with assumed low productivity and/or episodic recruitment. We present growth data for several deepsea species in the New Zealand region and discuss the need for validation. New Zealand ageing studies have been based on otolith growth ring counts. The assumption is that these zones, although narrow and somewhat different from those of more near shore species, and often particularly difficult to read, represent annual growth. As elsewhere, recent age readings are giving higher rather than lower ages. Work on several species has found one third live to over 100 years. Several have high ages at maturity. Species include orange roughy (Hoplostethus), oreos (Oreosomatidae), black cardinalfish (Epigonus), a grenadier (Macrourus), a scorpaenid (Helicolenus), rubyfish (Plagiogeneion), bluenose (Hyperoglyphe), and toothfish (Dissostichus). Currently more emphasis is being placed on validation studies which include radioisotopes (226Ra/210Pb) and the time-specific, bomb-produced radiocarbon marker. We are carrying out further application of the these techniques which we are optimistic will resolve issues with previous age validation studies of these deepwater species.

Relationships Between Otolith Growth and Somatic Growth in a Deep-Water Fish From Northeastern Mediterranean Waters

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The silver roughy (Hoplostethus mediterraneus) is a by-catch fish species of the deep-water trawling in the Mediterranean. During monthly samplings in the southern Ionian Sea, the species was caught in waters from 300 to 750 m. The total lengths of the collected specimens ranged between 46 mm and 236 mm TL, while a general trend of larger specimens to prefer deeper areas was displayed. Age determination was based on otolih readings, and specimens were classified to 11 age classes (0 to 10). Regression models of estimated age as a function of fish length, otolith weight and otolith measurements were calculated and tested using multivariate statistical tecniques, in order to investigate the possibility to use those parameters in confirming age readings and/or as diagnostic tools to predict age in silver roughy.

Discrimination Between Icelandic Cod Populations From Adjacent Spawning Grounds Based on Otolith Growth and Shape

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Studies on Atlantic cod (Gadus morhua L.) have demonstrated extensive variation in life history characteristics such as growth and maturity among populations exposed to different environmental conditions. In Iceland, cod have been found to exhibit distinct variation in growth among adjacent spawning areas along the south coast, where cod sampled in areas closest to shore tended to be significantly larger and heavier than those in areas further from the shore. Such difference in size and growth may indicate that these spawning aggregations belong to different populations. In this study, attempts were made to discriminate between cod populations from adjacent spawning grounds by comparing otolith growth and shape. Otolith growth estimates were based on annual increment width estimated for 6 and 7 year old mature cod. Otolith shape was determined using Fourier analysis and compared among the different spawning groups with Discriminant Factor Analysis (DFA) and Principal Component Analysis (PCA). Significant differences in growth performance and in otolith shape were seen among the adjacent areas and classification of individuals could be preformed with relatively high certainity. Therefore, it appears that cod from adjacent spawning areas may belong to different populations characterized by different life history patterns.

Ocean Ecology of Juvenile Bluefish, Pomatomus saltatrix, in Maryland Coastal Waters

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Shallow oceanic waters may provide valuable nursery grounds for fishes assumed to principally utilize estuaries during early life. Bluefish, Pomatomus saltatrix, are regarded as such obligate estuarine users; however, little is known of their ocean ecology during the juvenile period. Additionally, bluefish are economically important and widely distributed along the U.S. eastern seaboard and much remains unknown about environmental and biotic controls on recruitment. During May to October, approximately monthly sampling was conducted in shallow oceanic waters (5–18m) off the DelMarVa Peninsula (38°19'N–38°08'N) in 2000, 2001, and 2003 employing a mid-water trawl. Comparable data was available from the Chesapeake Bay estuary (39°25'N–37°05'N). We evaluated patterns of abundance, size, growth, and diet over seasons and years within and among these habitat types (e.g., ocean vs. Chesapeake Bay estuary). Juvenile bluefish abundance was c. 10-fold higher during July – October in ocean habitats than in the Chesapeake Bay estuary. Moreover, juvenile bluefish predominated at depths less than 10m in ocean waters. Anchoa sp., a chief prey item of young bluefish, exhibited similar relative abundances in ocean and estuarine environments. Analysis of otolith microstructure revealed much higher growth rates in ocean (2.7 mm day-1) vs. estuarine (1.3 mm day-1) systems for late summer- and fall-collected fish. We hypothesize that during late summer and early fall months, oceanic nursery habitats may often result in greater juvenile production of bluefish than estuarine nurseries.

Temperature-Dependent Otolith Growth Responses in Cod Larvae – Pitfalls and Potentials

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A temperature and size-dependent otolith growth model of cod larvae (Gadus morhua) derived from controlled laboratory studies is used to evaluate estimated age and growth estimates of larval cod populations from field conditions. Slow initial otolith growth, especially at temperatures below 6°C, is expected to lead to underestimation of actual age with a subsequent overestimation of growth and erroneously delayed hatching date estimate. A temperature-dependent correction of initial increment numbers is recommended, and examples are provided from published papers. It is suggested that in most reported cases surviving cod larvae are growing close to their growth potential set by their ambient temperature conditions. The potential of otolith based growth assessment in cod larvae is discussed.

The Use of Otolith Microchemistry to Monitor and Evaluate the Movement of Coral Reef Fish in South Florida Waters

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Stable isotopic ratios of carbon and oxygen, obtained from the otoliths of teleost fish, have been well documented as useful tools for providing a wealth of information about environmental variations and stock structure of fish throughout their life history. Some of the valuable data include information about habitat temperature and salinity, migratory patterns and habitat use, diet and metabolic rates, and determination of the degree of stock mixing. The aim of this study is to investigate the size-age structure of *Lutjanus griseus* juveniles in Florida Bay, their growth rates and migration patterns, and explore how these relate to habitat characteristics and environmental variables such as salinity, temperature, and ontogenetic shifts in habitat. Measurements of $^{18}O/^{16}O$ and $^{13}C/^{12}C$ ratios in the sagittal otolith carbonate were obtained from juvenile gray snapper *(Lutjanus griseus)* collected in 2001–2004 from various locations within Florida Bay. Using a high-resolution Micromill drill, portions of the otolith formed during juvenile and adult periods were collected and analyzed in order to assess ontogenetic and environmental transitions. Additionally, age data gives an insight into the age at which ontogenetic and environmental

transitions occur. We will discuss this data in light of natural variability in population parameters such as recruitment and growth and how these parameters are influenced by natural environmental variability. Ultimately, we are optimistic that we may be able to afford fisheries managers insights into the impacts of ecosystem change which will result from the effects of the Comprehensive Everglades Restoration Plan.

Comparison of Stable Isotopic Compositions in Otoliths of North Pacific Chum Salmon (Oncorhynchus keta): Stock Identification and Life History Understanding

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Stable oxygen (d18O) and carbon (d13C) isotope compositions of otolith were examined for comparison of isotope values with respect to life history and identification of stock of North Pacific chum salmon (Oncorhynchus keta). Otoliths of smolt and immature salmon were collected from the Korean hatchery and off the Aleutian Islands, respectively. Returned adult salmon were collected from four sites in Canada, Japan, Korea, and the USA during the 1997–1999 spawning seasons. The d18O and d13C values from whole ground otoliths increased with age, showing especially high correlation with salmon size. The mean d18O and d13C isotope ratios of smolt salmon showed –6.97‰ and –12.18‰, whereas the values of adult salmon were 0.62‰ and –4.86‰, respectively. The values of the two isotopes for immature salmon collected from the sea appeared in between those of the smolt and adult salmon. A combination of d18O and d13C signatures of immature salmon was largely separated depending on two size groups: 0.14‰ of d18O and –5.11‰ of d13C for large (>400 mm of body length) and –0.55‰ and –6.38‰ for small (<400 mm) immature salmon. The values of d18O and d13C isotopes of adult salmon separated largely into two groups: Asian and North American chum salmon. Though the mean lengths of Asian salmon were smaller than those of North American salmon, the d18O isotope appeared in decreasing order of Japan, Korea, US and Canada with mean differences of ca. 0.81‰ between Japan and Canada over three consecutive years. The enriched values in d18O of Asian stocks may represent a lower temperature of ocean habitat than North American stocks.

Chaetodon speculum of New Caledonia as an Indicator of Environmental Conditions

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The aim of this study was to determine if Chaetodon speculum, a reef fish from New Caledonia, is a good indicator of environmental conditions. Two types of parameters were used : 1- biological parameters : growth and settlement age, studied by counting otolith microincrements, and 2- chemical concentrations, using solution-based ICP-MS analysis of whole otoliths. Fish were sampled in four bays of New Caledonia that are subject to different rates of pollution (mining, anthropogenic activities, ...). Biological samples were collected in November, 2000 and those for chemistry in both October, 2002 and May 2003. The May samples are hopped to have recorded the cyclone Erica. Growth parameters were estimated by fitting the von Bertalanffy growth function to the number of microincrements counted at length data. Unfortunately it was not possible to validate the rate of microincremental deposition. Thus, we compare the growth curves assuming that the deposition rate is the same for every bay. The maximum likelihood method was used to compare the curves of the four bays. Results show that the growth rate for fish of the most polluted bay is slower and significantly different from the other three. Chemical element (Li, Mg, Co, Ni, Cu, Sr, Rb, Ba) concentrations were above detection limits and allow distinction between the four environments. In particular, mining and anthropogenic activities are reflected by otolith concentrations of Ni, and Co, and by Sr, respectively.

Tracing Migration Routes of European Eel Larvae

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The life cycle of the European eel (Anguilla anguilla) is still under question. After spawning in the Sargasso Sea, the leptocephali disperse over great distances in the North Atlantic Ocean to reach North African and European coasts. Based on oceanographic surveys and otolith age studies, glass eel reach North African and European estuaries between nine months to one year after the spawning. Consequently, glass eels become larger with latitude, consistent with the distance from the Sargasso Sea. However, one of the main questions is to understand if leptocephali swim actively or not, and at what water depth they migrate towards Europe. If leptocephali migrate through various water masses having different environmental characteristics (T°C, 18O, salinity), the transatlantic routes should be recorded in the stable isotope composition of glass eel otoliths. O-C stable isotope compositions obtained from aragonitic glass-eel otoliths coming from Swedish to Moroccan estuaries, including Mediterranean sites, show a clear relation with the latitude of the sites. Based on these data and on a numerical transport model, a new view of larval transatlantic migration is proposed.

Tracing Life History of Barramundi (Lates calcarifer) Using Otolith Microchemistry

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Stocked barramundi (Lates calcarifer) were used to test the application and accuracy of otolith microchemistry in documenting the life history of the tropical catadromous fish species. Laser ablation inductively-coupled plasma mass spectrometry (ICPMS) was used on sections of barramundi otoliths from both known-history stocked fish and wild stock to determine if this technique adequately explained the variable life histories known for this species. Our investigation found that the technique defined the freshwater phase of the first year of life of known-history fish by an initially low strontium:calcium (Sr:Ca) ratio. There was a general trend of decreased barium:calcium (Ba:Ca) ratios in the otoliths of older fish caught on the foreshores out from river mouths showing migration away from terrestrial impacts. This technique has the potential to provide a cost-effective tool in determining habitat usage from the adult fishery (commercial and recreational harvest) when compared with traditional tagging studies. In contrast, whilst tagging has been effective in providing information and movement of fish, thousands of fish have to be tagged to make up for losses through tag shedding and non-reporting. The laser ablation technique can quantify the importance and seasonal contribution of freshwater habitats to barramundi populations over time, and can be repeated annually to determine the impact of environmental influences such as flow events or anthropogenic impacts such as introduction of tidal barriers on habitat usage.

Otolith Microchemical Analysis of Juvenile Yellowfin Tuna From Nursery Areas in the Atlantic Ocean

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Yellowfin tuna (Thunnus albacares) are a very important fishery resource in the Atlantic Ocean and are fished throughout their range. Three primary spawning grounds have been identified in the Atlantic: the Gulf of Guinea, Gulf of Mexico, and southeastern Caribbean Sea. Tagging data provides evidence of trans-Atlantic movements. Determination of the contribution of the different nursery grounds to the population will help establish the relative importance of each site to the various fisheries, allow estimation of the rates of mixing, help elucidate unclear migratory behaviors, and greatly increase available scientific data on yellowfin in the Atlantic.

Microchemical analysis using solution-based ICP-MS and ICP-AES has been conducted on whole otoliths of juvenile yellowfin (29-57.7cm FL) from the Gulf of Guinea, the southeastern Caribbean Sea, and the Pacific, in an effort to establish the utility of using such methodology to delineate natal origin. The study consists of three analysis groups: 'Temporal' assessing inter-annual variation, including fish collected from the Gulf of Guinea at the same time of year in 2001 (n=12), 2002 (n=20), and 2003 (n=11); 'Spatial', assessing variability within a given region, with fish landed on the same date but three distinct locations in the Gulf of Guinea (n=40); and 'Regional' testing for elemental fingerprints of natal origin, including fish from the Gulf of Guinea, southeastern Caribbean (n=20), and Pacific (outgroup) (n=18). Of the elements analyzed, eight had concentrations consistently above detection limits allowing use in the discriminant analyses currently being performed: Mg, Ni, Rb, Sr, Ba, Mn, K, and Na.

Fluctuating Asymmetry in Otolith Shape and Heterozygosity in Ethmalosa fimbriata (Clupeidae) in an Estuary Stressful Environment (West Africa)

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Fluctuating asymmetry (FA) is assumed to reflect the developmental instability induced by genetic or phenotypic (environmental) influences. Fish otoliths represent a very good model to test the consequence of FA since the absence of perfect bilateral symmetry may reduce the individual fitness. FA analysis, coupled with genetic analysis, has been undertaken on the common West African bonga shad, Ethmalosa fimbriata, in two neighbouring estuaries, in order to test the salinity impact on the developmental stability. The Gambia estuary has a normal functioning with a downstream increased gradient of salinity, and the Saloum estuary is inverse (saltier waters in the upper river) reaching extremely high salinities (>100 psu), constituting high environmental constraints. Five sub-populations of E. fimbriata have been studied at five locations along a salinity gradient. Analysis of genetic differentiation at three intronic and one anonymous nuclear gene loci was carried out to investigate differences among locations and to measure the level of heterozygosity. The differences in otolith shape, between right and left sagittae, were estimated with image processing measuring several dimensions (area, radii). Results showed that otolith FA involved two sets of measures, those related to the area and others related to radii. The area FA increase was positively correlated with the fish size. No genetic structuration was observed among locations but the individual heterozygosity level seemed linked to the otolith area FA. However FA was not correlated with environmental salinity pressure suggesting that it did not reflect a phenotypic response such as some life-history trait variations.

Derivation of High-Resolution Life History Records from Fish Otoliths: Applications for the Study of Thermal Preference, Migration, and Natal Origin

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Computerized micromilling techniques have permitted development of life history records for a number of ecologically and economically important fish species. Our initial studies of wild populations have indicated that behavior of laboratory-reared fish may not provide an accurate model for predicting thermal preference and therefore metabolic rate in wild populations. For example, based on oxygen isotope values, we find that Lake Ontario chinook have annually inhabited water with temperatures above 19°C at least as far back as the late 1980's, in contrast to laboratory-derived temperature preferences near 11°C for cold-water salmonines. Chinook approach, but seldom exceed their perceived upper habitat limit of ~22°C in search of prey fish. Bioenergetic simulations indicate significant stress on chinook at these high temperatures, that greatly reduces specific growth rate and gross conversion efficiency relative to nominal laboratory simulations where chinook are kept at their preferred temperature, providing evidence that this fishery is near the limits of sustainability. In another example, temperature records from surgically implanted recording devices recovered from Lake Trout released in Lake Huron compared well with temperatures calculated from stable oxygen isotope values of their otoliths. Additionally, because hatcheries impart a distinctive hatchery food carbon isotope value for the portion of the otolith deposited during hatchery rearing, carbon values can be used to determine whether an adult fish was spawned naturally or raised in a specific hatchery. Therefore, extraction of sub-seasonal and in some cases sub-weekly aliquots of otolith carbonate for stable isotope analyses provides a means to examine behavior and diet on those scales.

Comparing the Functional Form of the Radiocarbon Chronometer in Coral to Known-Age Marine Fish Reference Curves

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The radiocarbon chronometer in coral has been used in the past as a reference curve for marine fish ageing validation. Recently however, the radiocarbon chronometer from otolith specimens of known-age marine fish species has been developed. This presentation uses a newly developed statistical method to compare the functional form of the radiocarbon chronometer in coral to known-age marine fish reference curves.

Spawning Season Fidelity in Sympatric Populations of Atlantic Herring (Clupea harengus L.)

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There is considerable debate concerning reproductive exchange between geographical and seasonal sub-units, which has implications for stock assessment and management. This study examines the level of mixing between two seasonal spawning components using otolith microstructure. Adult herring were collected from 1999–2003, at spawning grounds in the Celtic Sea, during the peak periods of spawning of the autumn- and winter-spawning components and from the summer feeding grounds of the Labadie bank. Fish were classified as autumn- or winter-spawned based on the pattern of otolith microstructure at the larval core. The maturity status of each group was assessed using macroscopic and histological analysis. Autumn and winter spawned fish occurred together at the feeding area and autumn-spawned fish were generally at a more advanced maturity stage than winter-spawned fish. The distribution of the two groups overlapped during the spawning season. However, catches of spawning fish (stage VI maturity) were homogenous with respect to population composition. The vast majority of spawning fish collected in autumn were themselves spawned in autumn. Likewise, most of the fish spawning in winter were winter-spawned. It appears that fish from the winter-spawning component occur at spawning grounds in the Celtic Sea from September, but delay spawning until winter. The results confirm that season of hatching exerts a strong influence on the timing of spawning in adult Atlantic herring from the Celtic Sea. These findings are contrary to current theories of herring population structure and have important implications for the understanding of spawning patterns in Atlantic herring.

Influence of Maternal Effects on Mesocosms Reared Cod (Gadus morhua) Inferred by the Otolith Microstructure Analysis

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Maternal effects are known to influence propagule size, and consequently their offspring fitness. In the present study, offspring from 25 different cod females were reared during ten weeks, under same environmental conditions in two large mesocosms (2500m³ and 4400m³). Additionally to egg size and egg quality measures, larval length and weight were recorded for the different rearing periods in the mesocosms, while the parental origin was assigned based on DNA fingerprint. Individual condition was estimated by the RNA/DNA method, and the growth trajectories were inferred by the otolith microstructure analysis. Female size was positively correlated to egg size and energy content, while otolith hatch-check width was positively correlated to egg size and larval condition. Finally, individuals that were small or large at hatching maintained the trend until the end of the experiment.

Stock Discrimination of King Mackerel, Scomberomorus cavalla, in U.S. Waters With Otolith Morphology

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Natural stock-specific tags were developed from otolith shape analysis to discriminate U.S. Gulf of Mexico and Atlantic stocks of king mackerel. Fish were sampled from May through September in 2001 and 2002 when stocks were separate, and sagittal otolith shape parameters were estimated with Fourier analysis. Discriminant function analyses were computed with shape data, and jackknifed classification accuracies ranged from 65% to 81%. A maximum likelihood stock mixing model then was parameterized with stock-specific otolith shape data and applied to samples from winter mixed stock landings taken off south Florida, USA. In 2001, mixing estimates indicated a gradient of distribution in both females and males from 80% to 90% Atlantic stock in SE Florida to approximately 60% Atlantic stock in SW Florida. In 2002, winter mixing estimates were not consistent between sexes. Males followed a distribution gradient from 80% Atlantic stock off SE Florida to 50% Atlantic stock off SW Florida while females were estimated to be 60% Gulf stock off SE Florida to nearly 100% Gulf stock off SW Florida. These results indicate the current management practice of assigning all south Florida winter landings to the Gulf stock greatly over-estimates the contribution of the Gulf stock to winter landings.

Validation of the Application of Otolith Microstructure for Determination of Spawning Type in Herring (Clupea harengus)

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In the eastern North Sea and the Skagerrak herring catches during the summer are comprised of a mix of autumn-, winter- and spring spawned individuals all belonging to different stocks. For individual stock assessments a split-factor is applied to the catches in the area. From 1996 the split has successively been changed from a population based mean vertebral count to an individual based otolith microstructure analysis. The otolith microstructure method identify spawning type by width of primary increments formed during the larval period, and was initially validated by the larval otolith structure in spawning herring from the different populations. The method assumes spawning time fidelity and since method is currently applied in an increasing number of national laboratories an independent validation method seems appropriate. A series of 0-group herring sagitta from archives will be selected and experienced readers will determine spawning type by visual inspection. Individuals with identified spawning type (100 spring-, 100 autumn-, and 100 winter spawners) will be analysed, counting daily rings from the centre to the edge. The number of days between hatch and catch with a correction for initial period

with non daily increment formation will identify hatch time and thereby spawning type, validation of the method will depend on the number of correctly classified individuals.

Regional Structure in Yellowfin Tuna Populations of the South West Pacific Ocean

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Affiations to be advised

Off the east coast of Australia yellowfin tuna (Thunnus albacares), bigeye tuna (Thunnus obesus) and broadbill swordfish (Xiphias gladius) are targeted by longline fishing. Within the Australian Fishing Zone the annual catch is 6,000 tonnes, which is valued at about $50 million AUD. The same species are targeted on a much larger scale in the areas adjacent to the Australian Fishing Zone by vessels from several nations including Japan, Taiwan and New Zealand. In order to determine the level at which the east coast fishery could be exploited sustainably Australian fishery managers needed information about the origin of recruits to the domestic fishery; limiting catch and effort within the Australian Fishing Zone would have different consequences depending on whether recruits came mainly from areas within the zone or if they came from the broader western Pacific region. We began by investigating the regional structure of the population of one of the species, yellowfin tuna, using data from a number of sources: otolith chemistry, tagging, genetics, catch and effort and oceanographic data. The analysis of otolith chemistry proved to be a useful technique – we analysed otoliths collected from juvenile yellowfin tuna caught at five natal sites and determined a chemical fingerprint of natal origin by measuring concentrations of elements at the otolith core. This was used to 'classify' yellowfin tuna caught within the Australian fishery: we compared the otolith chemistry at the core of the otoliths of these fish with the natal-site fingerprints to determine which they most closely resembled. The results provided evidence that the Coral Sea spawning area within the Australian Fishing Zone is the major source of yellowfin tuna recruits to Australia's east coast fishery but that the proportion of recruits from the Coral Sea is likely to vary temporally.

Spatial Variation in Otolith Elemental Fingerprints of Early Juvenile Halibut in Alaskan Waters

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Nursery grounds for eastern Pacific halibut (Hippoglossus stenolepis) are located throughout the Gulf of Alaska and southeastern Bering Sea. Following ~2 years of nursery residence juveniles are believed to migrate to the southeast, arriving on fishing grounds as 4–5 year-olds. However, little is known about the distance that juveniles migrate or the extent to which various fishing grounds are supplied by either specific nursery areas or are populated by a mixture of individuals reared throughout the geographic range. The answers to these questions may have important ramifications on spatial population structure and the management of both the directed fishery and halibut bycatch. The IPHC has a history of conventional tagging applied to juveniles, but such studies have not been successful due to high early juvenile mortality and artifacts associated with fishery-based recaptures. The present research represents an attempt to determine whether the chemical composition of otoliths (Otolith Elemental Fingerprints; OEFs) can be used to ascertain the nursery origin of adults and movement of juveniles. As a first step, we have analyzed OEFs of age-1+ and -2+ halibut, using solution-based ICPMS. In order for the technique to be useful for life history studies, OEFs must occur in regional patterns so that fish can confidently assigned to their geographic origin. Using juveniles from 16 sites within 12 nursery areas between British Columbia and the eastern Aleutian Islands, we compare variance in OEFs at a number of spatial scales, with geographic separations ranging from tens to hundreds of kilometers.

Post-Settlement Population Mixing in Gulf of Mexico Red Snapper, Lutjanus campechanus, Inferred From Otolith Chemistry

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Juvenile red snapper (total n=750) were sampled from three regions [northcentral (NC), northwestern (NW) and southwestern (SW)] of the U.S. Gulf of Mexico (Gulf) during November and December from 1996 through 2000. The chemical composition (Ca, Ba, Mg, Mn, and Sr) of juvenile sagittae was analyzed with solution-based magnetic sector field-inductively coupled plasma-mass spectrometry (SF-ICP-MS) and inductively coupled plasma-optical emission spectrometry (ICP-OES). Discriminant function analysis of otolith elemental signatures yielded high jackknifed classification accuracies (77–80%) for all years except 1998 (62%). Sub-adult and adult red snapper then were sampled in summer 2001 from fishery landings and trawl surveys in each region. One sagitta from each individual was sectioned and aged. Up to 30 fish from the 1996 through 2000 year classes were randomly selected from aged samples collected in each region. The core of the second sagittae from each fish then was mechanically extracted and its chemical composition analyzed with SF-ICP-MS. Year class-specific maximum likelihood models that were parameterized with juvenile elemental signatures and computed to estimate the source region(s) of sub-adults and adults revealed little post-settlement mixing between the NC Gulf and the other two regions. Significant mixing was observed between the NW and SW Gulf, however, with net movement from the NW to the SW region. Results indicated population structure may exist that had not been identified with traditional genetics approaches. Concurrent studies of red snapper population dynamics and genetic effective population size among regions also revealed population structure consistent with otolith chemistry results.

Utility of Transformed Elliptic of Fourier in the Discrimination Between Populations of Glass-Eels From the Shape Otolith

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In the practice, the studies in biology of the populations are based the most often on the analysis of the genome and the exam of the outside aspect of the individuals. The present survey will be based on the shape of otolith and will have for objective to estimate the homogeneity of the glass-eel Anguilla anguilla North African (Morocco) and European. Several studies showed differences of sizes and weights between glass-eel North Africans and Europeans. The following survey intends to bring some answers to some questions: 1) it's possible to find difference of the size and shape of the otolithes between glass-eel of A. anguilla North Africans and Europeans? 2) it's possible to find some describers in the shape of otolith others that those already used in order to get a better discrimination between the populations of glass-eels? This survey intends to apply to the contour of otolith (Sagitta), transformed elliptic Fourier. This fast and precise method permits to describe the closed contours. Coefficients of Fourier are extracted of it and permit to increase the number of variable thus discriminate used in factorial analysis discriminative. The gotten results allowed us to consider the shape of otolith of the glass-eel like a ecology scorer, a constant of the species. This property permits to consider use in the shape of otolith, as describer phylogeny.

Reducing Variability in Samples for Otolith Chemistry: Detecting Spatial Dynamics of Fishes in the Absence of High Environmental Gradients

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The most important demersal reef fish in the lower west coast of Western Australia is the West Australian dhufish, Glaucosoma hebraicum, a long-lived (40+ years), large (120+ cm TL), endemic species. At present this species is being managed as a single stock, but the spatial characteristics of dhufish populations must be understood to manage the fishery at the appropriate scale. Unfortunately dhufish are difficult to sample because they cannot be caught in large numbers due to their spatial distribution and habit. As the biology of dhufish is unsuitable for traditional methods of examining spatial dynamics, is the analysis of stable isotope ratios of oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) in otolith carbonates a useful method to detect the spatial scale of functional adult assemblages in the absence of obvious environmental gradients? This study examines the causes of variation in dhufish samples to maximize detection of spatial dynamics in this species. Samples of otolith carbonates in a restricted size range of dhufish (400–500 mm TL) differed significantly between two regions 450 kms apart. Yet, within one region this restricted size range of dhufish varied significantly from a broad size range of dhufish (370–775 mm TL). Overall, sex and sexual maturity, seasonal and small-scale spatial variability were not significant factors affecting the chemistry of otolith carbonates. In conclusion, the optimal design for sampling dhufish for chemical analysis of otolith carbonates is relatively robust to temporal and small-scale spatial variability within samples but very sensitive to size of this large species.

Does Reader Experience Count? A Case Study Using New Zealand Snapper (Pagrus auratus, Sparidae)

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The importance of reader experience in accurately ageing snapper (Pagrus auratus) otoliths was examined. Analysis of otolith readings showed reader bias and imprecision was relatively high in novice readers interpretations of otolith structure, especially for old age classes, and generally increased with fish age. An experienced reader would most often provide the more precise and least biased age estimate relative to the final agreed age. We found agreement between readers varied markedly between snapper stocks, and was related to stock growth dynamics and population age structure. The year class strength estimates derived from this ageing study correlate strongly with those predicted from an independent trawl survey-temperature recruitment index.

Ten Years of Routine Annual Exchanges of Age Reading Comparisons Between Norway and Russia – The Lesson Learned

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During ten years of routine exchanges and cooperation in this field by PINRO, Russia, and IMR, Norway the standardization of the equipment for age reading in the laboratories has been performed, as well as making the important elements identical when observing the otoliths (i.e., binocular magnification, light directivity and intensity, the way of otolith surface shadowing etc.). Grouping of otoliths according to quality and readability was introduced. Discrepancies in the present age reading have become less than they were ten years ago when the cooperation started. The reasons of discrepancies in age reading between laboratories were cleared up. A complete unification and standardization of method has failed so far. One laboratory read the age evaluating and counting the summer opaque rings, while the other reads the hyaline winter rings. It is clear that in this field the traditions are very strong, it is hard to re-teach an experienced, fully formed expert, only the way of age reading method applied by him/her may be corrected. It may be concluded that regular exchange of material, experts and data analyses are necessary, including the teaching of new age readers. A constant comparison and tuning to each other allow us to reduce errors and decrease the expenditure of time to correct them.

Identification of the First Annual Ring in the Otolith as a Tool to Age Trigla lucerna

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Digital analysis of 397 Trigla lucerna otoliths from Mondego estuary (Portugal) allowed the identification of several patterns in ring formation, which are described.

We found 60% sagitta with up to six false rings before the first winter ring, all of them identified by the average distance to the nucleus.

The first false ring is close to the nucleus of the otolith (215.32 to 621.05 Î¼m along the major axis). The average distance from the nucleus to the first winter ring is 1064.32 Âµm, ranging from 897.35 to 1272.71 Î¼m. The average distance to the nucleus for the subsequent rings is characterized, in order to make easier the interpretation for ageing each fish.

Inter-Agency Comparison of Age Estimates Derived From Spanish Mackerel (Scomberomorus commerson) Otoliths: Implications for Stock Assessment and Data Sharing Arrangements

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Abstract Spanish mackerel (Scomberomorus commerson) support important commercial, recreational, and artisanal fisheries throughout tropical and subtropical waters of the Indo-West Pacific. Age information is essential for stock assessment and effective fisheries management of the species throughout its distribution. Age estimation for Spanish mackerel, however, is not standardised across jurisdictions, at both the national or international level, and conflicting statements and methodologies have meant that a standardised protocol has not been ascribed. Within Australia, several agencies have been involved in age estimation of Spanish mackerel for ongoing fisheries monitoring and assessment studies. In order to compare any differences in age estimation, and to assess the impact these differences may have on age distributions and stock assessments, a comparative study of ageing methods was conducted between three of these agencies. A total of 100 pairs of otoliths were selected by each agency from their catalogue of samples, with one otolith of the pair aged whole and the other aged after sectioning. Otoliths were then exchanged between agencies for age interpretation using the normal procedures of each of the respective agencies. Independent age estimates for each agency were analysed for within-agency and between-agency comparisons of bias and precision, and for differences between methodologies (whole and sectioned ages). The implications of any biases in age estimation, for parameters used in age based stock assessments, and for combining separately aged data sets were then investigated by estimating growth and mortality parameters for each of the data sets. We discuss the findings of this comparison to determine acceptable levels of variation in the age data, for quality assurance purposes and outline the most appropriate methodology for aging Spanish mackerel.

The Otolin System: Preparing Demersal Fish Otoliths for Age Determination

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A prototype otolith line for routine age reading of demersal species (OTOLIN), was developed at the Netherlands Institute for Fisheries Research (RIVO-DLO), between 1994 and 1997. The OTOLIN project was funded by The Fisheries Directorate-General (DGXIV) of The European Commission. By 1997 the need for a more efficient otolith sectioning system was also recognised at the Aquatic Systems Branch (ASB) laboratories, of the Agriculture Food and Environmental Science Division (AF&ESD), of the Department of Agriculture and Rural Development for Northern Ireland (DARD). International co-operation between DARD ASB and RIVO-DLO, facilitated by membership of The European Network of Fish Ageing Laboratories (EFAN), resulted in the technology transfer of the OTOLIN project to the commercial market place. The demand for quality assurance and quality control of fish age determinations is increasing and the preparation of age reading materials must be supported by an acceptable procedure. In addition to instruction on how to operate the OTOLIN system, the DARD ASB OTOLIN procedure outlines the complete process from sample collection to age determination, for demersal fish species landed into Northern Ireland.

TACADAR – Towards Accreditation and Certification of Age Determination of Aquatic Resources

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TACADAR is a Concerted Action (European Commission, Q5CA-2002-01891) with the overall objective to increase reliability of age estimation procedures in the European

Community, compatible with the possibility of the future establishment of European wide international fisheries laboratories. TACADAR aims to increase the adoption of procedures that include quality assurance and quality control mechanisms, for the improvement of stock assessment and environmental management techniques. The ultimate objective is to stimulate the achievement of a higher level of quality within and integration between the member institutions of TACADAR, concerning fish age determination. The Institute of Marine Research, Norway, serves as the coordinating body for the Concerted Action (2002 – 2005) by maintaining the TACADAR Internet homepage, including databases, publishing TACADAR Newsletters and organising annual plenary meetings and workshops. TACADAR will : 1) Define the framework for the application of quality assurance and quality control mechanisms, to protocols for the determination of fish ages from hard tissues. 2) Discuss the levels of precision and accuracy to be used as qualifiers in statistical terms. 3) Discuss the evaluation of individual methods of age determination in cases where several methods are used to provide data input for the same stock assessment or environmental management model. 4) Develop guidelines for the creation and application of quality assurance and quality control mechanisms to protocols for the determination of the ages of fish from hard tissues. 5) Investigate legal aspects of accreditation and certification, including advice from externally invited specialists. 6) Submit a quality assurance manual including an evaluation of legal aspects and implications to the EU. Through a network of excellence, TACADAR will strengthen the competitive position of European institutions involved in fish ageing, through institutional synergy and international co-operation.

EFAN (European fish ageing network): A cooperative Effort to Exchange Experience and Protocols Between European Fish Institutes

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There is a discrepancy between sophisticated research into age determination, biomineralisation processes and the state of art of routine age reading for fish stock assessment. While sclerochronological research in Europe has progressed tremendously throughout the past decades, routine age estimation has not adequately kept pace. Often the quality of age data depends on individual skills and motivation, and in most cases lacks standardisation, objective control and statistical evaluation. The quality of input data, such as the age composition of fish populations, plays a vital role in the ability to manage fish resources. The need for reliable data is especially acute in times when stock levels are low and errors in predictions can have devastating effects on the resources. In Europe initiatives to improve ageing methods are often limited to small-scale studies, and thus it has been difficult to integrate innovations in routine protocols. In addition, there is a lack of pilot scale studies and clearly there has been a lack of implementation of control mechanisms in the age reading process. This was recognised and addressed by the European Fish Ageing Network (EFAN), which was a concerted action, funded by the European Commission (FAIR PL.96.1304) under the participation of 36 institutes from 18 European countries. Where has EFAN brought us so far? 1) The openness and transparency of EFAN has produced a co-operative, independent and informal network. For the first time age reading problems have found a common platform in Europe. 2) The quality of the EFAN internet homepage assures efficient communication between researchers. 3) The quality and frequency of EFAN reports and value of the databases are already widely appreciated and recognised in national and regional circles. These databases have clearly fulfilled a previously unrecognised need, for information integrated at the European level. 4) Improved awareness and sensitivity towards quality of age reading. It was clear from the beginning that establishing Europe-wide control mechanisms is a very sensitive issue. Imposing them needs time as well as a good international working climate, EFAN has undoubtedly achieved far more in this respect than initially expected. 5) The interdisciplinary approach has brought new perspectives. EFAN has very successfully bridged the gap between science and application. Through microstructural and microchemistry analyses we are beginning to develop an understanding of macrostructural features. The application of this research has started to be applied to routine age reading processes, through the involvement of experimentalists in age reading workshops. 6) Improved awareness that validation is and remains a key issue, and that assumptions must be evaluated regularly. 7) The network has facilitated joint projects, enabling progress in improving the quality of data for fishery management, e.g. cod, sardine, whiting, horse mackerel.

A Comparison of the Performance of Different Types of Neural Networks for Automatically Estimating Fish Age

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Artificial neural networks have the potential to consistently and accurately estimate fish age from relatively few data inputs. The performance of three different network types – back propagation, multiple hidden layer, and probabilistic – was compared for 8 different species of fish involving over 330,000 age estimates from over 37,000 individuals. Inputs to these models included various combinations of data from otoliths (luminance transects across otolith sections and otolith weight), biological data, and date of capture. Performance was assessed against bias (slope of regression) and precision (average percent error) criteria. Both criteria were satisfied for 10 species/network type combinations, the precision criterion alone was met for a further 11 species/

network types, and the bias criterion alone was met for the remaining 3 species/network types. The probabilistic neural network was successful more than other network types, but the best combination of network types and data inputs varied among species. Biological data alone or in combination with transect data were more effective in age prediction than transect data alone. No network type outperformed human readers.

The Fear of Losing Control: Digital Image Analysis and Semi-Automated Age Estimation

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Accurate age estimation is essential to population assessment and is the foundation upon which conservative fisheries management practices are built. Institutional inertia and conservatism among fisheries scientists has hindered the advancement of age estimation methodologies. Presently quality assurance in the field of fish age estimation is measured by the industry standard or the 'experts opinion' and in many cases 'validity' of estimates is falsely based on analyst experience (in years) rather than on scientifically justifiable validation techniques. The recent application of digital image analysis technology to fish age estimation has fostered the development and implementation of more rigorous methodologies for age estimation. The dream of automating tedious or repetitive steps in the age estimation process has become reality. Image analysis systems have become ultimately important in quality control and standardization of the age estimation process. The ability of image analysis and statistical software applications to communicate with one another has enabled the development of rigorous and sophisticated means of handling age estimation data and has allowed researches to deal with subjectivity and bias among analysts. For many fisheries scientists, image analysis and the possibility of automation represents losing control, whereas for others, it represents the critical step of admitting and dealing with uncertainty.

The Influence of Several Successive Generations of Otolith Readers on the Interpretation of Annual Increments

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Production fish ageing depends on a series of quality control and assurance measures to ensure precision as well as accuracy in age estimates. The use of precision measurements such as average percent error and age bias plots are often used to quantify errors. Whilst many studies have assessed inter and intra-reader variability in the age estimation process, issues relating to temporal drift in interpretation are seldom addressed. Furthermore, progressive drift as experienced readers pass on their skills is rarely examined. Testing for drift in interpretation within and between readers over time is an integral part of the ageing process. With access to a 10-year time series of blue-eye trevalla data, where age interpretation skills were progressively passed on to three different readers, it was possible to examine any biases through time, either between successively trained readers, disjunct readers and within readers. Monitoring of blue-eye trevalla age estimates indicated a modal shift in the age composition over a 7-year period. Whilst shifts in age composition can be a result of many factors, examination of historical estimates indicated a systematic shift in the interpretation. Whilst no differences were found between successively trained readers, there was a bias between the original reader and the most recently trained reader. These biases were primarily a function of ambiguous zone structure. As a result, the Central Ageing Facility has implemented procedural changes and developed reference collections of agreed age samples to address the detection and ultimately the prevention of inter-reader drift in interpretation over time.

A Practical Handbook for Determining the Age of Gulf of Mexico Fishes

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In 1995, the Gulf States Marine Fisheries Commission's Stock Assessment Team proposed a manual to facilitate consistent, quality age determination of exploited Gulf of Mexico fishes. This publication was completed in 2003 for the purpose of providing a practical guide for ageing marine fishes from the Gulf of Mexico. Current methodologies and techniques are generally described by species. Although we emphasize the use of otolith sections for age determinations, we also provide information on alternative processing and ageing techniques for particular species when appropriate including scales, fin rays, and fin spines. The manual should serve as a valuable training tool for new laboratory personnel and as a guide for ageing species of common interest to the Gulf States. The intent of this document is to be a dynamic resource, one that changes as species-specific processing techniques are developed. Documentation of these new and changing procedures will be posted in this manual as they occur and offered electronically. Standardization of techniques is a cornerstone of fisheries science, and we believe that this manual will facilitate the adoption of these techniques and standards for the same and similar species beyond the Gulf region. Moreover, adopting standardized ageing criteria for each species will provide comparable information necessary for age structured stock assessments both at state and regional levels.

Improving Otolith Scanning Precision and Throughput in a Proton Microprobe

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The precision of proton microprobe measurements of Sr in otoliths by proton induced X-ray emission (PIXE) has been improved significantly by use of a large area low resolution NaI(Tl) detector which gives much higher count rates for Sr than a typical high resolution Si(Li) detector. A Si(Li) is still used for simultaneous scans to measure the main constituent Ca and to confirm the absence of other elements in the counting window used by the large area detector. Experience with a large area HPGe detector is also described. In our experimental setup the count rate for Sr was improved by a factor of 30. We took advantage of this to both improve precision and achieve higher sample throughput in studies of diadromous fish such as the common bully, giant kokopu and inanga from New Zealand, and grayling and tupong from Australia.

Automatic Multiple Acquisition of Otolith Images for Routine Aging

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Image processing in the field of otolith research has mainly focused on classification issues, for instance, for stock discrimination, and on ring extraction for automatic age and growth estimation. However, as far as routine aging is concerned, the need for techniques offering efficient image acquisition is obvious to process large otolith sets. The framework presented here tackle this particular topic. More precisely, we present a scanner-based system for the automatic multiple acquisition of otolith images. Given a set of prepared otolith sections, the scanner is used to acquire an image containing the whole set of otoliths. Our goal is then to segment this image to extract one subimage for each otolith. Using a low-resolution version of the scanned image, it relies on different morphological operations to detect patterns corresponding to potential otolith subimage. Different geometric features are then exploited to discriminate otolith patterns from irrelevant ones. Sorting otolith subimages according to their positions within the scanned image, we are able to associate each subimage to the characteristics (name, biological information, fishing information,) provided by the user. Experiments carried out for pollock otoliths demonstrates the feasibility of using the proposed scanner-based acquisition framework for routine aging. In particular, we show that the eventual loss in image quality does not affect the perception of rings for otolith interpretation from acquired images. Besides, we discuss the application of this scheme to multiple image acquisition from a controlled stage.

Can Fish Age and Growth Be Actually Estimated Automatically Using 1D or 2D Techniques? The Case of Plaice (Pleuronectes platessa)

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This presentation provides an overview of the state-of-the-art methods in the field of automatic fish age and growth estimation from otolith images. We point out the potential benefits brought by automatic approaches in the context of quality control and insurance. Mainly, two broad categories of approaches can be distinguished. Firstly, 1{\sc d} schemes limit their analysis along a predefined direction from the otolith core to the edge, and rely on the extraction of the extrema of the extracted intensity profile. Secondly, 2{\sc d} methods perform a detection of the 2{\sc d} opaque and translucent rings in the image. Besides, we also discuss the use of statistical learning either as an alternative to the latter ones, or as a complementary tool. The evaluation is carried out, both in terms of age and growth estimation, for a set of 300 plaice otoliths from age 1 to 6 from the fourth trimester. The ground-truth is provided by an expert in Plaice otolith readings. These experimental results confirm that 2{\sc d} techniques outperform 1{\sc d} approaches. In addition, it is shown that statistical learning methods bring substantial improvements. With a best rate for age estimation close to 90\%, this evaluation brings the evidence that automatic techniques can now be an alternative for routine plaice aging. We will finally discuss the application of automatic age and growth estimation to other species, and stress the key issues to cope with complex ones such as whiting or European hake.

Combining the Extraction of Partial 2D Rings Within Otolith Images and Statistical Growth Modeling for the Bayesian Estimation of Fish Age and Growth

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We present a new 2D framework for the estimation of fish age and growth from otolith images. Contrarily to previous work (Troadec etal. 2000, Guillaud etal. 2002), 2D ring segmentation is not regarded as the detection of closed structures, but rather as the extraction of meaningful, eventually partial, ring curves. The main advantage lies in the improved robustness w.r.t. noise patterns, and local artifacts, since inferring ring positions within image areas where no information is available is no more required. The proposed scheme relies on a 2{\sc d} semi-local template-based approach. A priori growth information for the considered fish species is exploited to design a growth-adapted filtering. Given extracted ring curves, age and growth estimation comes to the selection of a relevant curve subset. Bayesian inference provides a general framework to solve for this issue. Our Bayesian scheme integrates a statistical growth model, which provides the mean to discriminate between realistic and erroneous curve configurations from the analysis of the associated growth patterns. This key feature enables us to cope with the presence of checks and false rings. Experiments for different otolith images of plaice and cod are first reported. Besides, given the evaluation of aging performances for a database of 220 plaice otoliths, this new approach outperforms previous work with a very high agreement rate (w.r.t. expert interpretations) greater than 88\% for age groups 1 to 6. We also discuss the remaining differences in otolith interpretation w.r.t. expert readings.

Toward an Automatic Estimation of Individual Fish Growth

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Fish growth analysis is a key element to study population dynamics for assessment or ecological issues. However, estimation of individual fish growth by otolith structure analysis is particularly tedious task, since experts have to perform for each otolith the visual localisation of growth rings and to measure inter-ring distance. Thus, new methodologies exploiting innovations in the field of signal processing are of particular interest. In a previous work, we have proposed a method to estimate growth patterns from signal modulation analysis. The alternation on otolith images of bright and dark growth zones, with variable bandwidths, corresponds to a modulated waveform signal. By means of a two-dimensional time-frequency analysis of this non-stationary signal, we can locate frequency variations in time and estimate the individual growth pattern.

Here, focusing on the transforms of Cohen's group, we investigate a framework to look for a well-suited time-frequency representation. To determine the growth model from the estimation of instantaneous frequency laws, two categories of approaches can be considered: parametric and non-parametric techniques. The second aim of this proposal is to evaluate the capacities of each one of these two techniques. In addition, we will present validation studies over a reference test set of 300 plaice otoliths, previously treated by a reader. Finally, through this analysis, source of variation in terms of precision and accuracy are described and discussed.

High Precision and Automatic Cutting Machine for Mass Production of Otolith Thin Slices

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Using a MELSEC FX2N PLS-system, a servosystem from Yaskawa Electric, and frequency converters from Mitsubishi Electric, whole otoliths mounted in epoxi are cut in units of 1/10 millimeter precision. It is possible to program and automatically slice up to 300 otoliths in one run. In addition to adjustments of slice thickness, the rotation speed of the diamond blade and the progress speed are programmed and controlled. Dependent on different factors like the size and hardness of the otolith or bone, it is very important with correct combinations of these settings that easily are programmed into an E300 operator terminal. Test sequences may be stored for later retrieval and re-starting. The display on the E300 tells the operator about the different alarm situations. The terminal also includes a help menu for safe usage by the operator.

Development of Optimum Conditions for Electron Microprobe Analysis of Sr/Ca Ratios in Fish Otoliths

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An analytical technique for measurement of strontium (Sr): calcium (Ca) concentrations in otolith was developed using an electron probe micro-analyzer (EPMA) equipped with wavelength dispersive spectrometers (WDS). Precisions of the measurement of Sr and Ca concentrations were determined with various electron beam conditions, which were a combination of different beam currents (1-30 nA: nano-ampere), beam diameter (1-20 μm), spectrum counting time (5-300 sec), and the X-ray diffracting crystals on among calcite- and aragonite-structured carbonate standards and eel otoliths. The precision decreased when beam power densities exceeded 2 μW/μm2 and/or beam diameter was less than 2 μm, resulting from beam damage on the specimen surface. The optimum analytical conditions for measuring the Sr/Ca ratios in the otoliths are suggested to be with a beam current at 3 nA, a scanning beam size of 5 μm x 4 μm, counting times of 60 sec (Sr) and 20 sec (Ca) at the peak, and of 15 sec (Sr) and 10 sec (Ca) at both lower and upper sides

for the back-ground intensities at an acceleration voltage of 15 kV with the aragonite standards. In these conditions, it is possible to obtain precise measurements of Sr/Ca ratios at 10 μm intervals along a transect from the primordium to the edge of the otolith with an error less than 0.05 wt% at the concentrations of Sr between the actual detection limit of 0.03 and 0.80 wt%, as these have been found to discriminate between marine and fresh waters.

Otolith Morphological Characteristics of Juvenile Bluefin Tuna Using Image Analysis Techniques

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Some otolith morphological characteristics of bluefin tuna, Thunnus thynnus, were studied using image analysis techniques and the relationships between otolith dimensions and fish size and age, as estimated from whole otoliths increment counting, were examined.

During 1998–2000, otoliths of 82 juvenile bluefin tuna ranging in fork length from 8.5 to 55.5 cm were collected in the Mediterranean Sea. Whole otolith length, width, area and perimeter, and two shape indices circularity and rectangularity, were extracted for each pair of sagittae. Otoliths were aged after immersion in Methybenzoate by counting the daily increments and the estimated ages ranged from 15 to 113 days. Since no statistical significant differences between left and right otolith morphometrics were found, only one otolith from each fish was used for otolith-fish size and age correlations. Logarithmic transformation was applied to all variables tested, before any statistical procedure was applied. Statistically significant relationships were observed between otoliths measurements and fish fork length when a linear regression was applied. Among the variables, otolith area was the one that showed the highest correlation with FL, followed by otolith length and perimeter whereas otolith circularity exhibited the lowest correlation. A moderate strong statistically significant relationship was observed for the variables tested and the age of the fish, with the otolith area and perimeter having the highest correlation with age and circularity having the lowest.

Annulus 1.0: Advanced Software for Fish Calcified Structure Analysis

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In January 2001, the Chippewas of Nawash Fisheries Assessment Program, and the Axelrod Institute of Ichthyology (University of Guelph) began building a facility for the analysis of fish calcified structures for the purpose of age and growth estimation. We began with an intensive review of the scientific literature and a thorough investigation of digital image analysis software in search of technology that would satisfy our processing requirements. We found that, while much of the required hardware technology is currently available, the software components have not been bundled into a single application that enables user-friendly, semi-automated, and statistically-rigorous analyses. Perhaps most importantly, none of the commercially-available software products (generalized or specialized) provided tools in support of statistical analysis and interpretation of age estimation data. As such the Chippewas of Nawash and the University of Guelph have set out to develop a specialized, user-friendly software for semi-automated age and growth analysis of fish calcified structures.

Some of the key features of Annulus 1.0 include:

1. Semi-automation
2. Reduced subjectivity
3. Analysis of precision
4. Analysis of sample size
5. Ability to account for influences of growth through edge analysis
6. Reduced subjectivity in implementing the fish birthday rule
7. Blind image presentation reduces analyst bias
8. Reference collection is a powerful means of quality control
9. Provide a fully documented, fully supported, product to the user in terms of data summary reports and images with associated tags and data.

Comparison of Techniques Based on Outline Analyses and Geometric Morphometrics for Identifying Tropical Anchovies from the Shape of Their Otoliths

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2D shape of fish otoliths is known to be species specific but for morphologically similar tropical anchovies of the genus Encrasicholina and Stolephorus, identification to the species level will highly depend on the discriminant power of the technique used.

Shape of sagittal otoliths extracted from adults of Encrasicholina devisi, E. heteroloba, E. cf punctifer and Stolephorus indicus caught in the lagoon of New Caledonia was determined with three techniques: elliptic Fourier shape analysis that works directly with the raw xy-coordinates, Fast Fourier Transform that operates on the tangent angle as a function of arc-length connecting the coordinates, and geometric morphometrics based on the Cartesian coordinates of a set of 13 landmarks (4 homologous and 9 semi-landmarks). Between-groups principal components analyses was performed instead of discriminant analysis as the later requires that the number of cases in the smallest group notably exceed the number of predictor variables.

Ratio of between-class inertia to total inertia was the lowest when using elliptic Fourier analysis and the highest when using geometric morphometrics. These ratios significantly increased when measures of otolith size were combined.

It is concluded that 1) both shape and size of otoliths have to be considered for identifying tropical anchovies, 2) geometric morphometrics not only performs better for discriminating species but it also allows global and local otoliths structure characterization.

Microscale Otolith: A Software Tool for Otolith Microstructure Analysis

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This software was developed to automate the analysis of otolith microstructure at different processing levels. It consists of the basic image processing engine and the otolith-specific plug-in. The target experimental hardware is a typical laboratory workstation equipped with a high resolution microscope and TWAIN compatible digital camera.

The analysis of daily growth rings requires obtaining a set of high-resolution images covering the whole important measurement region of an otolith sample. The first implemented here automation step is combining the overlapping partial images into a single image. This operation is performed with a high precision on the fly by the basic Microscale image processing engine using correlation algorithms. The user interface is designed in the way allowing both fully automated and interactively controlled image gluing process.

The otolith plug-in is used to perform measurements on a single sample image and to analyze and record the measurement data. The measurement process consists of detection of growth rings and other important features, scaling the radii of the rings, detecting the incremental growth trends. The otolith samples can be very different in quality after milling, therefore the software is designed to reasonably compromise automatic and interactive operations during the measurement. The user can correct the results of all automatic steps or perform them manually.

Presenting Author Index

Aguilera, Belen 111
Aliaume, Catherine 80
Alvarez, Paula 123
Andrews, Allen 32
Arai, Takaomi 50
Arkhipkin, Alexander 70
Bang, Anders 103, 111
Barnett-Johnson, Rachel 83
Barry, Bernard John 51, 146
Begg, Gavin 135
Bergenius, Mikaela 81
Baumann, Hannes 95, 105, 123
Black, Bryan 106
Brickle, Paul 93
Brophy, Deirdre 140
Brown, Ian 102
Brown, Randy 96
Büehler, Vivian 58, 140
Bush, Richard 115
Butler, Gavin 123
Cailliet, Gregor 32
Callihan, Jody 135
Campana, Steven 31
Cappo, Mike 52
Cardinale, Max 34
Carlson, John 123
Casini, Michele 57
Casselman, John 53
Chen, Hiu-Lun 34
Chen, Kuan-Yu 111
Chen, Lishu 112
Chic, Oscar 95
Chicharo, Maria 111
Choat, John Howard 61
Chu, Han 94, 124
Clardy, Todd 140
Clausen, Lotte Askgaard Worsøe 140
Clear, Naomi 141
Cobleigh, Molly 115
Coccetti, Susan 89
Courtney, Dean 124
Crook, David 60
Darnaude, Audrey 52
Daverat, Francoise 73
De Pontual, Helene 37, 124, 125
Dolgikh, Maria 125
Donohoe, Christopher 115
Dougherty, Annette 125
Elsdon, Travis Samuel 87
Ewing, Graeme 131
Fablet, Ronan 102, 147
Fey, Dariusz 104, 125, 126
Fitzhugh, Gary 55
Folkvord, Arild 105, 135
Fossum, Petter 126, 147
Fowler, Anthony 82
Francis, Chris 97
Gagliano, Monica 43
Gao, Yongwen 48
Geffen, Audrey 63, 126
Gerard, Trika 135
Gillanders, Bronwyn 51
Grimes, Churchill 53
Grønkjær, Peter 108
Hamel, Owen 33, 107
Hamer, Paul 60, 78
Harbitz, Alf 88, 89
Hobbs, James 81
Hoie, Hans 74
Humphreys, Robert 115
Husebø, Aase 56
Iizuka, Yoshiyuki 147
Jenkins, Gregory 60
Jitpukdee, Suwit 112
Jones, Cynthia 79, 100
Jonsdottir, Ingibjorg 56
Kang, Sukyung 74, 119
Katayama, Satoshi 98
Kerr-Ferrey, Lisa 70
Khrustaleva, Anastasia 112
Kim, Suam 136
Kimura, Daniel 85, 126
Kingsford, Michael 77
Kollmar, Richard 38
Kraus, Richard 87
Krusic-Golub, Kyne 126
Labonne, Maylis 116, 136
Lamantrip, Elisabeth 36, 127
Lara, Monica 64, 116
Lecomte-Finiger, Raymonde 133, 136
Lemberget, Tove 43
Limburg, Karin 116
Limont, Hilary 115
Lin, Shih-Huan 117
Lipinski, Marek 69, 112
Loher, Timothy 141
Lombardi-Carlson, Linda 127
Lombarte, Antoni 75, 113
Lou, Dong Chun 41, 133
Lo-Yat, Alain 79
Manning, Michael John 107
Mapleston, Amos 37, 143
Marriot, Ross 85
Matsumato, Takayuki 63
Mayer-Gostan, Nicole 42
McCulloch, Malcolm Thomas 64
McCurdy, William James 143
McDougall, Andrew 137
Meekan, Mark 49
Megalofonou, Persefoni 148
Miller, Jessica 65
Modin, Johan 76
Moksness, Erlend 90, 143, 144
Morales-Nin, Beatriz 35, 117, 127
Morison, Sandy 82, 144
Morize, Eric 128, 137
Mortensen, Donald 117
Mosegaard, Henrik 61

Presenting Author Index

Mouillot, David 78
Muir, Andrew Michael 145, 148
Munk, Kristen 129
Munk, Peter 128
Nash, Richard 50
Neer, Julie 69
Neil, Helen 72
Niva, Teuvo 118
Onorio, Tebaua Barerei 129
Oxman, Dion 39
Palmer, Miquel 86
Panfili, Jacques 75, 138
Parisi, Vicenç 97
Patterson, Heather 72
Patterson, William P 48, 138
Patterson, Will F 141
Payan, Patrick 57
Peverell, Stirling Charles 129
Piera, Jaume 96
Pilling, Graham Michael 49, 113
Pineiro, Carmen 129
Piner, Kevin 139
Plaza, Guido 100, 118
Ponton, Dominique 149
Popper, Arthur 31
Pothin, Karine 133
Pritchard, Janet 88
Pruell, Richard 119
Rahhou, Ilyesse 130, 142
Ralston, Stephen 47
Robbins, William David 71
Robertson, Simon 145
Rossetti, Helen 42
Sandin, Stuart 101
Santos, Paulo 130, 143
Schirripa, Michael 84, 108
Schmarr, David 98
Schull, Jennifer 77
Sellin, Michelle 130
Sheehy, Michael 83
Shen, Kang-Ning 119
Shiao, Jen-Chieh 130
Smale, Malcolm 93
Smirnov, Oleg 113
Smith, Nathan 113
Sogard, Susan 99
Sparks, Rodger 33
Stephenson, Peter 40
Stevens, Darren Wayne 131
St John, Jill 142
Stransky, Christoph 80
Stunz, Greg 119
Sutherland, Sandra 40
Suthers, Iain 103
Sutton, Colin 62, 131
Swan, Sarah 36, 119, 120
Swearer, Steven 86
Takagi, Yasuaki 38
Tanabe, Toshiyuki 58
Taylor, Matt 120
Terwilliger, Mark 104
Thorrold, Simon 47, 120
Titus, Robert 121
Tohse, Hidekazu 114
Tomas, Javier 35
Torres, Rabia Gulamo Abdula 41
Tracey, Dianne 71, 134
Troynikov, Vladimir 101
Tzeng, Wann-Nian 121
Uehara, Shinji 131
Valuev, Ilya 149
VanderKooy, Steve 145
Vassilopoulou, Vassiliziki 134
Vigliola, Laurent 106
Volkoff, Martha 54
Walsh, Cameron 142
Walther, Benjamin 121
Wang, Chia-Hui 122, 132
Wickstrom, Hakan 99
Wilhelm, Margit 54, 94, 132
Williams, Ashley John 59
Wischniowski, Stephen 122, 132
Wright, Peter 34
Yaragina, Natalia 114, 142
Young, Jock 76
Zhang, Zane Ziyang 132
Zuykova, Natalya 55