4th International Otolith Symposium

24-28 August 2009
Monterey, California USA

Cover art courtesy of Claudia Makeyev

Claudia Makeyev is a marine scientist who paints and draws the aquatic critters we all love so much. She is currently working on an illustrated children's book series on sea monster life cycles to educate in a fun and playful way. Currently in Santa Cruz, she welcomes any questions or compliments at claudia.makeyev@gmail.com

Our banner logo with the world map superimposed over the otolith was created by Allen Andrews

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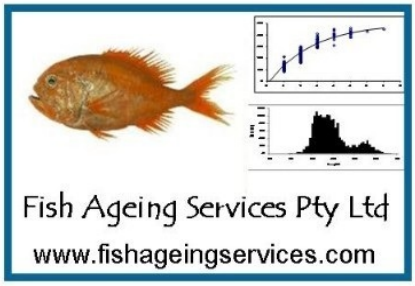

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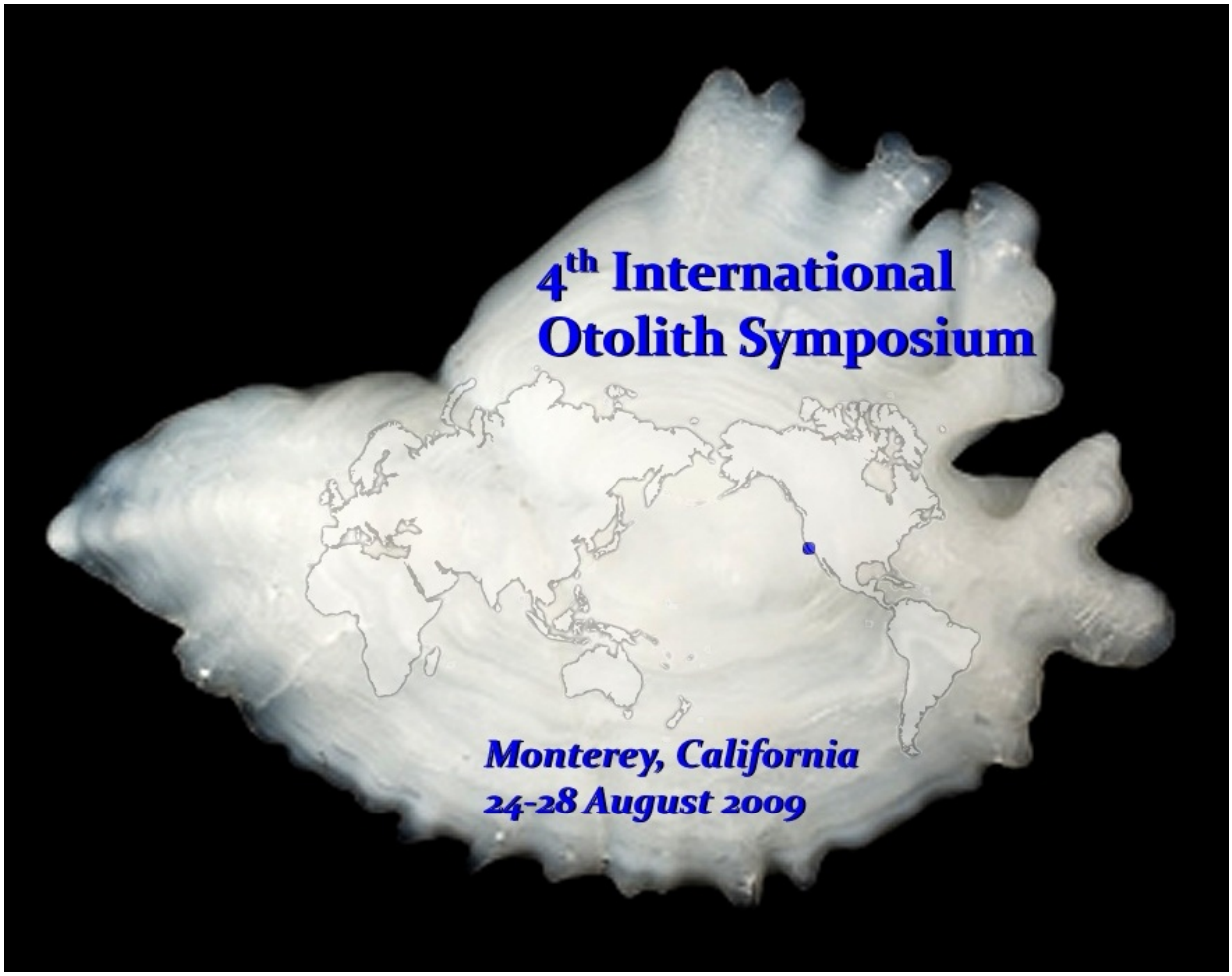


General Information

Welcome to Monterey, California and the Fourth International Otolith Symposium

This symposium will bring together leading scientists from around the world to present state-of-the-art research and future directions for this increasingly important area of science and its application to contemporary fisheries research and management problems. Since the last symposium five years ago in Townsville, Australia, there have been important new developments in the fields of fish ecology and fisheries science, based largely on the advances in extracting information from the otoliths of fishes. With more than 270 oral and poster presentations, we look forward to a productive meeting. We hope all participants will enjoy the beautiful Monterey venue.

Local Steering Committee: Churchill Grimes (Co-chair), NOAA Fisheries, Santa Cruz; Gregor M. Cailliet (Co-chair), Moss Landing Marine Laboratories; Allen Andrews, NOAA Fisheries, Hawaii; Rachel Barnett-Johnson, University of California, Santa Cruz; R. Bruce MacFarlane, NOAA Fisheries, Santa Cruz; Steve Miller, NOAA Fisheries, Santa Cruz; Don Pearson, NOAA Fisheries, Santa Cruz; Stephen Ralston, NOAA Fisheries, Santa Cruz; Susan Sogard, NOAA Fisheries, Santa Cruz; Brian Wells, NOAA Fisheries, Santa Cruz; Mary Yoklavich, NOAA Fisheries, Santa Cruz; Christopher Donohoe, University of California, Santa Cruz

International Committee: Takaomi Arai, Otsuchi Marine Research Center (Japan); Steven Campana, Bedford Institute of Oceanography (Canada); John Casselman, Ontario Ministry of Natural Resources (Canada); Anthony Fowler, SARDI, Aquatic Sciences, (Australia); Audrey Geffen, University of Liverpool (UK); Bronwyn Gillanders, University of Adelaide (Australia); Cynthia Jones, Center for Quantitative Fisheries Ecology, ODU (USA); Craig Kastelle, National Marine Fisheries Service (USA); Michael Kingsford, James Cook University (Australia); Karin Limburg, State Univ. of New York, College of Environmental Science & Forestry (USA); Shayne MacLellan, Department of Fisheries and Oceans (Canada); Gudrun Marteinsdottir, University of Iceland (Iceland); Mark Meekan, Australian Institute of Marine Science (AIMS) (Australia); Erlend Moksness, Institute of Marine Research, Flødevigen Marine Research Station (Norway); Beatriz Morales-Nin, Departamento de Recursos Naturales CSIC/UIB-IMEDEA (Spain); Henrik Mosegaard, DIFRES (Danish Institute for Fisheries Research) (Denmark); Jacques Panfili, IRD (Sénégal); Art Popper, Department of Biology University of Maryland (USA); Malcolm Smale, Port Elizabeth Museum (South Africa); Iain Suthers, University of NSW (Australia); Simon Thorrold, Biology Department Woods Hole Oceanographic Institution (USA); Dianne Tracey, National Institute of Water and Atmospheric Research (NIWA) (New Zealand); Wann-Nain Tzeng, National Taiwan University (Republic of China); Håkan Wickström, Swedish National Board of Fisheries (Sweden); Margit Wilhelm, Ministry of Fisheries and Marine Resources (Namibia); Peter Wright, Fisheries Research Services (UK)

Acknowledgments

We gratefully acknowledge the help of the many people who contributed their time and energy to making this symposium a reality. In particular we wish to thank Tom Laidig and Keith Sakuma (NMFS, Santa Cruz) for handling all of the audio-visual work for the symposium. We also wish to thank Lindsay Starrett (UC Santa Cruz) for organizing the volunteers. And of course we want to thank all of the volunteers without which we would have been overwhelmed with the many tasks needed to make the symposium happen. We also extend our appreciation to the bands

including Sam and the Flatfish (Steve Ralston, Brian Spence, Edward Dick, Keith Sakuma, Alec MacCall, Jacki Davis, and Gerald Draayer) who played at the opening reception and the band who played at the banquet (Don Pendergrass, Steve Fucello, and Dan Thacker). We also wish to thank Jay Walker (International Pacific Halibut Commission) for his assistance with hosting of the website and Shoshanna Love, the website creator. We also wish to express our gratitude to Jessica Miller (Oregon State University) who has graciously agreed to allow the publication of a special issue of the Environmental Biology of Fishes based on the proceedings of this symposium. And finally, we wish to thank Carly Weber of Oregon State University provided invaluable support in handling the conference registration.

Student Travel Awards

The International Otolith Symposium encourages student participation. This year we awarded subsidies of $1000.00 to each of ten students to help defray the costs of attending the symposium. The recipients were:

Salma Begum	Germany
Zofia Bystydzienska	Poland
Leslie Carroll	Canada
Wenping He	China
Kurin Imura	Japan
Leny Mercier	France
Mehis Rohtla	Estonia
Elena Torrecilla	Spain
Rita Vasconcelos	Portugal
Kazuki Yokouchi	Japan

David H. Secor earns the Lifetime Achievement Award at the Fourth International Otolith Symposium

By Gregor M. Cailliet, MLML

Dr. Secor is Professor at the University of Maryland's Chesapeake Biological Laboratory (CBL) and Application Center for Environmental Science (UMCES), and has been a leader in the series of International Symposia on Fish Otolith Research. Indeed, he was one of three editors of the 1995 publication resulting from the first International Symposium on Fish Otolith Research and Application in South Carolina. And, he has produced many ageing- and otolith-oriented publications, dating back to the 1991 and 1992 manuals on Otolith Removal and Preparation for Microstructural Examination and Analysis, for which he was a co-author. He continues in this role of leadership in the "otolith world."

Dr. Secor's main research focus has been connectivity among fish populations in estuarine and marine systems, with his focus being to use modern, often quite technological, otolith tracers to study fish movements, dispersal mechanisms, and nursery areas, as well as other aspects of their life history (age, growth, reproduction, and demography). He has applied these techniques to striped bass, eels, blue fish, sturgeon, and other species of fishes in Chesapeake Bay and along the Atlantic coast of the United States. Also, he has paid special attention to some of those fishes which require recovery strategies (i.e. sturgeon).

Dr. Secor also has an impressive publication record. He has written several books and over 60 peer-reviewed articles and chapters (many of which are on the use of otoliths to study fish ecology. Dr. Secor has also been a leading educator, having taught many courses on the ecology, physiology, and history of fishes and their fishery ecology in Chesapeake Bay and the Atlantic coast. He has been a mentor to many graduate students throughout his career at UMCES, and is much respected by them.

Please join me in congratulating Dr. David H. Secor as the 2009 recipient of the Lifetime Achievement Award in Otolith Research.

Evening Events

Welcome and Registration: Sunday August 23, 5:00 - 7:00 pm

If you arrive in time, join us at the Marriott Hotel (Ferrantes Bayview room) for hors d'oeuvres and music by Sam and the Flatfish.

Monterey Bay Aquarium: Monday August 24, 6:00 - 10:00 pm

Buffet dinner and no host bar at the beautiful Monterey Bay Aquarium. Dress is casual. Tickets are required (included with full conference registration or can be purchased separately). Enjoy this special event with your fellow researchers.

Poster Session: Tuesday August 25, 6:00 - 9:00 pm

Enjoy hors d'oeuvres and a no host bar at the Conference Center while you browse through the posters.

Banquet: Thursday August 27, 6:00 - 10:00 pm

Enjoy dinner, a live band, and a no host bar in the San Carlos Room at the Marriott Hotel.. Dress is casual. Tickets are required (included with full registration or can be purchased separately).

Venue: The conference will be held in the Monterey Convention Center. The center is conveniently located in downtown Monterey in close walking distance to Cannery Row and Fisherman's Wharf. The Marriott Hotel and the Pacific Hotel are adjacent to the Convention Center. Most of the presentations will be in the Convention Center (either the Steinbeck Room or the Colton Room); however, some of the sessions will be held in the Marriott Hotel (San Carlos 2 Room). The Banquet on Thursday night will be held in the Marriott Hotel.

Monterey Visitor Activities:

Big Sur coast: dramatic coastline 20-60 miles south of Monterey—interesting parks and restaurants on the cliffs--local bus #22 runs from Marriott Hotel to Nepenthe, very nice Big Sur restaurant (www.mst.org/routes/PDFs/8_30_08/22_Big%20Sur.pdf)

Carmel: charming small town 6 miles south of Monterey with quaint shopping and art galleries--public bus #5 runs from Marriott Hotel to Carmel (www.mst.org/routes/PDFs/2009/5_23_09/4_Carmel_Rancho.pdf); free local trolley (www.mst.org/news/items/Carmel%20Trolley.htm)

17 Mile Drive/Pebble Beach: beautiful homes/resorts/coast 3 miles south of Monterey. Special tip: $9 entrance fee refunded if you dine or shop (www.pebblebeach.com)-- bus 2X runs from Marriott Hotel to Pebble Beach Lodge (www.mst.org/routes/PDFs/2009/5_23_09/2X_Pebble_Beach.pdf)

Wine Tasting: wineries (with tasting rooms) are located throughout the Salinas Valley and Monterey. Special tip: the Grapevine Express bus #24 runs Fri/Sat/Sun from the Marriott Hotel to Carmel Valley, stopping at 11 wineries—all day pass for $6.00 (www.mst.org/routes/PDFs/2009/MST_24.pdf)-runs.

Golf : world famous courses at Pebble Beach. Special tip: modest price municipal course in Pacific Grove

Kayaking: Monterey harbor or Elkhorn Slough (www.MontereyBayKayaks.com)

Fishing: half-day charter trips, in Monterey Bay or deep-sea (www.chrissfishing.com)

Whale/Dolphin/Otter watching cruises: from Monterey Harbor (www.gowhales.com)

Hiking: many beautiful parks with trails—including Pt Lobos and Pinnacles National Monument. Special tip: Julia Pfeiffer Burns State Park has the tallest waterfall into the ocean in the US (www.seemonterey.com/top-day-hikes-monterey-county).

Biking: bike paths run along the ocean cliffs. Rent a bike in town and bike paths go in both directions (www.baybikes.com)

Literary tour: John Steinbeck Museum (Salinas)—one of America's most renowned authors—his books are set in the Salinas/Monterey area, including Cannery Row, right around the corner from the Conference center (www.steinbeck.org); Robert Louis Stevenson House (Monterey); Henry Miller Library (Big Sur); Robinson Jeffers House (Big Sur)

Pacific Grove: adjacent cute town, including NOAA/NMFS Environmental Research Division (note Ray Troll mural around building on theme of "Green Sea, Blue Sea"—http://swfsc.noaa.gov/textblock.aspx?Division=ERD&id=3430&ParentMenuId=200)—public bus #1X runs from Marriott Hotel through PG (http://www.mst.org/routes/PDFs/2009/5_23_09/1_Pacific_Grove.pdf)

Elkhorn Slough National Estuarine Research Reserve: rich estuary and visitors center—15 miles north of Monterey (Elkhorn Slough National Estuarine Research Reserve)

Monterey historical tour: one block from Marriott Hotel is the original capital of California (http://www.parks.ca.gov/?page_id=575)

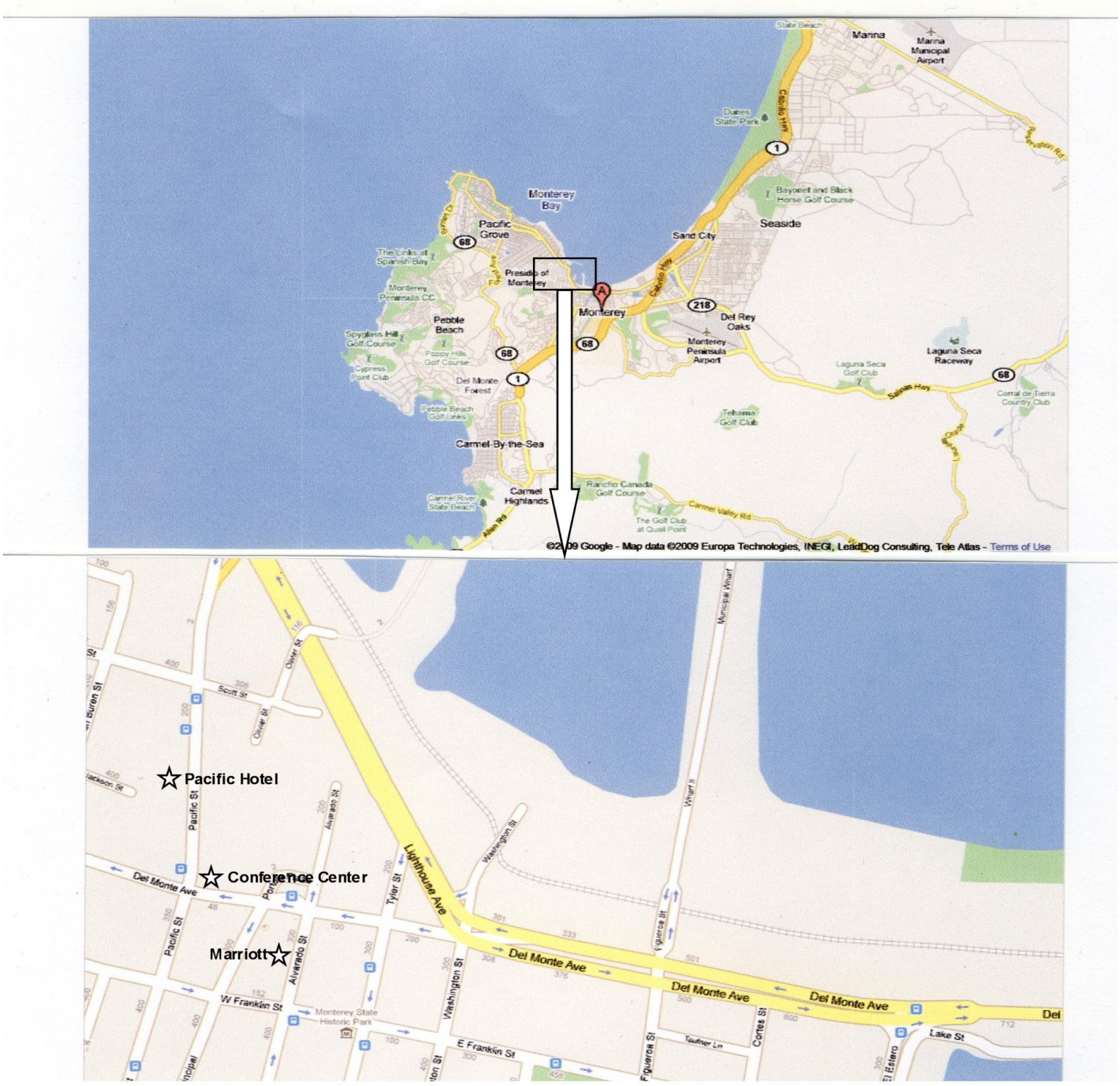
Fisherman's Wharf/Cannery Row: short walk from Marriott Hotel, Fisherman's Wharf and Cannery Row are a commercial visitor centers with shops recognizing the historical setting of Monterey--free trolley runs through visitor areas (www.mst.org/routes/MST_Trolley_Brochure.pdf)

Resources:

Visitor Bureau website: www.SeeMonterey.com

Visitors Bureau telephone: 877-MONTEREY

Maps


Marina
Marina Municipal Airport
Dunes State Park
Monterey Bay
Pacific Grove
Bayonet and Black Horse Golf Course
Seaside
Sand City
The Links at Spanish Bay
Presidio of Monterey
Monterey Peninsula CC
Monterey
Pebble Beach
Del Rey Oaks
Spyglass Hill Golf Course
Poppy Hills Golf Course
Monterey Peninsula Airport
Laguna Seca Raceway
Cypress Point Club
Del Monte Forest
Laguna Seca Golf Club
Cerral de Tierra Country Club
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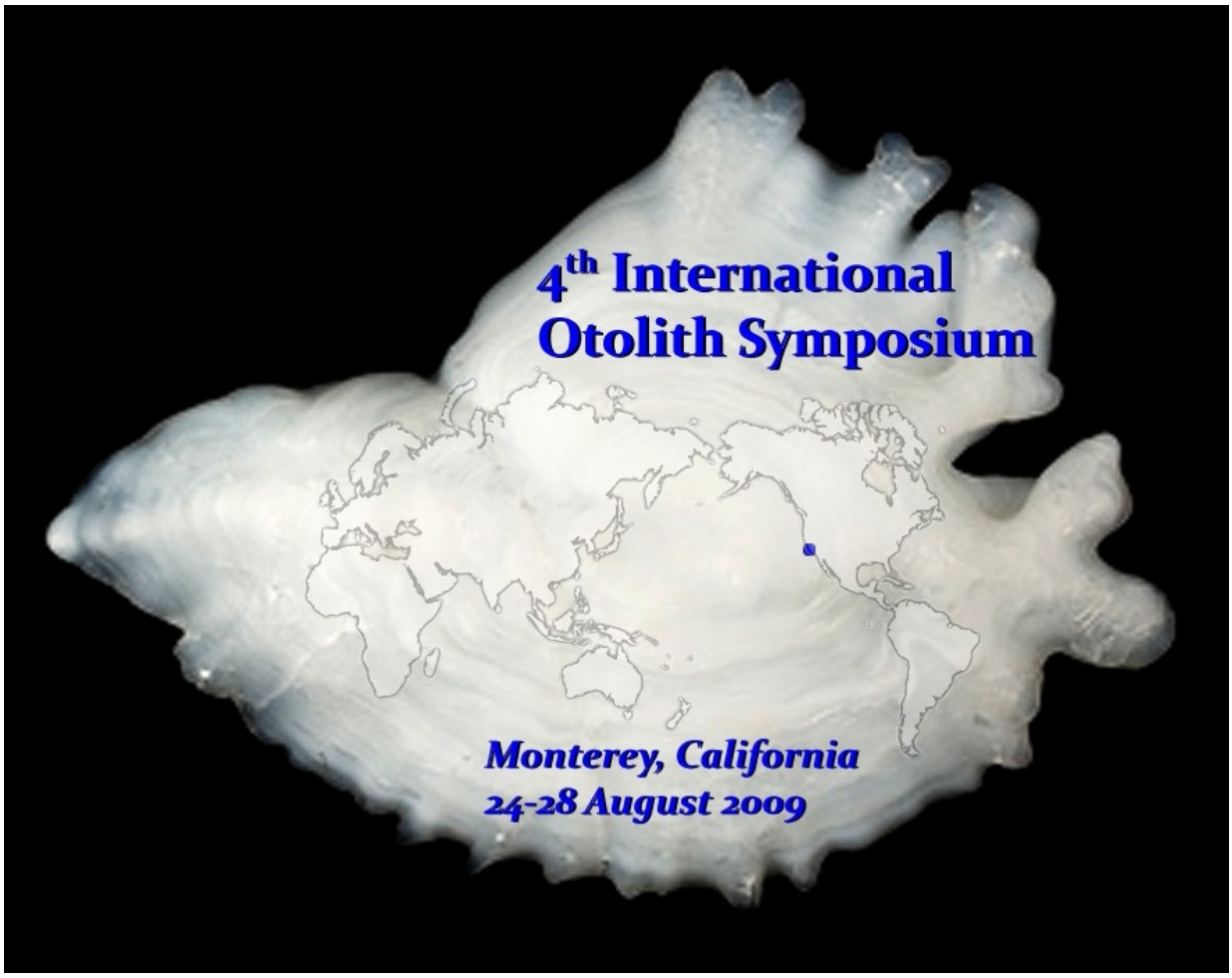
Lighthouse Ave
Pacific St
Alvarado St
Tyler St
Washington St
Scott St
Oliver St
Municipal Wharf
W Franklin St
E Franklin St
Monterey State Historic Park
Figueroa St
Cortes St
Lake St



Program Schedule

Events and Presentations

Oral Presentation Information

Oral presentations should be in Microsoft PowerPoint (any version) for Windows or as a PDF file. All presentations should be on a USB flash drive, CD, or DVD. Presentations should be given to the Audio Visual (A/V) personnel *the day before* you are to give your presentation. Monday presentations will be loaded Sunday at registration. To load your presentation, please bring it to the A/V table, or to the room where you will speak. Depending on time and work load, your presentation will be loaded immediately and you can then preview it to make sure it operates correctly on our computers, or the A/V crew will let you know the approximate time it will be loaded and available for preview. Keith Sakuma and Tom Laidig will be available during the entire conference if you have any questions. Your punctuality in getting your presentation in on time will be greatly appreciated. Please do NOT make us come and find you in order to load your presentation.

Poster Presentation Information

Posters should be set up in the designated staging areas in the Convention Center no later than 1:00 pm Tuesday afternoon. Presenters should be available to answer questions at the Tuesday evening poster session. Posters will remain on display through Thursday evening. Presenters are responsible for removing their poster Thursday night. Students should be sure to pick up a flag to mark their poster in order to be eligible for the student award.

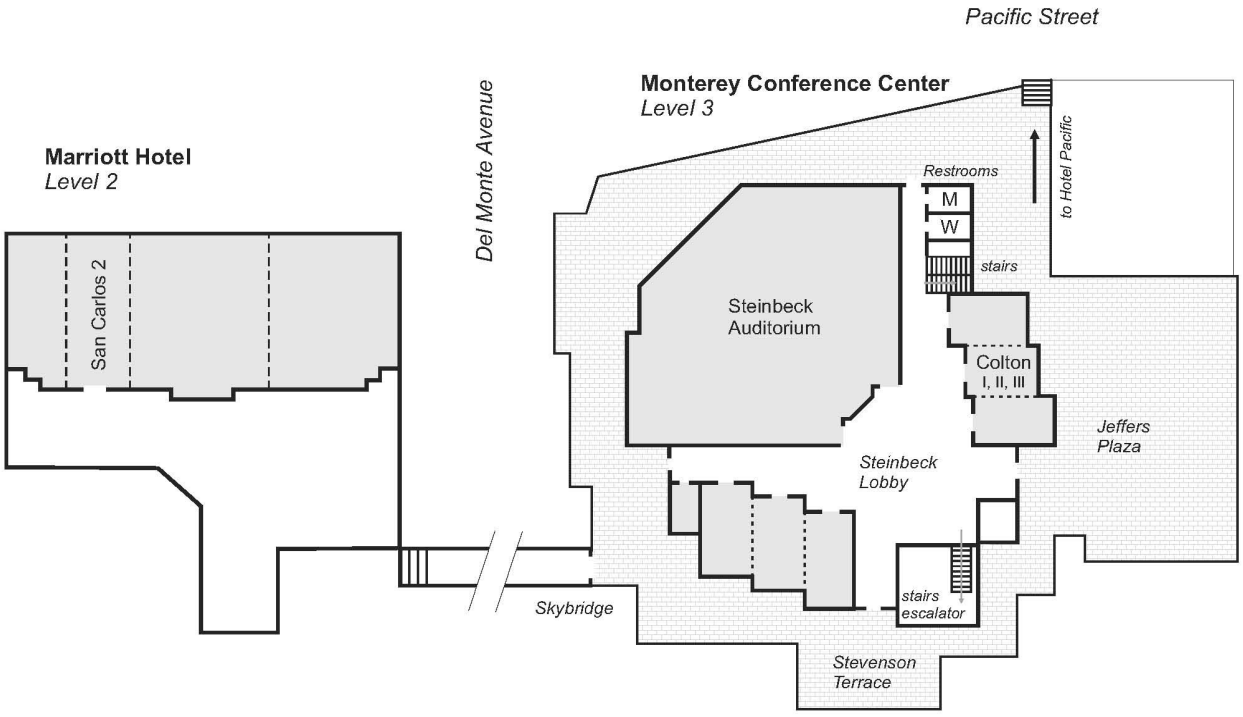
Special Publication Information

A special issue of Environmental Biology of Fishes will be published with papers from the Symposium. All participants are welcome to submit a paper based on their presentation (talk or poster) for possible publication in the special issue. All submissions should be made directly to the journal and follow their format. Information on formatting and submission requirements can be found at their website: http://www.editorialmanager.com/ebfi/ . A link to this site can be found on the Otolith Symposium's website.

When submitting your manuscript be sure to indicate in the cover letter that the manuscript is being submitted for consideration in the 4th International Otolith Symposium Special Issue. Also, when submitting your manuscript, for the article type, select the "Special Issue - Otolith" entry to make sure that it is routed correctly.

Deadline for submission is October 1, 2009.

Otolith Symposium Meeting Rooms



Meeting Schedule Overview

	Monday			Tuesday			Wednesday			Thursday			Friday		
	Aug 24			Aug 25			Aug 26			Aug 27			Aug 28		
Room	Steinbeck	San Carlos	Colton	Steinbeck	San Carlos	Colton	Steinbeck	San Carlos	Colton	Steinbeck	San Carlos	Colton	Steinbeck	San Carlos	Colton
8:00-8:30	Welcome and Introduction			Coffee			Coffee			Coffee			Coffee		
8:30-9:30	Keynote: *Dave Secor*			Keynotes: *Life History*			Keynotes: *Sclerochronology*			Keynotes: *Chemistry*			Keynotes: *Age and Growth*		
9:30-10:00	Break			Break			Break			Break			Break		
10:00-12:00	Keynotes: *Physiology*			Chemistry	Life History	Physiology	Sclero-chronology	Life History	Physiology	Chemistry	Sclero-chronology	Age and Growth	Age and Growth	Chemistry	Life History
12:00-1:30	Lunch			Lunch			Lunch			Lunch			Lunch		
1:30-3:30	Chemistry	Physiology	Age and Growth	Chemistry	Life History	Physiology	*Free afternoon*			Chemistry	Life History	Age and Growth	Age and Growth	Chemistry	Life History
3:30-4:00	Break			Break						Break			Break		
4:00-5:20	Chemistry		Age and Growth	Age and Growth	Life History	Sclero-chronology				Various themes			Age and Growth	Chemistry	
	6:00-10:00 **Banquet** *(Monterey Bay Aquarium)*			5:30-9:00 **Poster Reception** *(Monterey Conference Center)*						6:00-10:00 **Banquet** *(Marriott - San Carlos Room)*					

5:00-7:00 Sunday - Welcome Reception *(Marriott - Ferrantes Bayview Room - 10th Floor)*

Program Schedule
Monday, August 24

	Room	Steinbeck (Main)		San Carlos 2		Colton
	Theme	**Physiology and Morphology**				
8:30		Otoliths Speak Volumes on Fish Migration **Presenter: Secor, David H.**				
9:30		Break				
10:00		Why Otoliths? The Rest of the Story! **Presenter: Popper, Arthur**				
		The Extraordinary Inner Ear of Fishes **Presenter: Hastings, Mardi**				
		The Otolith Organs and Hearing by Fishes **Presenter: Fay, Richard**				
		Neuroethology of Audio-vocal Communication Among Fishes **Presenter: Bass, Andrew**				
12:00		Lunch				

Note: An * by the presenter's name indicates a student

Monday

	Room	Steinbeck (Main)		San Carlos 2		Colton
	Theme	**Chemistry** **Moderator: T. Elsdon**		**Physiology and Morphology** **Moderator: C. Donohoe**		**Age and Growth** **Moderator: L. Tomaro**
1:30		Assessing the Usefulness of Pressed Powder Pellet Standard Prepared From Three Biogenic Calcium Carbonate Certified Reference Material for Improving the Accuracy of Otolith Chemistry Using LA-ICP-MS **Presenter: Shirai, Kotaro**		Understanding Otolith Biomineralization Process: New Insights on Spatial Distribution of Organic and Mineral Fractions from Raman Micro-Spectrometry **Presenter: de Pontual, Helene**		Using Otolith Microstructure to Infer Age of Adult Eastern Baltic Cod (Gadus morhua L.) **Presenter: Mosegaard, Henrik**
1:50		Otolith Elemental Fingerprints of Pacific Herring Clupea pallasii in Northern Pacific Part of Japan **Presenter: Yamane, Kodai ***		Can We Model Otolith Growth and Opacity Patterns as a Response to Environmental Factors and Fish Metabolism? A DEB-Based Framework **Presenter: Fablet, Ronan**		Evaluating Age and Growth of Young Swordfish, Xiphias Gladius L., in Taiwan Waters Using Otoliths **Presenter: Sun, Chi-Lu**
2:10		Microchemical Characterization of Chinook salmon (Oncorhynchus tshawytscha) Otolith Cores Using FIB and HTEM **Presenter: Chevalier, Desiree E. ***		Sparc is an Otolith Protein and Required for Normal Mineralization **Presenter: Kollmar, Richard**		Age and Growth of European Bitterling Rhodeus amarus Larvae. **Presenter: Zaki, Shama**
2:30		Apples and Oranges, Selenium and Barium: What Can be Learned about Otolith Chemistry from Comparing Different Analytical Techniques **Presenter: Limburg, Karin**		Two Types of Otolith Opaque Zone **Presenter: Satoshi, Katayama**		Environmental Determinants of Growth and Selective Mortality of the Fast-Growing Clupeid, Spratelloides delicatulus **Presenter: Villacorta-Rath, Ana Cecilia ***
2:50		Stable N Isotopes in the Organic Matrix of Otoliths Reveal the Trophic Position of Individual Cod **Presenter: Groenkjaer, Peter**		The Effect of Vateritic Sagittae on Sound Reception, Otolith Morphology, and Inner Ear Sensory Epithelia in Chinook Salmon **Presenter: Oxman, Dion**		Larval Stage Duration, Age and Growth of Blue Lanternfish Tarletonbeania crenularis (Jordan and Gilbert, 1880) Derived From Otolith Microstructure **Presenter: Bystydzienska, Zofia E. ***
3:10		Otolith Geochemistry Does Not Reflect Dispersal History of Clownfish Larvae **Presenter: Berumen, Michael**		Otolith Morphology and Hearing Abilities in a Cave- and a Surface-Dwelling Form of the Atlantic Molly (Poecilia mexicana) **Presenter: Schulz-Mirbach, Tanja**		
3:30		Break				

Monday

	Room	Steinbeck (Main)		San Carlos 2		Colton
	Theme	**Chemistry** **Moderator: A. Munro**				**Age and Growth** **Moderator: S. Sogard**
4:00		Estimating Mortality with Natural Tags **Presenter: Jones, Cynthia**				Three Otolith-Derived Insights About the Settlement Process in Rolland's Demoiselle (Chrysiptera rollandi), a Tropical Damselfish From the Great Barrier Reef **Presenter: Baumann, Hannes**
4:20		Identification of Fish Origin Using Otolith Fingerprints: Classification Method Matters **Presenter: Mercier, Leny ***				Linking (or not) Larval Occurrence Nearshore With Early Life Traits of a Temperate Cryptobenthic Reef Fish Species From Otolith Analysis **Presenter: Borges, Rita**
4:40		Statistical Considerations for Inference of Demographic Connectivity From Natal Otolith Microchemistry - Optimal Scaling and Improved Allocation **Presenter: Neubauer, Philipp ***				Planktonic Larval Duration of Eleven Species of Temperate Cryptobenthic Reef Fishes - Relation With Possible Dispersive and Retention Patterns at the Arrabida Marine Park **Presenter: Goncalves, Emanuel**
5:00		An Analytical Method for Detecting the Timing of Continental Habitat Shifts in Individual Life Histories of the Japanese Eel (Anguilla japonica) Using Otolith Sr:Ca Transects **Presenter: Yokouchi, Kazuki ***				The Use of Otolith Microstructure to Examine Estuarine Utilization and Life History Diversity in Natural and Hatchery Reared Fall Chinook Salmon of the Nisqually River, WA **Presenter: Larsen, Kim**

Dinner at Monterey Bay Aquarium (Dress is casual)

Program Schedule
Tuesday, August 25

	Room	Steinbeck (Main)		San Carlos 2		Colton
	Theme	**Life History and Fisheries Management**				
8:30		Life Histories and Fisheries Management: The Otolith Toolbox **Presenter: Sponaugle, Su**				
9:00		When the Going Gets Tough: Fish Populations in a Changing Climate **Presenter: Gagliano, Monica**				
9:30		Break				

Tuesday

	Room	Steinbeck(Main)		San Carlos 2		Colton
	Theme	**Chemistry** **Moderator: B. Gillanders**		**Life History and Management** **Moderator: E. Goncalves**		**Physiology and Morphology** **Moderator: B. MacFarlane**
10:00		Validating Otolith Ba/Ca as a Proxy for Environmental Change in Marine Habitats **Presenter: Walther, Benjamin**		Behavioral Basis for Selective Mortality in a Coral Reef Fish **Presenter: Rankin, Tauna ***		A New Otolith Image Contour Descriptor Based on Partial Reflection **Presenter: Jose Antonio Soria**
10:20		Effects of Diet and Water Temperature on the Multi-Element Composition of European Eel (Anguilla anguilla) Otoliths **Presenter: Marohn, Lasse ***		Early Life History Traits of Two Black Rockfish (Sebastes inermis) Populations in Japan, Using Otolith Microstructure Analysis: a Multivariate Approach **Presenter: Ruano, Miguel ***		Ecomorphologic Comparisons of Otolith Sagittae on Nototheniidae **Presenter: Lombarte, Antoni**
10:40		Development and Validation of Otolith Microchemistry Techniques in Support of the Retrospective Geolocation of Fully Marine Fishes **Presenter: Lewis, Anna ***		Otolith Microstructure Reveals Recruitment Processes for Snapper (Chrysophrys auratus) **Presenter: Saunders, Richard ***		Age Distribution of North East Arctic Cod Estimated From the Contour of Otolith Section Images **Presenter: Harbitz, Alf**
11:00		Barium as an Indicator of Upwelling Exposure in the Otoliths of Central California Juvenile Rockfish **Presenter: Starrett, Lindsay ***		Determining Metal Exposure in Lake Trout From Pipestone Bay, Ontario Using LA-ICP-MS Analysis of Otoliths **Presenter: Carroll, Leslie ***		Otolith Shape Development in Herring and its Application in Stock Assessment and Population Ecology **Presenter: Mosegaard, Henrik**
11:20		Fish Otoliths and Coral Cores as Environmental Loggers of Pulsed Environmental Events **Presenter: Kingsford, Mike**		Survival of Mid-Upper Columbia River Spring Chinook Salmon: the Effects of Size and Growth During Migration **Presenter: Tomaro, Londi ***		Six Years of the Interactive AFORO (Otolith Shape Analysis) Database Website (2003/2009) **Presenter: Lombarte, Antoni**
11:40						
12:00		Lunch				

Tuesday

	Room	Steinbeck (Main)		San Carlos 2		Colton
	Theme	**Chemistry** **Moderator: D. Secor**		**Life History and Management** **Moderator: G. Jackson**		**Physiology and Morphology** **Moderator: B. MacFarlane**
1:30		Is Chinook Life History Strategy Related to Juvenile Growth? Evidence From Reconstructed Juvenile Growth Rates From Otoliths Sampled From Returning Adults **Presenter: Chittaro, Paul**		Migratory Ecology of Amphidromous ayu in the Coastal Waters of Japan Revealed by Otolith Aging **Presenter: Tsukamoto, Katsumi**		Otolith Identification of Merluccius Populations and Sympatric Species with Local Discriminant Bases **Presenter: Soria, J. Antonio**
1:50		Isotopic Otolith Networks for Salmonid (IONS): Using Sr isotope Mapping to Reconstruct Early Life-History Movements of Spawning Chinook Salmon **Presenter: Barnett-Johnson, Rachel**		The Larval Dispersal of Giant Mottled Eel Anguilla marmorata as Indicated by Otolith Daily Growth Increment and Sr/Ca Ratios **Presenter: Tzeng, Wann-Nian**		Can Otolith Shape be Used as an Indicator of the Protection Effect? **Presenter: Criquet, Geraldine ***
2:10		Microchemical Pattern in Otoliths of Coelacanth (Latimeria chalumnae) **Presenter: Fietzke, Jan**		Habitat and Sex Specific Life History Patterns of Yellow Tang, Zebrasoma flavescens, With Implications for Fisheries Management Using Protected Areas **Presenter: Claisse, Jeremy T. ***		Sagittal Otoliths of the Gerreidae Fishes in the Tropical Eastern Pacific: Taxonomy and Phylogenetic Implications **Presenter: Diaz, Bertha ***
2:30		Modern and Neolithic Baltic Sea Cod Otolith Chemistry: Potential to Track Juvenile Habitat Use and Other Life History Parameters **Presenter: Limburg, Karin**		Investigating Density-Dependent Growth in Snapper (Sparidae) in Shark Bay, Western Australia **Presenter: Whitten, Athol ***		A Comparison of Otolith Microchemistry and Otolith Shape Analysis in Unraveling Spatio-Temporal Connectivity in a Deep-Sea Teleost, Coryphaenoides rupestris **Presenter: Longmore, Craig ***
2:50		Metabolic Rates and Life Histories in Deep Water Fish **Presenter: Trueman, Clive**		Otolith Retrieval From Feces and Reconstruction of Prey Fish Size in Great Cormorant (Phalacrocorax carbo) at Poyang and Dongting Nature Reserves of China **Presenter: Xie, Songguang**		Discrimination of NW Mediterranean populations of Two Fish Species (Mullus barbatus and Solea solea) by Otolith Shape Analyses **Presenter: Morat, Fabien ***
3:10		Life History Diversity Within Imperiled Chinook Salmon Populations Determined by Otolith Strontium and Oxygen Isotopes **Presenter: Phillis, Corey ***		Marine Preserves Confer Little Benefit on a Fast-Growing, Heavily Targeted Parrotfish Species in the Western Pacific **Presenter: McILwain, Jennifer L.**		Otolith Shape Analysis as a Tool for Cod Stock Discrimination in the Baltic Sea **Presenter: Paul, Katrin ***
3:30		Break				

Tuesday

	Room	Steinbeck (Main)		San Carlos 2		Colton
	Theme	**Age and Growth** **Moderator: A. Arkhipkin**		**Life History and Management** **Moderator: M. Hansen**		**Sclerochronology & Environment** **Moderator: B. Black**
4:00		The Relationship Between Age, Otolith Radius and Size of Fishes: A Case Study Using the Sparid Acanthopagrus butcheri **Presenter: Chuwen, Ben ***		Natal Origin of Northern Pike (Esox lucius) in the Baltic Sea, a Coastal Stock Assessment Using Otoliths **Presenter: Engstedt, Olof ***		Using Otolith Elemental Composition of Demersal Fishes as a Biological Indicator of Benthic Environment **Presenter: Chang, Mei-Yu**
4:20		Age Estimation, Growth and the Size at Sexual Maturity of Southern African Tigerfish, (Hydrocynus vittatus) **Presenter: Gerber, Ruan ***		Resolving Natal Origins and Life History of Wild Fall Chinook Salmon (Oncorhynchus tshawytscha) Using Otolith Microchemistry and Geospatial Analysis **Presenter: Hegg, Jens ***		Linking Otolith Biochronology to the Establishment of Invasive Species and other Environmental Perturbations **Presenter: Davis-Foust, Shannon**
4:40		Validation of the Method of Estimating Age, Modeling Growth and Describing the Age Composition of Coilia mystus (Linnaeus) From the Yangtze Estuary, China **Presenter: He, Wenping ***		Estimating the Contribution of Atlantic Stock King Mackerel (Scomberomorous cavalla) to Mixed-Stock Winter Landings in South Florida with Otolith Markers **Presenter: Shepard, Katherine E. ***		Bomb Radiocarbon Dating of White Abalone (Haliotis sorenseni): Investigations of Age, Growth and Lifespan **Presenter: Andrews, Allen H.**
5:00		Age Validation, Growth and Mortality of Tilapia zillii (Pisces: Cichlidae) from Crater Lake Nkuruba, Western Uganda, East Africa **Presenter: Efitre, Jackson**		Connectivity Between Estuaries and Marine Areas: Integrating Metrics to Assess Multiple Species Nursery Role of Estuaries **Presenter: Vasconcelos, Rita ***		Using a Dendrochronological Approach to Examine Possible Relationships Between Redbanded Rockfish (Sebastes babcocki) Growth and Climate in Waters off the Coast of Oregon **Presenter: Thompson, Josie E.**

Poster Session in Evening

Program Schedule
Wednesday, August 26

	Room	Steinbeck (Main)		San Carlos 2		Colton
	Theme	**Sclerochronology and Environment**				
8:30		Tree rings, otoliths, and the development of annually resolved growth-increment chronologies for fish species **Presenter: Black, Bryan A.**				
9:00		The Use of Salmon Scales to Test Hypotheses About Salmon Growth, Climate, and Ocean Carrying Capacity **Presenter: Ruggerone, Greg**				
9:30		Break				

Wednesday

	Room	Steinbeck (Main)		San Carlos 2		Colton
	Theme	**Sclerochronology and Environment** **Moderator: G. Pilling**		**Life History and Management** **Moderator: S. Xie**		**Physiology and Morphology** **Moderator: R. Kollmar**
10:00		Otolith Microchemistry: a Tool for Managing the Competing Interests of Resource Extraction and Conservation **Presenter: Friedrich, Lisa ***		Fine-Scale Population Structure in Atlantic Cod (Gadus morhua L.) Suggests Very Precise Homing Behaviour **Presenter: Svedang, Henrik**		Puberty Blues: Ontogenetic Changes in Sub-Adult Argyrosomus japonicus (Sciaenidae) **Presenter: Taylor, Matt**
10:20		The Use of Delta-18O Analysis of Young-of-the-Year Arctic Charr, Salvelinus alpinus, Saggital Otoliths to Infer Thermal Habitat Use Within Quttinirpaaq National Park, Nunavut Canada **Presenter: Sinnatamby, Niloshini ***		Anadromous Sockeye Salmon (Oncorhynchus nerka) Reappear After Extirpation Nearly 90 Years Ago: a Case of Reverse Evolution? **Presenter: Godbout, Lyse**		Otolith Microstructure in Lanternfishes (Myctophidae): a Revision of the Existing Nomenclature **Presenter: Linkowski, Tomasz B.**
10:40		Dynamics of d13C Isotope Ratio in Fish Otoliths and Bivalve Shells in the Context of the Dynamic Energy Budget (DEB) Theory **Presenter: Pecquerie, Laure**		Rapid Climate-Driven Changes in the Demography of a Damselfish, Stegastes obreptus **Presenter: Meekan, Mark**		Atlas of Otolith Formation in the Zebrafish **Presenter: Iimura, Kurin ***
11:00		Cross-Dating: a Potential Tool for Assessing the Quality of Production Age Data Created From Rockfish Otoliths **Presenter: MacLellan, Shayne**		Sixteen Years of Thermal Marking in Alaska **Presenter: Agler, Beverly**		Otoliths and Maturity: Using Otolith Features to Examine the Impacts of Fishing on Plaice Populations **Presenter: Walton, Joanne K.**
11:20		Climate-Driven Synchrony in Otolith Growth-Increment Chronologies for Three Bering Sea Flatfish Species **Presenter: Matta, Mary Elizabeth**		Recent Initiatives in Otolith-Based Ageing for Assessments of Demersal Indicator Species in the West Coast and Gascoyne Coast Bioregions of Western Australia **Presenter: Jackson, Gary**		A Generic Ad-Hoc Algorithm for Automatic Nucleus Detection From the Otolith Contour **Presenter: Harbitz, Alf**
11:40		Use of Otoliths as Data Storage Recorders in Arctic Charr: Understanding Consequences of Climate Variability and Change **Presenter: Godiksen, Jane A. ***		Indirect Age Validation of the Shallow-Water Hake Merluccius capensis in the Northern Benguela Using Otoliths From Monthly Seal Scat- and Annual Demersal Survey Samples **Presenter: Wilhelm, Margit R. ***		Rapid Differentiation of Norwegian Cod Stocks by Automatic Image-Segmentation of Internal Otolith Growth Structures **Presenter: Harbitz, Alf**
12:00		Done for the Day				

Program Schedule
Thursday, August 27

	Room	Steinbeck (Main)		San Carlos 2		Colton
	Theme	**Chemistry**				
8:30		Using Otolith Chemistry to Determine Population Structure, Movements and Environmental History of Fish **Presenter: Gillanders, Bronwyn**				
9:00		Targeted Elemental Analysis of Biomineralised Structures and Their Utility in Understanding Population Structure: a Study of Two Octopus Populations **Presenter: Doubleday, Zoe**				
9:30		Break				

Thursday

	Room	Steinbeck (Main)		San Carlos 2		Colton
	Theme	**Chemistry** **Moderator: S. Herzka**		**Sclerochronology and Environment** **Moderator: C. Zimmerman**		**Age and Growth** **Moderator: A. Andrews**
10:00		Otolith Microchemistry as a Tool to Discriminate Sole (Solea solea) Nurseries and Spawning Grounds **Presenter: Cuveliers, Els L**. *		Otolith Age Interpretation and Recruitment Dynamics of St. Lawrence River American Eels (Anguilla rostrata): Procedures and Influencing Factors **Presenter: Casselman, John M.**		Age Determination, Bomb Radiocarbon Validation and Growth of Atlantic Halibut (Hippoglossus hippoglossus) From the Northwest Atlantic **Presenter: Armsworthy, Shelley**
10:20		Analyzing Habitat Linkages for Snapper (Lutjanidae) Using Otolith Microchemistry in Southern Florida **Presenter: Garcia, Estrella** *		Relationships Among Otolith Growth-Increment Chronologies, Climate, and Recruitment for Red and Gray Snapper in the Northern Gulf of Mexico **Presenter: Allman, Robert**		Validation of a New Method of Age Determination for Greenland Halibut (Reinhardtius hippoglossoides) Using Otoliths **Presenter: Brogan, John D**
10:40		Characterizing Otolith Element and Geochemical Signatures: Descrimination of Dolly Varden (Salvelinus malma) Populations From the Yukon Territory North Slope and Northwest Territories, Canada **Presenter: Loewen, Tracey N.** *		Resolving Environmental Effect on Stage Transitions in Anchovy Early Life History Using Dynamic Energy Budget (DEB) Theory **Presenter: Pecquerie, Laure**		High Resolution Bomb Dating for Testing the Accuracy of Age Interpretations in a Short-Lived Pelagic Fish **Presenter: Campana, Steven**
11:00		Variation in Otolith Microchemistry Fingerprints of French Grunt (Haemulon flavolineatum) and Schoolmaster (Lutjanus apodus) in Nursery Habitats in Puerto Rico and St. Croix (USVI) **Presenter: Mateo, Ivan** *		Climate and the Carbon Footprint: What Can we Learn From Oxygen and Carbon Isotope Measurements? **Presenter: Pilling, Graham**		Quantifying the Strength of Age Validations Based on Bomb Radiocarbon **Presenter: Campana, Steven E.**
11:20		Stable Carbon Isotope Analysis of Amino Acids in Otolith Protein: A New Tool for Tracking Fish Movement **Presenter: McMahon, Kelton** *		Long-Term Variability of Arctic Cisco Growth Rates: Using Otolith Growth Rates to Test for Evidence of Environmental Control **Presenter: von Biela, Vanessa R.**		A California Current Bomb Radiocarbon Reference Chronology and Petrale Sole Age Validation **Presenter: Haltuch, Melissa A.**
11:40		Batch-Marking Otoliths of Australian Native Larval Fish Using Immersion Techniques with Combinations of Enriched Stable Isotopes **Presenter: Woodcock, Skye** *		Growth and Lifetime Energy Budget of the Bivalve A. islandica in Geographically Distinct Populations **Presenter: Begum, Salma** *		A Review and Evaluation of Methods for Comparing Reference and Validation Time Series in Bomb Radiocarbon Age Validations. **Presenter: Hamel, Owen**
12:00		Lunch				

Thursday

	Room	Steinbeck (Main)		San Carlos 2		Colton
	Theme	**Chemistry** **Moderator: K. Limburg**		**Life History and Management** **Moderator: L. Kerr**		**Age and Growth** **Moderator: B. Chuwen**
1:30		Water Sr:Ca Appears to be the Primary Factor Influencing Otolith Sr:Ca for Freshwater and Diadromous Fish but not for Marine Fish **Presenter: Brown, Randy**		Stock Structure of Grey Mackerel (Scomberomus semifasciatus) Across Northern Australia, Based on Otolith Isotope Chemistry **Presenter: Jackson, Gary**		Age and Growth of Greater Amberjack in the Gulf of Mexico, With Application of Finrays for Non-Lethal Aging of Tag-and-Released Fish **Presenter: Murie, Debra**
1:50		The Utility of Stable Isotopes in Otoliths to Infer Historical Habitat Usage **Presenter: Augley, Julian**		Application of Multiple Otolith Techniques to Inform the Spatial Management of a Deepwater Fishery Species, Blue Grenadier Macruronus novaezelandiae, in Southern **Australia Presenter: Hamer, Paul**		Growth in Evolutionary Exile: Morid Fishes (Gadiformes) in the Southwest Atlantic **Presenter: Shcherbich, Zhanna**
2:10		Bayesian Multielemental Approach Reveals the Diversity of Catchment Colonisation Tactics of European Catdromous Species **Presenter: Daverat, Francoise**		Otolith Microchemistry Offers a New Insight on A. anguilla Panmixia Hypothesis and on the Transoceanic Migration Timing **Presenter: Martin, Jean**		Larval and Juvenile Growth Rates From Atlantic Herring Otoliths, in Relation to Plankton, Fishing Effort and Year Class Strength **Presenter: Suthers, Iain**
2:30		Otolith Elemental Signatures Reflect Residency in Coastal Water Masses **Presenter: Nishimoto, Mary**		Segregation of SE Pacific and SW Atlantic Blue Whiting Stocks: Evidence From Complementary Otolith and Parasite Natural Tags **Presenter: Niklitschek, Edwin J.**		Annual Growth and Production of Lost River Suckers From Upper Klamath Lake During the Last Century **Presenter: Terwilliger, Mark**
2:50		Test of the Relationship Between Otolith Sr:Ca and Salinity Using a Euryhaline Species Submitted to a High Salinity Gradient **Presenter: Panfili, Jacques**		Can Stable Isotopes Help Reveal Behavioural Differences in Individual North Sea Cod? **Presenter: Pilling, Graham**		Individual Growth in Two Otolith-Marked Stocked Eel Populations **Presenter: Wickstroem, Hakan**
3:10		Effects of Mercury on Selenium Incorporation into Fish Otoliths **Presenter: Lochet, Aude**		Southern Garfish (Hyporhampus melanochir) - Analysis of Stock Structure From Multiple Otolith-Based Techniques **Presenter: Steer, Mike**		How Bomb Radiocarbon Fish Age Validation is Affected by Differences Among Marine Radiocarbon Reference Chronologies **Presenter: Kastelle, Craig**
3:30		Break				

Thursday

	Room	Steinbeck (Main)		San Carlos 2		Colton
	Theme	**Various Themes** **Moderator: C. Grimes**				
4:00		Evaluation of Recruitment Connectivity Between the Florida Keys and Mesoamerican Reefs Using Otolith Microchemistry **Presenter: Gerard, Trika**				
4:20		Tracking Dispersal of Clownfish Larvae in a Network of Marine Reserves Using TRAnsgenerational Isotope Labeling (TRAIL) and DNA Parentage Analysis **Presenter: Thorrold, Simon**				
4:40		Plasma Membrane Calcium ATPase Required for Semicircular Canal Formation and Otolith Growth in the Zebrafish Inner Ear **Presenter: Shiao, Jen-Chieh**				
5:00		Nature vs Nurture: is Otolith Core Chemistry a Marker of Natal or Maternal Origin? **Presenter: Swearer, Stephen**				

Banquet in the Evening (Dress is casual)

Program Schedule
Friday, August 28

	Room	Steinbeck (Main)		San Carlos 2		Colton
	Theme	**Age and Growth**				
8:30		Exploring the Value of Life-History Patterns Revealed by Otolith Ageing **Presenter: Jones, Cynthia**				
9:00		Lead-Radium Dating: The Evolution of Radiometric Age, Growth and Lifespan Determination of Marine Fishes **Presenter: Andrews, Allen**				
9:30		Break				

Friday

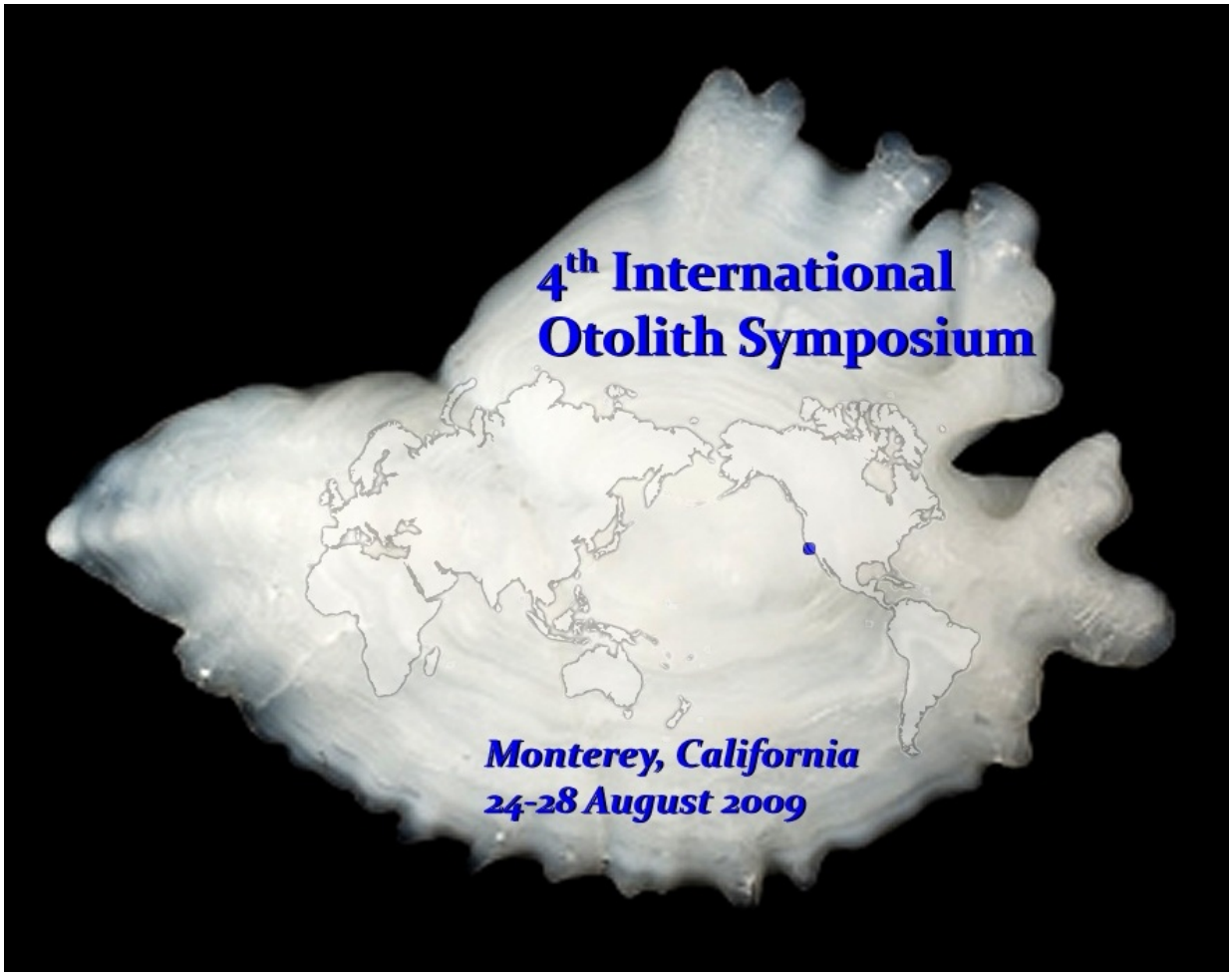
	Room	Steinbeck (Main)		San Carlos 2		Colton
	Theme	**Age and Growth** **Moderator: B. Wells**		**Chemistry** **Moderator: R. Barnett-Johnson**		**Life History and Management** **Moderator: S. Ralston**
10:00		Variability in Fish Size/Otolith Size Relationships Among Populations of Chinook Salmon **Presenter: Zabel, Rich**		Partial Migration of Fishes as Exemplified by the Estuarine-Dependent White Perch **Presenter: Kerr, Lisa A.**		Supporting Adaptive Management of European Fisheries by Otolith-Based Stock Identification **Presenter: Stransky, Christoph**
10:20		Otolith Image Classification and Conditional Models for Fish Ageing: Plaice Cod and Anchovy Case Studies **Presenter: Parisi, Vicenc**		Integrating Ecogeochemistry and Satellite Archival Tagging to Resolve Migratory Connectivity of Basking Sharks in the Western Atlantic Ocean **Presenter: Thorrold, Simon**		Migratory History of the Fourspine Sculpins (Cottus kazika) **Presenter: Tahara, Daisuke**
10:40		Thirty Years After: State-of-the-Art in Cephalopod Age and Growth Studies **Presenter: Arkhipkin, Alexander**		Differences in the Elemental Composition of the Otoliths of Pacific Sardines Caught in the Mexican Pacific and Gulf of California Using LA-ICPMS **Presenter: Herzka, Sharon**		Linking Recruitment of Fish to Ecosystem Processes Using Otolith Chemistry **Presenter: Elsdon, Travis S.**
11:00		Ageing Studies Done 50 Years Apart for an Inshore Fish Species of Southern Australia: Contribution to Understanding Current Fishery Status **Presenter: Fowler, Anthony**		Otolith Sulfur Isotopes and Microstructure Demonstrate that Hatchery Salmon Dominate Spawning on the Mokelumne River, California **Presenter: Weber, Peter**		Reconstructing Environmental History and Movement of Fish Inhabiting Estuarine and Hypersaline Waters Using Multivariate Analyses **Presenter: Munro, Andrew**
11:20		Validation of Scales and Otoliths for Estimating Age of Redband Trout in High Desert Streams of Idaho **Presenter: Schill, Daniel**		The Use of Strontium Isotopes 87Sr:86Sr to Manage Threatened, Endangered and Commercially Important Species in the Western US **Presenter: Hobbs, James**		European Eel Movements During Continental Life in the Rhone River Delta (South of France): High Level of Sedentarity Revealed by Otolith Microchemistry **Presenter: Panfili, Jacques**
11:40				Reconstructing the Marine Food Chain: Nitrogen Isotopes in Skeletal Remains **Presenter: Rowell, Kirsten**		
12:00		Lunch				

Friday

	Room	Steinbeck (Main)		San Carlos 2		Colton
	Theme	**Age and Growth** **Moderator: G. Cailliet**		**Chemistry** **Moderator: L. Carroll**		**Life History and Management** **Moderator: C. Grimes**
1:30		Is Bigger Really Better? A Detailed Demographic Analysis of a Grouper Spawning Aggregation in Micronesia **Presenter: Taylor, Brett M**.		Isotopic Correlation (d18O vs. d13C) of Otoliths in Identification of Groundfish Stocks **Presenter: Gao, Yongwen**		Successful Application of Stable Isotopes Measurements of Sulphur to Discriminate Among Alternate Life History Forms of Sockeye Salmon (Oncorhynchus nerka) **Presenter: Godbout, Lyse**
1:50		Life History of the Spotfin Croaker (Roncador stearnsii) in the Southern California Bight **Presenter: Williams, Jonathan**		Otolith Microchemistry to Resolve Alternate Chinook Salmon Life History Strategies in Cedar River (WA, USA**) Presenter: Kennedy, Brian**		Life History Differentiation Between Deep-Water and Shallow-Water Forms of Lake Trout in Large Lakes of North America **Presenter: Hansen, Michael**
2:10		Computer-Aided Age Estimation Techniques Using Calcified Structures **Presenter: Vasil'kov, Valeriy**		Use of Otolith Chemical Analysis to Determine the Recruitment Responses of an Introduced Pest Fish, Cyprinus carpio, to Flow Management in Regulated Rivers **Presenter: Crook, David**		Otolith Microstructure Analysis Reveals Proportions of Life History Types for Ocean-Type Chinook Salmon of the Skagit River, WA **Presenter: Larsen, Kim**
2:30		Why Problems With Orange Roughy Ageing Precision Just Won't Go Away! An Inter-Agency Ageing Workshop and Protocol Testing **Presenter: Krusic-Golub, Kyne**		Discriminating the Natal Origin of Pacific Bluefin Tuna Thunnus orientalis by Otolith Stable Isotope Signature **Presenter: Shiao, Jen-Chieh**		The Importance of Attitude: the Role of Behaviour in Influencing Survival at a Life History Transition **Presenter: McCormick, Mark**
2:50		The Effect of Otolith Sectioning Position on Precision of Tropical Fish Age Estimation **Presenter: Lou, Dong C.**		The Potential Use of Otolith Shape and Microchemistry to Distinguish Cod Species (Genus Pseudophycis) in the Diet of Australian Fur Seals **Presenter: Kemp, Jodie**		Reconstructing Juvenile Migratory History of Modern and Pre-Historic Columbia River Chinook Salmon (Oncorhynchus tshawytscha) **Presenter: Miller, Jessica**
3:10		Web Services for Support of Growth and Reproduction Studies **Presenter: Christoph Stransky**				Variation of Otolith Microstructure and Microchemistry Among Nine Species of Anguillid Glass Eels in Relation to Their Migratory Patterns **Presenter: Kuroki, Mari**
3:30		Break				

Friday

	Room	Steinbeck (Main)		San Carlos 2		Colton
	Theme	**Age and Growth** **Moderator: G. Cailliet**		**Chemistry** **Moderator: S. Campana**		
4:00		Determination of a Cost Effective Methodology for Ongoing Age Monitoring Needed for the Management of Scalefish Fisheries in Western Australia **Presenter: Stephenson, Peter**		Stable Isotopic Comparison in Otoliths of Yelloweye Rockfish and Canary Rockfish **Presenter: Gao, Yongwen**		
4:20		Validation of Annual Periodicity in Otoliths of Red Snapper, Lutjanus campechanus **Presenter: Szedlmayer, Steve**		Nursery Origin of Yellowfin (Thunnus albacares) and Bigeye Tuna (Thunnus obesus) in the Hawaiian Islands **Presenter: Wells, David**		
4:40						
5:00						



Oral Abstracts

Agler, Beverly

Beverly Agler

Alaska Dept. of Fish and Game

Sixteen Years of Thermal Marking in Alaska

For the past 16 years, the Alaska Department of Fish and Game has been using otolith thermal marking of hatchery-raised salmonids to distinguish stocks and assist with management of mixed-stock fisheries. In addition, thermal marked otoliths have provided insight into the high seas distribution and movements of salmonids in the North Pacific Ocean and the Bering Sea. Analysis of thermal marked otoliths has replaced coded-wire tags in several instances. Alaska released approximately 1.3 billion thermal marked salmon (40% chum, 55% pink) in 2007, and the ADFG Thermal Mark lab processes ~20,000-30,000 otoliths per year from returning adult salmon. Within Alaska, several smaller labs exist at the hatcheries and the ADFG Cordova office to examine thermal marks on site and provide timely information for management of local fisheries. In addition, ADFG co-coordinates the North Pacific Anadromous Fish Commission Working Group on Salmonid Marking to facilitate and coordinate thermal marks throughout the North Pacific Ocean. The number of thermal marks ADFG applied to salmonids has increased steadily until 2001. From 2001-present ADFG has marked 68-78 different mark groups each year. Digital images of otolith thermal mark patterns and release information for all NPAFC countries are available on the Internet. Due to the fact that there are not "known" otoliths, thermal mark lab staff second read at least 50% of each year's samples. Then Kappa and Latent Class statistics are used to compare and assess inter-reader accuracy. In this talk, I will present the ADFG and NPAFC internet sites and discuss how thermal marks have been applied to fisheries research during the past 16 years.

Allman, Robert

Robert Allman[1]; Bryan Black[2]; Michael Schirripa[1]

National Marine Fisheries Service[1]; Oregon State University[2]

Relationships Among Otolith Growth-Increment Chronologies, Climate, and Recruitment for Red and Gray Snapper in the Northern Gulf of Mexico

We apply tree-ring (dendrochronology) techniques to develop indices of somatic growth for red snapper (*Lutjanus campechanus*) and gray snapper (*Lutjanus griseus*) using otolith growth-increment widths. The objectives of this study are to i) develop otolith growth chronologies, and ii) integrate chronologies with instrumental records of the environment and time series of year-1 red snapper abundance to evaluate the interrelationships among somatic growth, biomass, recruitment, and climate. From 1991 to 2007, red and gray snapper were sampled from recreational, commercial and fishery-independent landings from Louisiana and Florida. Visual cross-dating was used on sagittal otolith thin-sections, identifying conspicuously narrow increments in 1996, 1993, 1987, and 1978 and conspicuously wide increments in 1999, 1990, 1982, and 1979, which aided in ensuring that all growth increments had been assigned the correct calendar year. Otolith growth increment widths were measured, and crossdating was statistically verified. Master chronologies were then developed by averaging all otolith measurement time series after age-related growth declines had been removed via the process of detrending. Red and gray snapper master chronologies spanned 30 years (1975-2005) and significantly correlated ($r = 0.68$; $p < 0.001$) with one another. The red and gray snapper master chronologies both significantly correlated with March and April sea surface temperatures, Multivariate ENSO Index (MEI) during the prior year, and weakly positive relationships with Mississippi River discharge in February and March. Red snapper recruitment patterns also related to environmental variability and in much the same manner as the red and gray snapper growth chronologies. Considering the overlap in climate-growth relationships, the gray snapper chronology positively and significantly related to red snapper recruitment. The relationship with the red snapper chronology was also positive, but not significant ($p > 0.1$). Overall, growth was remarkably similar across these snapper species, and was positively related to recruitment through shared sensitivities to environmental variability.

Andrews, Allen — Keynote Speaker

Allen Andrews

NMFS, Aiea, Hawaii

Lead-radium dating: The evolution of radiometric Age, Growth and Lifespan determination of Marine Fishes

One of the most recent technological developments in the science of fish age validation is the lead-radium dating technique. Its use is novel relative to the evolution of age determination of fishes because the chronological relationship is almost completely independent of fish somatic growth characteristics, if the application is applied correctly and in using the latest technology and application. For most studies that sought an accurate quantification of the age and growth of fishes, an observation of some kind of change in the structure of fish with time is required. Validation of age is based on observations of growth over time that are measurable and translatable into a growth rate, and this observation must be valid through ontogeny. Use of lead-radium dating provides the first opportunity in the history of age validation to determine the age of fish with no direct observation of growth because it relies solely on the law of radioactive decay. Given a closed system into which radium-226 has entered, it is certain that with sufficient time lead-210 will begin to appear in a process called ingrowth at a rate that is well defined and functions as a natural clock. Fish otoliths provide a unique experimental opportunity to use this chronometer to determine ages for fishes for which little or nothing is known. Technological advances in trace metal chemistry and mass spectrometry have created conditions that have largely circumvented assumptions that were previously necessary in lead-radium dating. This aspect of the science is epitomized by the story behind orange roughy (*Hoplostethus atlanticus*) age validation. The history of determining the age of this species has been complicated. Age validation methods have been applied, but lifespan has remained an unresolved issue. Lifespan estimates ranged from ~20 to >100 years. Centenarian age estimates were derived from thin otolith sectioning and support was provided in an early lead-radium dating study. Necessary assumptions associated with lead-radium dating at the time led to disbelief in the >100 year age determinations. Numerous studies have since focused on either discrediting or properly testing the assumptions of lead-radium dating. An improved lead-radium dating technique provided support for thin section ages and an opportunity to address the issues associated with the validity of the technique. As an independent estimate of age, lead-radium dating indicated fish in the oldest age group were at least 93 years old, providing robust support for a centenarian lifespan. In addition, results from lead-radium dating of many other fish species have provided further evidence that this technique is valid and useful for age validation of fishes.

Andrews, Allen H.

Allen H. Andrews[1]; Gregor M. Cailliet[2]; Robert T. Leaf[3]; Thomas Brown[4]; Laura Rogers-Bennett[5]; Kenneth H. Coale[2]

NMFS, Aiea, Hawaii[1]; Moss Landing Marine Laboratories, Moss Landing, California[2]; Department of Fisheries and Wildlife, Virginia Tech, Virginia[3]; Lawrence Livermore National Laboratory, Livermore, California[4]; Bodega Marine Laboratory, Bodega Bay, California[5]

Bomb Radiocarbon Dating of White Abalone (*Haliotis sorenseni*): Investigations of Age, Growth and Lifespan

Bomb radiocarbon dating was used to answer unresolved questions about age, growth and lifespan of white abalone (*Haliotis sorenseni*). Abalone species in central and southern California have suffered population declines resulting in the closure of both commercial and recreational fisheries. Of the seven Haliotis species in California, white abalone is perhaps the most threatened and was the first marine invertebrate listed as an endangered species under the federal Endangered Species Act. An understanding of life history information is critical to restoring the species from its extirpated state and will be necessary, if the population can recover, for harvest management. A significant issue in this regard is to determine accurate age and growth parameters that describe ontogenetic growth and to estimate lifespan. It is possible that remnant white abalone populations may be composed of senescent individuals that are incapable of contributing to population growth, and that natural mortality may take the remaining population due to recruitment failure. Age, growth rates, and lifespan were estimated in previous studies from limited observations of growth in the field and captive environments. Growth was described as initially rapid, slower with increasing size, and highly variable. From those observations, age near maximum size (~210 mm MSL) was extrapolated to ~35 years; however, these estimates of age, growth and lifespan remain unconfirmed. Bomb radiocarbon dating has provided well-constrained age determinations from a series of white abalone shells with known collection dates. In this work, a series of shells with a range of lengths (148 mm - 200 mm MSL) and collection years (1952 - 1996) were used in concert with a reference bomb radiocarbon data series to examine growth parameters for this species. The lifespan of a large shell (193 mm MSL) was confirmed at 24 ± 2 years, and a larger shell (200 mm MSL) may have lived 29 ± 2 years. These independent estimates of age provide support for early age and growth estimates, and greater confidence in the development of growth parameters necessary for population recovery and responsible management of white abalone.

Antonio Soria, Jose

Ramon Reig-Bolano[1]; Pere Marti-Puig[1]; Antoni Lombarte[2]; Vicens Parisi[3] ; Jose Antonio Soria[4]

UVIC, University of Vic (Spain)[1];ICM-CSIC (Spain)[2]; UPC, Polithecnic University of Catalonia[3]; Polithecnic University of Catalonia[4]

A New Otolith Image Contour Descriptor Based on Partial Reflection

The automatic classification of otoliths species is based on their image contours. Usually a standard protocol is used for the positioning and the capture of these images. In some previous works it has been confirmed that the analysis of these contours in transformed domains, such as FFT, wavelets or wavelet packet is suitable for obtaining discriminative parameters. Classic approaches to contour descriptors like radial descriptors, with a polar representation of the contour radius respect the otolith image nucleus, is the most widely used representation for the contour-based otoliths classification. Apart from the analysis of otolith contours from the 2D images, we are highly interested on having the information of the volumetric surface of the otolith, in a 3D representation that will provide many details for the classification process (i.e. the representation of the acoustic groove). This 3D approach to the problem requires choosing a volumetric descriptor simple and easy to use. The extension of contour descriptors to 3D superficies is thus a challenging task. It is not straightforward from 2D radial descriptors. In this work we propose a new descriptor of contours on 2D images that can be easily extensible to 3D. It is based on the reflection of a normalized closed contour, with a definite horizontal and vertical axis, used as a reference for the reflection, and followed by an extraction of a non redundant contour descriptor from this new duplicated contour image. Its efficiency has been tested with different species below to the Family mugilids: Chelon labrosus, Liza aurata, Liza ramada, and Mugil cephalus. This group is characterized by a close external similarity between species, and a good and detailed shape analyses of their otoliths can help to identify and discriminate morphologically close species. First results are promising and motivate the use of these descriptors in future tools for otolith 3D identification based on wavelet parametrization.

Arkhipkin, Alexander

Alexander Arkhipkin

Fisheries Department, P.O. Box 598, Stanley, FIQQ 1ZZ, Falkland Islands

Thirty Years After: State-of-the-Art in Cephalopod Age and Growth Studies

An up-to-date overview of all known increment-bearing structures and ageing techniques employed worldwide in octopus, cuttlefish and squid is presented. The discovery of daily growth increments in squid statoliths and development of the innovative ageing techniques thirty years ago overturned previous assumptions about squid age, growth and metabolism. It showed that the majority of recent coleoid cephalopods live in the "fast lane", growing rapidly and completing their life cycles in a year or less. Surprisingly, these seemingly brilliant perspectives to study age and growth in cephalopods have not gained much momentum. Approximately an eighth of more than 300 squid species have their basic age assessed and described. Two dozen species have their growth estimates with on-going arguments about the shape of their growth curves. Major problems encountered during age and growth studies of cephalopods are outlined and possible ways to improve the techniques and apply them to a wider spectrum of species are suggested.

Armsworthy, Shelley

Shelley Armsworthy; Steven Campana; Tania Davignon-Burton

Bedford Institute of Oceanography, Fisheries and Oceans Canada

Age Determination, Bomb Radiocarbon Validation and Growth of Atlantic Halibut (*Hippoglossus hippoglossus*) From the Northwest Atlantic

Atlantic halibut (*Hippoglossus hippoglossus*) is the largest, most widely-ranging and commercially-valuable groundfish in the Atlantic Ocean. Atlantic halibut are presumed to be long-lived, but their age and growth is largely unknown. Ages were estimated by counting growth increments from approximately 2,500 thin-sectioned Atlantic halibut sagittal otoliths collected from the Scotian Shelf and Southern Grand Banks, Canada. Age estimates were validated using bomb radiocarbon assays of 20 otolith cores where year of formation ranged from 1949 to 1975, encompassing the timeframe of the global radiocarbon pulse. A comparison of age determined by bomb radiocarbon with age determined by counting annuli indicate that growth increments are laid down annually, and that otolith thin-sectioning and counting annuli is an appropriate and accurate indicator of age of Atlantic halibut. Known-age one year olds were used to identify the location of the first annulus. After 8 years of growth, annulus width narrowed considerably, possibly in concert with sexual maturation. Growth rate for males and females was similar up to about 7 or 8 years (~100 cm), after which point male growth slowed, while female growth continued to up to 20 years reaching a larger maximum size (200 cm) than males (140 cm). A comparison of otoliths collected in the 1960s and 1970s with those collected in recent years shows that growth rate may have increased in recent years, and may result in harvesting prior to sexual maturation. These results demonstrate that Atlantic halibut is a long-lived fish, living up to at least 50 years, an important consideration for the management of the fishery.

Augley, Julian

Julian Augley[1]; Mark Huxham[2]; Teresa Fernandez[2]; Alastair Lyndon[3]

FRS Marine Laboratory[1]; Edinburgh Napier University[2];Heriot-Watt University, UK[3]

The Utility of Stable Isotopes in Otoliths to Infer Historical Habitat Usage

Stable isotopes of carbon and oxygen are naturally occurring and can show predictable spatial variation in organic materials, correlated with temperature and photosynthetic origin. The utility of this predictability to infer habitat occupancy by different life stages of migrating fish, was tested in both a temperate estuarine-coastal marine system, the Forth estuary and Firth of Forth, Scotland, and in a tropical mangrove-seagrass-reef system in Gazi Bay, Kenya. Whole-otolith stable isotope ratios in otoliths of juvenile plaice were measured from 4 sites along an estuarine-marine d13C gradient. Although not significant, a trend of increasing d13C was found in the otoliths from more negative d13C in the estuarine sites, to more positive d13C in the marine Firth of Forth. d18O in plaice otoliths showed a similar trend. In Gazi Bay, otoliths of adults of various species caught in the mangroves and on the adjacent reef were sectioned and d13C and d18O measured. All species studied showed species-specific patterns in d13C; however, there was a general trend of increasing d13C with age for migrant reef species, albeit significant in only two of the eight species. Non-migrant reef species and one of the mangrove residents did not show this trend. The other mangrove resident species showed a greater seagrass influence on otolith d13C, demonstrating trophic dependence on seagrass of this species and indicating the importance of linked seagrass-mangrove systems. d18O did not show any differentiation between otolith sections or species. The results from both studies indicate that d13C in otoliths can be used, although perhaps not in isolation and with methodological refinement, to infer historical habitat usage, and potentially to indicate high-quality nurseries in different coastal-linked ecosystems. D18O in otoliths showed less potential in the tropical mangrove-seagrass-reef system, possibly due to the close proximity of each of the habitat types to each other, and the tendency for d18O to be deposited at isotopic equilibrium with the d18O of the seawater.

Barnett-Johnson, Rachel

Rachel Barnett-Johnson[1]; Matthew Jones[2]; Peter Weber[3]; J.D. Wikert[4]; Tim Heyne[5]; Crystal Sinclair[5]; Elizabeth Vasquez[6]

University of California, Santa Cruz, Institute of Marine Sciences[1]; University of Montana, College of Forestry and Conservation[2]; Lawrence Livermore National Laboratory[3]; United States Fish and Wildlife Service, Anadromous Fish Restoration Program[4]; California Department of Fish and Game[5]; United States Bureau of Reclamation[6]

Isotopic Otolith Networks for Salmonid (IONS): Using Sr isotope Mapping to Reconstruct Early Life-History Movements of Spawning Chinook Salmon

The generation and analysis of continuous maps of isotope ratios (isoscapes) are growing tools to track animal migrations across the landscape. These maps have focus on regional variation in light isotopes (e.g., oxygen, carbon, and nitrogen) generated by processes resulting in spatial differences in foodwebs. This realization has led to a renaissance of interest in describing and predicting isoscapes from local to continental scales as a means to track animal migration. The development of an aquatic Sr isoscape, which is predicated on variations in watershed lithology, is in its infancy relative to light-isotope mapping and has not been developed or used in fish ecology until now. The success of using 87Sr/86Sr as natal markers in the California Central Valley to link freshwater sources of Chinook salmon to their ocean distributions has prompted interest in its use for other ecological and resource management questions. Specifically, in years with increased river flows, spawning abundances are high 2.5 years later. Yet, there is little known about what factors in the early life history specifically improve the survival of the juveniles. Information regarding the relative size (e.g., life history) of juvenile out-migrants to the adult spawning population has been limited due to the methodological challenges of reconstructing early life history movements of returning adults. This study focuses on using the California Central Valley Sr isoscape and analysis of Sr isotopes in otoliths from spawning adults to bridge the information gap between adult abundance, river conditions (wet vs. dry), and juvenile out-migration patterns.

Bass, Andrew

Andrew Bass

Cornell University

Neuroethology of Audio-vocal Communication Among Fishes

Aside from humans, the animal groups that typically come to mind when most of us think of the biological sources of sound are insects, frogs, birds, bats, and cetaceans. And yet, sound production among fishes has been well documented in the scientific literature for over a century. In terms of species number, teleost fish are the largest group of living vertebrates; some of the best-known species documented to be sonic would include catfish, sunfish, croakers, and drumfish. Current estimates are that the majority of the nearly 60 orders of teleosts include members that use acoustic signals (vocalizations) for social communication. In this brief review of the behavioral, biomechanical and neural mechanisms of vocalization among fishes, I will first consider the kinds of sounds that fish use for social communication functions, namely in aggressive and reproductive contexts. Next, I will discuss how the actions of vocal organs and the brain together contribute to the remarkable diversity of vocal behaviors exhibited by fishes. For example, vocal mechanisms range from the rapid contraction of paired vocal muscles that vibrate either the swimbladder or pectoral girdle, to the rubbing together of parts of either the pectoral girdle-fin complex (stridulation) or teeth. Unlike vocal organs, the functional organization of the brain regions controlling vocalizations is highly conserved both across distantly related groups of fishes, as well as between fishes and terrestrial vertebrates (including primates). Hence, the current database strongly supports the hypothesis that the neural bases for vocal mechanisms of acoustic communication first evolved among fishes and have retained their basic organizational features in more recently evolved groups of tetrapods. Lastly, I will briefly review recent studies of the hormone-dependent changes in audio-vocal mechanisms among fishes in the context of seasonal shifts in the production of reproductive-related vocalizations.

Baumann, Hannes

Hannes Baumann[1]; Mark McCormick[2]

Stony Brook University, Stony Brook, NY, 11794, US[1]; School of Marine & Tropical Biology, JCU, Townsville, Queensland, Australia[2]

Three Otolith-Derived Insights About the Settlement Process in Rolland's Demoiselle (*Chrysiptera rollandi*), a Tropical Damselfish From the Great Barrier Reef

From a recruitment pulse in December 2007, we sampled *C.rollandi* juveniles (8.3-14.6 mm SL) shortly before and after they were settling at a local reef at Lizard Island (north-east Australia). Otolith analyses enabled us to address 3 distinct questions: (i) whether pre-settlers and settlers differed in their otolith:fish size relationships, (ii) whether growth histories differed between early vs. late born settlers, and (iii) whether settlers found at 3 depth strata of the reef (0-10m, 10-20m, 20-30m) had different otolith growth patterns. Firstly, in settlers we observed an isometric otolith:fish size relationship as expected, but in pre-settlers otolith size was unrelated to fish size. Particularly the largest pre-settlers (9.7 - 10.5 mm) had significantly smaller otoliths compared to settlers of the same size. The discrepancy might be attributed to selection occurring around the time of settlement and/or a pronounced shift in otolith vs somatic growth before vs after settlement. Secondly, otolith growth trajectories of settlers born early in the pulse differed systematically from those of later born settlers: older settlers grew slower initially and reached their maximum otolith growth about 2 days later than the youngest age group in our samples; a shift that is consistent with rising ambient temperatures during the initial pelagic phase of the settlers. Thirdly, we were unable to detect any consistent differences in otolith growth patterns with settlement depth, indicating that at least until shortly after settlement, environmental conditions at the 3 depth strata were equally conducive to the new settler's growth and survival.

Begum, Salma

Salma Begum[1]; Larisa Basova[2]; Eva Philipp[3]; Olaf Heilmayer[1]; Doris Abele[1]; Thomas Brey[1]

AWI Bremerhaven, Germany/University of Bremen[1]; Zoological Institute, St. Petersburg, Russia[2]; Institute of Clinical Molecular Biology, University of Kiel, Germany[3]

Growth and Lifetime Energy Budget of the Bivalve *A. islandica* in Geographically Distinct Populations

We compare lifetime and population energy budgets of the extraordinary long-lived ocean quahog *A. islandica* from six different sites; NORWEGIAN COAST, KATTEGAT, KIEL BAY, WHITE SEA, GERMAN BIGHT and off NE ICELAND, covering a temperature and salinity gradient of 4 - 10°C (annual mean) and 25 - 34, respectively. Based on von Bertalanffy growth models and size-mass relationships we compute organic matter production of body PSB and of shell PSS, whereas gonad production PG is estimated from the seasonal cycle in mass. Respiration R is computed by a model driven by body mass, temperature and site. *A. islandica* populations differ distinctly in maximum lifespan (40 y, KIEL BAY, to 197 y, ICELAND) but less in growth performance (?? = 2.41, WHITE SEA, to 2.65, KATTEGAT). Individual lifetime energy throughput, as approximated by assimilation, is highest in ICELAND (43730 kJ) and lowest in WHITE SEA (313 kJ). Net growth efficiency ranges between 0.251 and 0.348, whereas lifetime energy investment distinctly shifts from somatic to gonad production with increasing lifespan; PS/PG decreases from 0.362 (KIEL BAY, 40 y) to 0.031 (ICELAND, 197 y). Population annual energy budgets are derived from individual budgets and estimates of population mortality rate (0.035 y-1, ICELAND, to 0.173, KIEL BAY). Relationships between budget ratios are similar on the population level, albeit with more emphasis on somatic production; PS/PG ranges from 0.196 (ICELAND) to 2.728 (WHITE SEA) and P/B from 0.203 – 0.285 y-1. Lifespan is the principal determininant of the relationship between budget parameters, whereas temperature affects net growth efficiency only. In the WHITE SEA population, both growth performance and net growth efficiency of *A. islandica* are lowest. We presume that low temperature combined with low salinity represent a particularly stressful environment for this species.

Berumen, Michael

Michael Berumen[1]; Harvey Walsh[1]; Nuria Raventos[2]; Serge Planes[3]; Geoffrey Jones[4]; Simon Thorrold[1]

Woods Hole Oceanographic Institution[1]; University of Barcelona[2];University of Perpignan[3]; James Cook University[4]

Otolith Geochemistry Does Not Reflect Dispersal History of Clownfish Larvae

Natural geochemical signatures in calcified structures are commonly employed to retrospectively estimate dispersal pathways of larval fish and invertebrates. However, the accuracy of the approach is generally untested due to the absence of individuals with known dispersal histories. We used genetic parentage analysis (genotyping) to divide 110 new recruits of the orange clownfish, *Amphiprion percula*, from Kimbe Island, Papua New Guinea, into two groups: "self-recruiters" spawned by parents on Kimbe Island and "immigrants" that had dispersed from distant reefs (> 10km away). Analysis of daily increments in sagittal otoliths found no significant difference in PLDs or otolith growth rates between self-recruiting and immigrant larvae. We also quantified otolith Sr/Ca and Ba/Ca ratios during the larval phase using laser ablation inductively coupled plasma mass spectrometry. Again, we found no significant differences in larval profiles of either element between self-recruits and immigrants. Our results highlight the need for caution when interpreting otolith dispersal histories based on natural geochemical tags in the absence of water chemistry data or known origin larvae with which to test the discriminatory ability of natural tags.

Black, Bryan A.

Bryan A. Black

Hatfield Marine Science Center, OSU, Newport, OR

Tree rings, otoliths, and the development of annually resolved growth-increment chronologies for fish species

In recent years, tree-ring techniques have been increasingly applied to growth increments of various bivalve, fish, and coral species for age validation and development of environmentally sensitive growth chronologies. A defining characteristic of these studies is that they incorporate "crossdating", the procedure of matching synchronous, climate-induced growth patterns among all individuals in a sample set. Aligning these growth ‘bar codes’ ensures that all growth increments have been correctly identified and assigned the correct calendar year. By crossdating from the increment formed at the known year of capture to the core, crossdating can be used as an age validation technique. Growth increment widths can then be measured to generate chronologies and determine i) the effects of climate on growth, ii) establish relationships among diverse taxa and ecosystems, and iii) reconstruct climate prior to the start of instrumental records. For example, Pacific rockfish (*Sebastes*) chronologies along the California coast are strongly related to February and March upwelling, thereby demonstrating a sensitivity to wintertime ocean conditions. These California chronologies negatively relate to rockfish chronologies along the British Columbia coast, reflecting an inverse productivity regime between those regions. Also, rockfish chronologies significantly relate to Pacific geoduck (a marine bivalve) and tree-ring chronologies from Alaska to California, underscoring the pervasive and synchronous influences of climate from the continental shelf to alpine forests. To date annually resolved, multidecadal growth-increment chronologies have been completed for fish species from the Gulf of Mexico to the Bering Sea. These techniques could undoubtedly be applied across a wider range of systems as more candidate species are identified.

Borges, Rita

Rita Borges[1]; Gustavo Franco[2]; Henrique Folhas[2]; Emanuel J. Gonçalves[2]

CCMAR of the Algarve University[1]; Eco-Ethology Research Unit-ISPA, Portugal[2]

Linking (or not) Larval Occurrence Nearshore With Early Life Traits of a Temperate Cryptobenthic Reef Fish Species From Otolith Analysis

The early life history patterns and the mechanisms regulating temperate reef fish populations are still poorly understood. The larval stage of these species is assumed to be the dispersive stage connecting different populations. The connectivity patterns are, in turn, dependent upon several physical and biological factors, including early life history traits such as larval behaviour, planktonic larval duration (PLD) or growth rates and condition during the pelagic phase. Linking the larval phase to the early recruitment survival and condition is thus of major importance for this central question in ecology. Larval and juvenile otolith analysis can thus reveal important information on these early life history traits and the extent of dispersal or about the relationship between larval supply and recruitment. *Tripterygion delaisi* is one of the most abundant species of the cryptobenthic reef fish assemblage present at the Arrabida Marine Park (Portugal). In this work we investigate the relationship between small scale temporal patterns of larval occurrence and growth patterns and the early life history traits of early recruits of *T. delaisi* at the Arrabida Marine Park. Larvae were caught using a plankton net attached to an underwater scooter and recently settled juveniles were caught by divers with plastic bags on algal tufts. Otoliths of both larvae and settlers were extracted and analysed for comparison of ring width and growth rates during the larval and juvenile stage. PLD was estimated from settlement marks and pre- and post-settlement ring width were also measured for condition estimation. From the juvenile otoliths analysis, the estimated PLD was 17-21days. Although lower than that for other temperate species, the values of the PLD obtained could nevertheless allow for dispersal of these larvae. However, the presence of larvae with different developmental stages indicates local growth and possible larval retention. These results agree with those derived from recent genetic studies in these coastal fish species and indicate that like in some tropical species, factors other than the PLD can be modulating the retention of larvae of this species.

Brogan, John D

John D Brogan; Delsa M Anderl; Daniel K Kimura ; Craig R Kastelle

NMFS

Validation of a New Method of Age Determination for Greenland Halibut (*Reinhardtius hippoglossoides*) Using Otoliths

Greenland halibut have been traditionally aged using surface patterns on whole sagittae or sectioned otoliths. Previous validation studies have shown Greenland halibut aged using these methods were underaged. We used bomb radiocarbon (14C) to validate age estimates produced using a stained cross-section method to age Greenland halibut. Otoliths were collected in the eastern Bering Sea and selected on the basis of estimated birth years that coincided with atmospheric atomic bomb testing. The 14C in Greenland halibut was compared to a Pacific halibut (*Hippoglossoides stenolepis*) reference chronology from the Gulf of Alaska. The Pacific halibut reference chronology and our Greenland halibut 14C values showed similarities, suggesting a general accuracy in our age estimates. There was high variability associated with the 14C values in our samples that could be explained by oceanographic processes in the eastern Bering Sea and the geographic range of our samples. This variability shows the need for a reference chronology specific to the eastern Bering Sea.

Brown, Randy

Randy Brown[1]; Kenneth Severin[2]

U.S. Fish and Wildlife Service[1]; University of Alaska Fairbanks[2]

Water Sr:Ca Appears to be the Primary Factor Influencing Otolith Sr:Ca for Freshwater and Diadromous Fish but not for Marine Fish

Water chemistry is thought to be the primary factor influencing fish otolith chemistry. Experimental results with freshwater and diadromous fish have been consistent with this paradigm, but with marine fish they have often been ambiguous or contradictory. A review of water chemistry data indicated that Sr:Ca (mmol:mol) levels were higher in marine water than in most freshwater systems and that Sr:Ca variability was lower in marine water than in most freshwater systems. We therefore hypothesized that lifetime otolith Sr:Ca profiles of freshwater fish would exhibit low levels of Sr:Ca with moderate variability, of diadromous fish would exhibit highly variable Sr:Ca levels, and of marine fish would exhibit high levels of Sr:Ca with low variability. Otolith Sr:Ca profiles from 81 species of freshwater, diadromous, and marine fish revealed that freshwater fish had low levels of Sr:Ca and lower variability than expected relative to marine fish, diadromous fish had Sr:Ca levels and variability that were consistent with expectations, and marine fish had high maximum Sr:Ca levels, as expected, and high Sr:Ca variability, similar in magnitude to diadromous fish, which was not expected. These findings are consistent with the paradigm that water Sr:Ca is the primary factor influencing otolith Sr:Ca variation for freshwater and diadromous fish but not for marine fish.

Bystydzienska, Zofia E.

Zofia E. Bystydzienska[1]; Jason A. Phillips[2]; Tomasz B. Linkowski[1]

Sea Fisheries Institute in Gdynia, Poland, Gdynia 81-332, ul. Kollataja [1]; Oregon State University, College of Oceanic and Atmospheric Sciences, U.S.A.[2]

Larval Stage Duration, Age and Growth of Blue Lanternfish *Tarletonbeania crenularis* (Jordan and Gilbert, 1880) Derived From Otolith Microstructure.

Tarletonbeania crenularis (n=99, standard length (SL) 25.5-78.0 mm) were collected off Oregon in 2006 and aged by examination of otolith section (central, middle, and external zones) microstructure. The mean number of increments in the central zone was 103.1 (80-139). The middle zone was made of 72.6 (51-102) hardly visible increments, grouped into 11-16 thick “bands”. There is an overall agreement that increments in the central zone are deposited during early larvae growth in surface waters, but the interpretation of middle zone is less clear. The numerous and highly variable increments of the middle zone cannot be interpreted as being deposited only during metamorphosis and included only as part of the larval stage. The middle zone apparently represents a non-migratory behavior of the metamorphosing larvae and early juveniles where they remain at several hundred meters depth. Thus, the separation between larval and non-migratory juvenile growth increments was not possible. The number of well defined growth increments which was presumably formed during migratory behavior of juveniles and adults in the external zone varied between 16 and 315. The total number of increments including all zones of the otolith section varied from 185 to 504. If the enumerated increments were deposited daily, as previously validated in other myctophid species, the examined individuals were calculated to be 6-17 months old. There was a strong curvilinear relationship between the number of increments in the migratory zone and SL. A similar but weaker relationship was found between the total number of increments and SL. The samples available for this study lacked enough larvae and non-migratory juveniles to calculate a growth equation for the whole life cycle of *T. crenularis*, but we attempted to back-calculate a hatch date from age estimated growth increments. Our data suggests a prolonged spawning season of this species in Eastern North Pacific with no distinct peak.

Campana, Steven

Steven Campana[1]; Gary Melvin[2]

Bedford Institute of Oceanography[1]; St. Andrews Biological Station[2]

High Resolution Bomb Dating for Testing the Accuracy of Age Interpretations in a Short-Lived Pelagic Fish

Although stock assessments of Atlantic herring (*Clupea harengus harengus*) have relied on tens of thousands of annual age determinations each year for more than 20 years, recent assessments and otolith exchanges have suggested that the otoliths have been aged incorrectly by at least five laboratories. Tag-recapture and routine age validation studies have failed, in part because the species is fragile, abundant, highly migratory and short-lived (mean age of 6 yr). Although bomb radiocarbon validation studies are typically restricted to long-lived species, the availability of archived otoliths from the early to late 1960's made herring an ideal candidate for investigation using a targeted, high-resolution approach. Unlike other such studies, radiocarbon assays focused on the 1962 cohort through time, thus allowing the extent of any ageing error to be quantified. The results clearly demonstrated that all of the laboratories were under-ageing fish > 8 yrs, and that some laboratories were under-ageing by a factor of two. The margin of uncertainty around the bomb radiocarbon ages was 0.6 yr. This study represents the first time the bomb carbon dating method has been applied to a short lived fish with accuracy at the sub-annual level.

Campana, Steven E.

R.I.C. Chris Francis[1]; Steven E. Campana[2]; Helen L. Neil[3]

NIWA, Wellington, New Zealand[1]; Bedford Institute of Oceanography, Halifax, Canada[2]; NIWA, Wellington, New Zealand[3]

Quantifying the Strength of Age Validations Based on Bomb Radiocarbon

Atmospheric testing of nuclear weapons in the 1950's and 1960's has produced a characteristic pattern of radiocarbon (14C) in fish otoliths that has been used to validate fish age estimates based on otolith annulus counts. These validations are essentially informal tests, based on graphical comparisons, of the null hypothesis of zero bias in the age estimates. A method is proposed to formalise this hypothesis test by producing a confidence interval showing the possible extent of bias. The width of the confidence intervals also provides a quantitative measure of the strength of the validation. The method is illustrated using data for bluenose (*Hyperoglyphe antarctica*) and haddock (*Melanogrammus aeglefinus*).

Carroll, Leslie

Leslie Carroll[1]; Nadine Thébeau[2]; Norm Halden[3]; Mark Hanson[4]; Vince Palace[1]

Department of Fisheries and Oceans Canada/ University of Manitoba[1]; Ontario Ministry of Natural Resources[2]; University of Manitoaba, Department of Geological Sciences[3]; University of Manitoba, Department of Environment and Geography[4]

Determining Metal Exposure in Lake Trout From Pipestone Bay, Ontario Using LA-ICP-MS Analysis of Otoliths

Over the last decade a drastic decline has occurred in the once renowned lake trout (*Salvelinus namaycush*) from Red Lake, Ontario. Since 2001, a collection of spawning assessments, surveys and bioassays directed at their primary breeding shoals on Pipestone Bay have been conducted to assign a causal agent for the ongoing recruitment failure. The Red Lake area has a history of gold mining, and metals associated with gold mining warrant special attention as the driver of low recruitment. A retrospective analysis of zinc (Zn), copper (Cu), cadmium (Cd), manganese (Mn), lead (Pb), and nickel (Ni) in archived lake trout otoliths was performed using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). The objective of the study was to determine if temporal increases in any of these metals were associated with the timing of lake trout recruitment failure. Concentrations for Cu, Cd, Pb and Ni were generally below 6 ppm with marked variations. Mn concentrations were generally below 10 ppm and tended to be greater in earlier annual growth zones compared to zones corresponding to more recent years of deposition. Zn distribution patterns were oscillatory and well defined compared to all other analyzed metals. Zn concentrations ranged from 5.5 ppm to 92 ppm. Both Zn and Mn oscillatory patterns were well defined in the earlier years of lake trout development, however, in later years the oscillations for both metals were abnormally attenuated. This suggests that an environmental disturbance could have occurred, resulting in altered exposure or dietary conditions for the lake trout. Results also suggest diet as a source of exposure to these metals as both Zn and Mn can be incorporated into the otoliths as a result of dietary influence.

Casselman, John M.

John M. Casselman

Queens University, Department of Biology, Ontario, Canada

Otolith Age Interpretation and Recruitment Dynamics of St. Lawrence River American Eels (*Anguilla rostrata*): Procedures and Influencing Factors

American eel recruitment and abundance in the St. Lawrence River have decreased dramatically over the past three decades. Otolith age determination of these and other catadromous anguillids is extremely difficult, partly because their complicated migratory life cycle results in variable growth. A study was conducted to improve otolith growth and age interpretation procedures for this long-lived, slow-growing stock, which is at the northern extremity of the species' range. Preparation interpretation methods (lateral-medial grinding, transverse thin sectioning, and section acetate replicating) were compared. Validated techniques involving tetracycline labeling elucidated factors affecting recruitment. Dams can delay migration, reduce otolith growth, and complicate age interpretation. Otoliths collected in the 1960s confirmed that increased recruitment during the war years (1943-45) was associated with decreased exploitation and increased escapement. Long-term recruitment of young yellow eels to the upper St. Lawrence River was correlated with the North Atlantic Oscillation index when appropriate lags corresponding to age were considered (9 years, r=-0.74). Age interpretation of nine annual samples collected at Moses-Saunders eel ladder between 1976 and 2007 confirms that strong year classes, from the mid-1970s, mid-1980s, 1992-93, 1995-96, and 1999-2002, make it possible to more precisely determine oceanic factors affecting recruitment (Sargasso Sea temperatures r=-0.82, and primary productivity).

Chang, Mei-Yu

Mei-Yu Chang[1]; Chia-Hui Wang[2]; Chen-Fong You[3]; Jen-Chieh Shiao[1]

Institute of Oceanography, National Taiwan University, Taiwan, R.O.C.[1]; Earth Dynamic System Research Center, National Cheng Kung University, Taiwan, R.O.C.[2]; Department of Earth Sciences, National Cheng Kung University, Taiwan, R.O.C.[3]

Using Otolith Elemental Composition of Demersal Fishes as a Biological Indicator of Benthic Environment

Otoliths grow throughout the life of the fish and incorporate elements from the surrounding environment in the process. Therefore, elemental composition in otoliths has been used as a natural tag in studying population structure and individual movement, modeling larval advection from oceanic features, mapping phenotypic characters, and locating and enumerating discrete spawning areas. However, the research about using otolith as a pollution or environmental marker is rare. In this study, we tried to find out if the elemental composition of otoliths could be used as a biological indicator of environment. For this study, we collected samples of 5 species of demersal fishes in 2008 from the East China Sea: *Pseudohombus pentophthalmus*, *Pennahia argentata*, *Lepidotrigala alata*, *Apogon lineatus*, and *Caelorinchus multispinulosus*. The sediment samples were also collected at the same time as well. In order to compare the difference of elemental composition between otolith and environment (sediment), the powder drilled from the edge of otolith and the sediment were both analyzed by solution based ICPMS. We also compared the otolith elemental composition among five species to clarify the most suitable species as a bioindicator.

Chevalier, Desiree E.

Desiree E. Chevalier; Joel Gagnon; Christopher Weisener; Brian Fryer

Great Lakes Institute for Environmental Research, University of Windsor, Ontario

Microchemical Characterization of Chinook salmon (*Oncorhynchus tshawytscha*) Otolith Cores Using FIB and HTEM

Otolith microchemistry has become one of the most important tools in fisheries research. Nucleation mechanisms and the composition of the otolith core, in particular the primordia around which the otolith nucleates and grows, are of particular importance in fisheries management because they provide information about the natal origin and maternal signature of the fish. Laser ablation inductively coupled mass spectrometry (LA-ICP-MS) can be used to determine the trace element content of otoliths. This method, however, provides only elemental, not structural or molecular data and depends on the use of an internal standard (e.g., Ca), the concentration of which is estimated based on the assumption that the otolith is composed entirely of calcium carbonate (CaCO3). Several studies, however, have demonstrated that otolith primordia may be composed of a protein or a different mineral altogether, which would affect the accuracy of LA-ICP-MS data. Furthermore, otolith core nucleation and growth mechanisms are poorly understood and additional investigation is required to better constrain the composition and structure of otolith core primordia. Previous methods of microtoming otoliths have not been precise enough to allow high-resolution imaging and determination of the composition of otolith primordia (generally 1-20 µm in diameter). Therefore, in order to precisely section the core through the primordia, we used a focused beam of Ga ions (FIB) to section otolith cores from Chinook salmon (*Oncorhynchus tshawytscha*), which produced a section of approximately 100 nm thickness. The microchemistry and microstructure of the otolith primordia will be determined using high-resolution transmission electron microscopy (HTEM Titan Krios). It is anticipated that the results from this study will provide insights into otolith nucleation and growth systematics and improve the accuracy of elemental analysis by LA-ICP-MS.

Chittaro, Paul

Paul Chittaro[1]; Jens Hegg[2]; Brian Kennedy[2]; Kerri Haught[2]; Rich Zabel[1]

Northwest Fisheries Science Center, NOAA-NMFS[1]; Department of Fish and Wildlife & Water Resources Program, University of Idaho[2]

Is Chinook Life History Strategy Related to Juvenile Growth? Evidence From Reconstructed Juvenile Growth Rates From Otoliths Sampled From Returning Adults.

Snake River fall Chinook salmon in the Northwest US have recently been shown to have two life history strategies: ocean-types migrate out to sea shortly following hatching and the recently discovered stream-type that, following hatching, reside approximately one year in freshwater before migrating out to sea. The expression of this apparently novel life history type is thought to be a response to changes in juvenile growth conditions following the construction of hydroelectric dams. The stream-type is well-represented in returning adults, but details are lacking, for example, regarding whether juvenile growth rates differ between stream- and ocean-type fish. Using isotopic (87Sr/86Sr) analyses of otoliths collected from successfully returning wild adult Chinook, we first identified their natal rearing area. We then determined their migration strategy based on scale samples. Next, using otolith microstructural analyzes of the same otoliths we tested the hypothesis that adults that exhibited the stream-type life history had lower juvenile growth rates than their ocean-type counterparts. Our results are an important step toward understanding which factors are important for the expression of the alternative life-history types, which can potentially lead to better management of this threatened species.

Chuwen, Ben

Ben Chuwen; Norm Hall; Alex Hesp; Alan Cottingham; Ian Potter

Centre for Fish and Fisheries Research, Murdoch University

The Relationship Between Age, Otolith Radius and Size of Fishes: A Case Study Using the Sparid *Acanthopagrus butcheri*

Exploratory analyses of data collected for *Acanthopagrus butcheri* in four environmentally-divergent estuaries on the south coast of Western Australia demonstrated that, with increasing age, fish length decoupled from otolith radius and that the relationship differed between sexes and among estuaries. The annual increment in otolith radius for successive annuli in otoliths from individual fish of each sex in each estuary declined exponentially towards a positive, non-zero asymptote, demonstrating that material continued to accrete on the otoliths throughout the life of the fish. Curves representing such a decline were fitted to the annual increments in otolith radii for individual sexes and estuaries, both with and without annual effects, where variability among individual fish was assumed. Comparisons between the curves suggested that the increase in otolith size was best described by including annual effects and thus the otolith accretion was presumably influenced by interannual differences in environmental conditions. WinBUGS was used to fit a growth curve to otolith radius-at-age data for individual fish of each sex in each estuary, where, as above, this curve assumed that material was continually deposited on the otolith throughout the life of the fish. A von Bertalanffy growth curve was also fitted to the corresponding length-at-age data for the same fish. The parameters for these two growth curves were then used to derive the parameters of a curve that described the relationship between the length and otolith radius for fish of the same age and the resulting parameters for the two sexes and each estuary compared. The differences in the growth of fish and otolith radii between sexes and among estuaries resulted in different trajectories of plots of fish length versus otolith radius, reflecting the decoupling of these two variables.

Claisse, Jeremy T.

Jeremy T. Claisse[1]; Marco Kienzle[2]; Megan E. Bushnell[1]; David J. Shafer[1]; James D. Parrish[1]

University of Hawaii, Department of Zoology[1]; CSIRO, Marine and Atmospheric Research Division[2]

Habitat and Sex Specific Life History Patterns of Yellow Tang, *Zebrasoma flavescens*, With Implications for Fisheries Management Using Protected Areas

Yellow tang, *Zebrasoma flavescens*, is the primary coral reef fish taken in Hawaii for the aquarium trade. A network of nine MPAs was established in 1999 to manage the aquarium fishery and reduce stakeholder conflict. While results of protection have been positive, interpretation of monitoring data was limited due to lack of habitat and sex specific life history information. We examined sexual differences in ontogenetic patterns of habitat use, growth rate, size dimorphism and longevity. Age validation using tetracycline to mark otoliths provided evidence that a single annulus formed each year. Yellow tang are a long lived species (the oldest individual collected was 41 years old) and display an asymptotic growth pattern typical of the family Acanthuridae. Median size and age at habitat transition from deeper coral rich to shallow turf dominated habitat were about 20 mm longer and about 2 years older for males than females, and coincided with an increase in reproductive output. The sexual difference in size at habitat transition, combined with sexual size dimorphism results in differences in the size distribution of each sex in the two habitats. Sexual size dimorphism resulted from an increased growth rate in males through the juvenile period. These results improved the interpretation of long term monitoring data and led to important refinements in monitoring protocols of the MPA network.

Criquet, Geraldine

Geraldine Criquet[1]; Jessica Garcia[1]; Jean-Philippe Maréchal[2]; Lionel Reynald[3]; Philippe Lenfant[1]

UMR 5244 CNRS-EPHE-UPVD Perpignan University, France[1]; Martinican Observatory of Marine Environment Martinique, France[2]; IFREMER Robert Station Martinique, France[3]

Can Otolith Shape be Used as an Indicator of the Protection Effect?

Marine Protected Areas (MPAs) are increasingly advocated as a tool for resource protection and fisheries management. Numerous studies have demonstrated protection effects through the analysis of densities, abundances, the mean size and catches of fishes. Variations in otolith shape is widely considered as a useful and powerful descriptor to identify and discriminate fish stocks. In this study, we examined the feasibility of using otolith shape as an indicator of the protection effect on exploited fishes. We collected sagittae of *Sparisoma aurofrenatum*, *Sparisoma chrysopterum*, *Acanthurus bahianus*, *Acanthurus chirurgus*, *Lutjanus synagris* and *Ocyurus chrysurus* caught within two MPAs and in surrounding fishing areas. These species, with different life history traits, are abundant members of Caribbean reef fish fauna and are exploited by local fisheries. Shape indices and Fourier descriptors were compared between fishes from Caribbean and Atlantic localities of Martinique and between fishes from protected and unprotected areas within both localities. Spatial differences both locality-specific and level of protection-specific were found for most species. Canonical discriminant analysis based on Fourier descriptors indicated, with high classification rates, a strong discrimination between fishes from MPAs and fishing areas suggesting that fishes are affected by differences in local environmental conditions such as habitat and food availability and quality. Our results suggested that otolith shape can be considered as an indicator of the protection effect.

Crook, David

David Crook; Jed Macdonald

Arthur Rylah Institute for Environmental Research

Use of Otolith Chemical Analysis to Determine the Recruitment Responses of an Introduced Pest Fish, *Cyprinus carpio*, to Flow Management in Regulated Rivers

The common carp, *Cyprinus carpio*, was first introduced into Australia in the 1850's and became widespread in rivers of the Murray-Darling Basin following extensive floods during the 1970's and 1980's. The species is currently considered a major pest in many parts of Australia and throughout the world. Inundated floodplain habitats are well recognised as major spawning and recruitment zones for carp and, in regulated rivers, flow management has a drastic effect on the frequency and duration of floodplain inundation events. Thus, there is the potential that the provision of managed flow events for particular purposes (e.g. irrigation flows, environmental flows for native fish and waterbird breeding) may have the inadvertent effect of increasing carp spawning and recruitment.
Here, we present results from recent work that used otolith chemical analysis to determine the recruitment responses of carp to flow management in two large regulated river systems in south-eastern Australia. Firstly, the otolith multi-elemental chemical signatures of early post-larval carp collected from all known potential floodplain nursery sources were characterised using laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS). Approximately six months later, the same cohort of fish (now young-of-year) was sampled from main channel habitats. Maximum likelihood estimation was then used to classify the young-of-year fish to their likely nursery based on the multi-elemental signatures of the post-larval otolith growth region. This information was used to estimate the relative annual contribution of the various nursery sources to regional carp recruitment over a four year period. By relating this information to flow management at each of the nursery sources, we were able to make inferences about the effects of managed flows on carp recruitment success and identify "hotspots" of carp recruitment in the river systems.

Cuveliers, Els L.

Els L. Cuveliers[1]; Gregory E. Maes[1]; Filip A.M. Volckaert[1]; Audrey J. Geffen[2]

Katholieke Universiteit Leuven, Leuven Belgium[1];University of Bergen, Fisheries Ecology and Aquaculture, Bergen, Norway[2]

Otolith Microchemistry as a Tool to Discriminate Sole (*Solea solea*) Nurseries and Spawning Grounds

Estimating connectivity between juvenile and adult habitats of fish is fundamental for effective fisheries management. Indirect methods, such as geochemical or genetic techniques, require the definition of natal origin for subsequent assignment of adults from various origins to their natal location. We initially determined the elemental composition of otoliths from 148 juvenile sole (*Solea solea*) collected at four sampling locations in the North Sea, using laser-ablation inductively-coupled plasma mass spectrometry (LA-ICPMS). A total of 13 elements were measured in sufficient concentrations at the edge of the juvenile otoliths to perform statistical analyses. Significant differences in elemental composition were detected among the four locations. Discriminant analysis assigned the juvenile fish to their respective nursery grounds with a 90 % success rate. Secondly, we analyzed a total of 244 adult sole otoliths originating from seven sampling locations in Northern Europe (North Sea, Irish Sea, Celtic Sea and Kattegat). Using multivariate statistics, we investigated the geochemical signal from three areas on the otolith (core, nursery signal and the edge) to assign fish from different natal locations and to detect differences in habitat use across the life cycle of common sole. Elemental concentrations differed significantly between the 'core', 'nursery' and 'edge', suggesting that the adult sole were caught in different environments than where they grew up. Results of otolith microchemistry will be combined with results from genetic markers (microsatellite markers) to provide complementary information about connectivity in the North Sea sole populations at small and large scales.

Daverat, Francoise

Francoise Daverat[1]; Jean Martin[1]; Christophe Peycheran[2]; Ronan Fablet[3]

Cemagref[1];UMR CNRS 5034 Pau University[2]; CNRS FRE 3167 LabSTICC Brest[3]

Bayesian multielemental approach reveals the diversity of catchment colonisation tactics of European catdromous species

The colonization of Gironde (SW France) river catchment by juveniles of three catadromous species: , eel, (*Anguilla anguilla*), flounder (*Platychtys flesus*) and thinlipp mullet (*Liza ramada*) was investigated comparatively using Sr/Ca and Ba/Ca composition of otolith. The relation between Sr/Ca and Ba/Ca in the otoliths and trace element concentration in water was validated with an experimental setting while the relation between Sr/Ca and Ba/Ca and habitat was validated with a 6 months caging experiment at four sites along the estuary-river gradient. 50 mullets, 30 eels and 47 flounders were collected in the Gironde river catchment. Otoliths were analysed with Femtosecond LA ICPMS along a trajectory from the core to the edge. A 20 micron wide laser beam was used together with a small ablation cell, providing high spatial resolution. Positions of annual checks were recorded to obtain time series. The validation demonstrated that all species incorporated Sr and Ba in their otoliths in proportion with water concentration. Based on Sr and Ba concentrations in the eel otoliths, the four caging sites of the catchment could be discriminated. A signal processing method based on Gaussian hidden Markov models was applied to the multi-elemental life histories data. The strength of this approach relied in its ability to provide a quantitative, automated analysis and classification of habitat use patterns without any a priori. Using Sr and Ba in synergy, allowed a finer geographic scale than using one alone. Together with the validation results, the analysis revealed that the three species used at least three different habitats during their growth phase along the catchment gradient. The three species had a large diversity of habitat use patterns with resident and nomadic tactics. The resident tactic was less frequent than the tactics using two or more habitats within each individual pattern. Mullet used more habitats in the lower part of the estuary than eel and flounders and changed habitats much more frequently. Eels and flounders tended to colonize first freshwater, and then estuarine habitats later in life while mullets used all the range of catchment habitats throughout their life.

Davis-Foust, Shannon

Shannon Davis-Foust[1]; Ronald Bruch[2]; George Spangler[3]; Derek Ogle[4]; Donald Pereira[2]

University of Wisconsin-Milwaukee Great Lakes WATER Institute[1]; Wisconsin Department of Natural Resources[2]; University of Minnesota[3]; Northland College, Wisconsin[4]

Linking Otolith Biochronology to the Establishment of Invasive Species and other Environmental Perturbations

Like many natural environments around the world, Lake Winnebago, Wisconsin is constantly facing new anthropogenic pressures. Some of the major events that have occurred in the recorded history of this lake include the manipulation of natural water levels, eutrophication from agricultural practices, an intensive rough fish removal program, and the establishment of several aquatic invasive species including the common carp (*Cyprinus carpio*) and the zebra mussel (*Dreissena polymorpha*). The development of comprehensive and integrative metrics for monitoring environmental change is of critical importance in this large complex ecosystem because more changes are likely imminent. It is well-established that the increment widths observed in otoliths of some fish species reflect environmental changes that can be treated as a growth history record, or biochronology. We applied a linear mixed effects model to the increment widths obtained from cross-sectioned sagittal otoliths of freshwater drum (*Aplodinotus grunniens*) to separate extrinsic environmental effects from intrinsic age effects. We then compared the resulting biochronology of environmental effects to other time series or known perturbation events. Our results showed a correlation between increment widths and temperature data and a decrease in increment widths following the cessation of the intensive drum removal program. Our key finding was a significant increase of increment widths of large drum (>35cm) that corresponded to the establishment of zebra mussels. This correlation was supported by diet analysis data, which found that only larger drum were utilizing this new food resource. As a control, we examined the biochronologies of archeological drum otoliths dated to the 1830's and older.

de Pontual, Helene

Aurelie Jolivet[1]; Jean-Francois Bardeau[2]; Ronan Fablet[3]; Yves-Marie Paulet[4]; Helene de Pontual[1]

IFREMER, Sciences et Technologies Halieutiques, Brest[1]; University du Maine, LPEC, Le Mans[2]; Institut Telecom/Telecom Bretagne, Brest[3]; IUEM, LEMAR, Brest[4]

Understanding Otolith Biomineralization Process: New Insights on Spatial Distribution of Organic and Mineral Fractions from Raman Micro-Spectrometry

Otolith opacity has long been thought to be driven by the ratio of organic and mineral fractions both at the micro and macrostructure scales. This widely accepted assumption had been derived from analytical studies that required otolith preparation methods that fundamentally modify the material prior to its analysis. We reexamined this hypothesis using Raman micro-spectrometry. This non destructive technique simultaneously provides qualitative and quantitative information on organic and mineral compounds at very high resolution. Given appropriate methodological adjustments, this technique was first applied to thin sections of hake (*Merluccius merluccius*) otoliths. The primordium appeared as a punctual area with low aragonite signatures and high organic concentration. Similar characteristics were observed in structural discontinuities, namely checks. Analyses along transects covering series of otolith microstructures in opaque zones indicated that L- and D- zones contained the two fractions with periodic and synchronous variations. Contrary to the results obtained after EDTA etching, L-zones depicted greater concentrations in organic compounds containing CH-groups, conversely to D-zones richer in aragonite. This result challenges the usual definition of L- and D- zones as respectively "mineral-rich" and "organic-rich" structures. The analysis of macrostructures on hake and pollock *(Pollachius virens*) otoliths revealed a strong correlation between otolith opacity and the magnitude of the organic and mineral Raman signatures with maxima in translucent zones. A model predicting otolith opacity from the Raman signatures was also proven meaningful and stressed: 1) a partial decorrelation between aragonite signatures which might be explained by changes in the orientation of aragonite crystals between the two types of macrostructure; 2) the role of specific categories of organic signatures which may induce opposite effects on the opacity. Raman micro-spectrometry thus appears as a promising quantitative technique for acquiring spatial information on mineral and organic contents and opens new research avenues for better understanding otolith biomineralization.

Diaz, Bertha

Bertha Diaz; Jose De La Cruz

Centro Interdisciplinario de Ciencias Marinas CICIMAR-IPN

Sagittal Otoliths of the Gerreidae Fishes in the Tropical Eastern Pacific: Taxonomy and Phylogenetic Implications.

Otoliths are crystalline deposits of calcium carbonate in the inner ear of fish. The Sagitta otolith is the largest pair and with a complex morphology allowing it to be used as a diagnostic character for stock and species identification. In spite of these properties, they have not been commonly used as a taxonomic or phylogenetic tool. Furthermore, its application is important in groups where a taxonomic problem exists as well as in the Gerreidae family (type of sea breams). However, sea breams have many taxonomic problems particularly those inhabiting the tropical East Pacific (TEP). The aim of these work is to analyze the morphologic properties of the sagitta otolith from the Gerreidae in TEP, as a diagnostic character and assess their phylogenetic value. Samples used are deposited in the Icthyological Collection (CI) of the Centro Interdisciplinario de Ciencias Marinas (Interdisciplinary Center for Marine Sciences CICIMAR-IPN). Otoliths were digitized in different views (e.g. ventral, dorsal) and measured using TPS-Digital software. Total lengths were recorded from 247 Sagittal otoliths from *Diapterus brevirostris* (n= 72), *Eucinostomus entomelas* (n= 45), *Eucinostomus dowii* (n= 15), *Eucinostomus gracilis* (n = 4), *Eugerres axilliaris* (n= 4) *Eugerres lineatus* (n= 49), *Gerres cinereus* (n=58) and were compared using shape indexes (form-factor, roundness, circularity, rectangularity, ellipticity and eccentricity) and shape by elliptical Fourier analysis. Results are discussed in terms of morphological similarities and the contribution of Fourier descriptors of the otolith shape in the existing phylogenetic matrices of the family.

Doubleday, Zoe

Zoe Doubleday

Tasmanian Aquaculture & Fisheries Institute, Marine Research Laboratories

Targeted Elemental Analysis of Biomineralised Structures and Their Utility in Understanding Population Structure: a Study of Two Octopus Populations

The quantitative and spatial distributions of chemical elements within the hard biomineralised structures of marine organisms can be influenced by the chemical, physical and biological environment, and can thus be used to examine structure and connectivity within populations. Stylet elemental signatures were used to investigate the population structure of two commercial octopus species, *Octopus maorum* and *Octopus pallidus*, in south-east Australia and New Zealand. Stylets are small shell-like structures found in the mantle muscle of octopus, and have temporally-related incremental growth. Unlike fish otoliths stylets are not composed of CaCO3, therefore, the spatial distribution of elements within stylet cross-sections was initially investigated using proton induced x-ray emission (PIXE). Subsequently, laser ablation inductively-coupled plasma-mass spectrometry (LA ICPMS) was used to target and analyse the early life history region of the stylet. Twelve elements were analysed, several of which were excellent spatial discriminators. There was evidence of sub-structuring within the *O. maorum* population despite the species high dispersal potential. Individuals from an aggregation in south-east Tasmania were particularly distinct and appeared to share a local common origin. *O. pallidus* showed a relatively high level of population structure with all samples appearing distinct from each other, which is in accord with the species limited dispersal potential. The population structure of *O. maorum* was also investigated using microsatellite DNA markers and morphometrics; these results are also discussed and compared to the elemental data. This is the first study to utilise elemental signatures to investigate population linkages in octopus, and should have widespread application for the conservation and management of other commercial species.

Efitre, Jackson

Jackson Efitre[1]; Debra Murie[2]; Chapman Lauren[3]

Department of Zoology, Makerere University, Kampala, Uganda[1]; Fisheries and Aquatic Sciences, University of Florida, Gainesville, USA.[2]; Department of Biology, McGill University, Montreal, Quebec, Canada[3]

Age Validation, Growth and Mortality of *Tilapia zillii* (Pisces: Cichlidae) from Crater Lake Nkuruba, Western Uganda, East Africa

Knowledge of fish age and growth is critical for stock assessments and understanding fish life history. We estimated growth and mortality rates for *T. zillii* from Crater Lake Nkuruba, following validation of the formation of annuli in otoliths using marginal-increment analysis. Deposition of annuli in *T. zillii* otoliths was bimodal (March-May and September-November), corresponding to two seasonal peaks of precipitation characteristic of this equatorial region. In general, *T. zillii* caught in gillnets in deeper water had faster growth and were larger at age than inshore trapped fish (Linf. = 146 and 90 mm TL, respectively). Maximum age of *T. zillii* in Lake Nkuruba was 8 years. Estimated total mortality (Z) ranged between 0.71 and 0.74, and natural mortality (M) values ranged between 0.52 and 0.54. Differences in gear selectivity dictated that estimates of population parameters of *T. zillii* need to be gear-specific when used to formulate management practices. This study adds to the growing list of tropical species for which age estimates have been successfully validated using otoliths, and provides an essential first step in appropriate management of the artisanal fishery in crater lakes.

Elsdon, Travis S.

Travis S. Elsdon

Southern Seas Ecology Laboratory, University of Adelaide, Adelaide, Australia

Linking Recruitment of Fish to Ecosystem Processes Using Otolith Chemistry

Anthropogenic impacts, such as increased nutrients, can have large effects on aquatic systems but direct and indirect links to fish and fisheries are less well understood. The abundance and diversity of fish may be altered in estuaries that are nutrient limited or enriched if nutrients are beneficial or detrimental to ecosystem components (habitat, food etc) used by fish. However, examples that link recruitment of fish to nutrients within systems are scarce. I used otolith chemistry to examine the recruitment dynamics of an estuarine fish that has maximum abundance in estuaries of low nutrient concentrations. The objective was to determine if estuaries that contribute most to the recruitment of black bream (*Acanthopagrus butcheri*, Sparidae) have low nutrients and high abundance of the species. To determine recruitment, young-of-year fish were collected in estuaries and their chemical signature determined, and subsequent year classes (1+ and 2+ fish) were assigned to their estuary of origin as young-of-year fish. Of the eight estuaries examined, only four estuaries successfully contributed recruits to the next generation, with these estuaries contributing between 7 and 55% of the total recruits. Consequently, many estuaries acted as sinks in recruitment. Estuaries that contributed to recruitment had moderate nutrients, with estuaries of low and high nutrients not contributing recruits, however, recruitment success was not proportional to abundance of bream. The data highlights individual estuaries for conservation that require further investigation on indirect effects of nutrients and the ecosystem processes that enhance recruitment.

Engstedt, Olof

Olof Engstedt; Per Larsson; Patrik Stenroth; Lars Ljunggren

University of Kalmar, School of Pure and Applied Natural Sciences

Natal Origin of Northern Pike (*Esox lucius*) in the Baltic Sea, a Coastal Stock Assessment Using Otoliths

Several fish species of freshwater origin inhabit estuarine environments and brackish seas. In the increasing salinity gradient from north to south in the Baltic Sea, salinity stress is enhanced for fish of lake and stream origin. As salinity increases fish migrate to freshwater environments to spawn, similar to anadromous species such as salmon (*Salmo salar*) and trout (*Salmo trutta*). The habitats used for spawning include brackish water bays, brooks and rivers. In the southern Baltic Sea, species such as pike (*Esox lucius*), perch (*Perca fluviatilis*), whitefish (*Coregonus* sp), bream (*Abramis brahma*), ide (*Leusicus idus*), roach (*Rutilus rutilus*) and burbot *(Lota lota*) are among those that undergo extensive spawning migration to freshwater. The role of brooks and rivers as spawning areas for these species have not been quantified in relation to spawning success in brackish bays. The freshwater habitats in the last few centuries have been degraded as recruitment areas by agricultural development. The brackish environment has also suffered recruitment damage, as results of over fishing (top-down effects) and eutrophication. In this study, we sampled 175 adult pike (*Esox lucius*) in their foraging stage in the sea in order to determine their origin. The fish could either be born in brackish bays (salinity of 7 ppt) or in rivers entering the Baltic Sea. Fish were taken from two different regions of the Baltic coast line (more than 600 km apart). The sagittal otoliths were prepared and then analysed in Lund, Sweden, using the PIXE-method. Using Sr:Ca-ratios, origin of the pike were determined. The results show that 69 of the 175 pike were born in freshwater, and several of the larger specimens showed reoccurring migration behaviour. These data show that freshwater is an important recruitment environment for the Baltic Sea pike, and with habitat improvements in the rivers former levels of pike might be restored.

Fablet, Ronan

Ronan Fablet[1] ; Laure Pecquerie[2] ; Hans Hoie[3] ; Aurelie Jolivet[4] ; Richard Millner[5] ; Henrik Mosegaard[6]; Sebastian A.L.M. Kooijman[7]; Helene De Pontual[8]

Institute Telecom, Brest France[1] ; University of California, Santa Barbara, California[2]; Department of Biology, University of Bergen, Norway[3] ; Lemar/IUEM, Technopole Brest-Iroise, Plouzane[4]; Centre for Environment, Fisheries and Aquaculture Science, UK[5] ; National Institute of Aquatic Resources, Technical University of Denmark[6]; Vrije Universiteit, Department of Theoretical Biology, Amsterdam[7]; Ifremer/STH, Plouzane, France[8]

Can We Model Otolith Growth and Opacity Patterns as a Response to Environmental Factors and Fish Metabolism? A DEB-Based Framework

Although fish otoliths are recognized as invaluable sources of information at the individual and population level, the extraction of the metabolic and environmental information archived in the otoliths remains critical in numerous cases. This situation results from a lack of understanding of the physiological and environmental mechanisms driving the biomineralization of the otoliths. The DEB (Dynamic Energy Budget) theory is considered to address these issues. This theory models within a conceptual and mathematical framework the metabolic organization of an organism. Here we show how a DEB-based model of the formation of the otolith can be derived to relate otolith biomineralization to fish metabolism and environmental conditions. Relying on the notion of DEB product, the proposed dynamic model involves two elementary components. First, otolith growth and opacity are formally stated as functions of the DEB elementary metabolic fluxes (i.e., somatic growth and maintenance fluxes). In addition to this direct metabolic modulation, a biomineralization-specific temperature effect is considered as calcium carbonate precipitation is known to be temperature-dependent. A two-dimensional extension of the model is also proposed. The model was calibrated using data from cod rearing experiments. It is shown to conform to the relations observed empirically in different experiments regarding the effects of metabolism and environmental conditions (i.e., food availability and temperature) on global otolith characteristics (growth and opacity). This model provides a clear interpretation of the interactions between these two (opposite in some cases) effects. An application to the understanding of the differences in otolith patterns among fish stocks is presented. Considering two cod stocks, namely Southern North Sea (NS) and Barents Sea (BS) cod otoliths, we show that the differences in the experienced temperature and feeding conditions explain the opposite opacity patterns (i.e., formation of a translucent zone in fall (resp. le winter) for the NS stock (resp. the BS stock). We will further discuss this modelling approach for analyzing individual life traits.

Fay, Richard **Keynote Speaker**
Richard Fay

Loyola University of Chicago

The Otolith Organs and Hearing by Fishes

All fishes that have been investigated so far have been shown to hear. One or more of the otolith organs of the inner ear (commonly, the saccule) are the receptor organs for hearing. All fishes may detect sound through the response of the otolith organ(s) to acoustic particle motion functioning similarly to an inertial accelerometer. In some specialized species, the ear may respond indirectly to sound pressure (as most terrestrial animals do), making use of the swim bladder or other gas-filled structure in close association with the ear to transform fluctuations of pressure into motions that move the otolith organ(s) or the otoliths themselves. These species, which include goldfish, zebrafish, minnows, and cods, among others, are known as "hearing specialists". Unspecialized fishes detect sounds from well below 50 Hz to 200-300 Hz, while hearing specialists generally have an extended frequency range up to 3000-4000 Hz. Unspecialized fish can detect motions as small as 0.05 nanometers at optimal frequencies, while pressure-specialized fish can detect sound pressures as low as 65 dB with respect to 1 micro Pascal. Thus, hearing sensitivity of fishes is well within the sensitivity range of most terrestrial animals, including humans. The goldfish (*Carassius auratus*) has been extensively studied with respect to its general sense of hearing using behavioral conditioning methods. Goldfish have been evaluated in terms of their frequency analysis and intensity discrimination abilities, capacities for detecting tones in noise backgrounds, their ability to perceptually segregate sounds from different sources, and in their discriminations among various temporal patterns of sounds. The general picture that emerges is that goldfish (and probably all fishes) have a sense of hearing similar to that of all vertebrate animals. The general function of hearing in fishes and other vertebrates is likely to be to detect and help determine all sources in the scene or soundscape so that behavior may be appropriate with respect to them.

Fietzke, Jan
Jan Fietzke[1]; Hans Fricke[2]; Karsten Zumholz[1]; Karen Hissmann[1]; Thor H. Hansteen[1]; Benjamin Ngatunga[3]

IFM-GEOMAR, Wischhofstr. 1-3, 24148 Kiel, Germany[1]; MPI Bremen/ IFM-GEOMAR Kiel/ AS Tutzing, Beiselestr. 19, 82327 Tutzing, Germany[2]; TAFIRI, P.O. Box 9750, Dar es Salaam, Tanzania[3]

Microchemical Pattern in Otoliths of Coelacanth (*Latimeria chalumnae*)

Known as a living fossil, the Coelacanth (*Latimeria chalumnae*) provides a fascinating link between today´s and Devonian ocean's fauna. Despite the large interest of palaeontologists and biologists little is known about the life history and age of individual specimens. Otoliths may provide a key to reconstruct the latter. We used an electron microprobe (EMP) to obtain high-resolution elemental mappings (3 Âµm steps) of S, P, Ca, Sr and Na of polished cross sections of Coelacanth otoliths. Already optical microscopy had revealed regions of distinct growth pattern within the disc-shaped otolith. Radial growth exceeds the axial one by about a factor of 5 resulting in nearly parallel growth laminations in the order of 20 to 50 Âµm for the latter. Radial growth laminations of 50 to 300 Âµm width show a partially concentric growth pattern. Lines of relatively high S and P concentrations indicating organic rich laminations resemble the major growth increments already observed using optical microscopy. Besides these dominant ones thinner increments (5-10 Âµm) were found in the S high-resolution EMP mappings of the radial growth section. Within these regions being separated by major S laminations cyclic variations of Sr also were found. As this Sr cyclicity differs significantly from the one observed for S we conclude that the processes causing them should differ too. As Sr in otoliths of other fish species worked as an environmental proxy we also consider it as a candidate to provide such information for the Coelacanth. One possible interpretation would be Sr records changes in the ambient water temperature caused by seasonal influences of the monsoons which change the oceanographic settings of the area. Additional information about the temporal variability of the hydrographical conditions of the Coelacanth's habitat will provide the base to evaluate the timing of the growth increments formation. The latter should allow a better estimation of the age of individuals.

Fowler, Anthony

Anthony Fowler

South Australian Research and Development Institute, Adelaide, Australia

Ageing Studies Done 50 Years Apart for an Inshore Fish Species of Southern Australia: Contribution to Understanding Current Fishery Status

The methods for direct ageing of fish from otoliths have changed over time, having been predominantly based on whole otoliths prior to the 1980's and subsequently based on tranverse sections of otoliths. Nevertheless, historical age datasets may still have some scientific value, so long as the methodological issues can be reconciled. This study pertains to the southern garfish (*Hyporhamphus melanochir*) in South Australia. Population age structures were developed 50 years apart, i.e. in 1954-55 and 2005-08, when the fishery was in different stages of development. For the latter period, fish ageing was based on TS-sections, and a QA/QC protocol that involved validation by tetracycline tagging, and reference collections for testing otolith readers. The results indicated that catches were dominated by fish in the 1+ and 2+ age classes. The fish ageing work of the 1950's used whole otoliths, and validation by edge analysis. This work indicated that fishery catches were dominated by the 3+ to 5+ age classes. Overall, the results imply that current age structures are truncated relative to earlier ones. Yet, the differences in ages may be artefacts related to the methodological differences in otolith preparation and interpretation. A further analysis was done to assess the tractability of ageing garfish using whole otoliths. This study identified that the increment counts from the TS-section of one otolith and the whole otolith from the same fish were remarkably comparable. This supported the likelihood that the age structures from whole otoliths collected in 1954/55 were correct. As such, the comparison of results between the two time periods support the hypothesis that current populations are truncated due to their longer history of exploitation. As such, the historical dataset has provided a valuable contribution towards determining the current stock status.

Friedrich, Lisa

Lisa Friedrich

University of Manitoba

Otolith Microchemistry: a Tool for Managing the Competing Interests of Resource Extraction and Conservation

Assessing environmental change relies on monitoring physical, chemical, and biological parameters over extended periods of time. However, detecting change is difficult in areas where baseline data is sparse or non-existent. Biominerals, which may archive chemical information, are becoming important tools for monitoring environmental change. In particular, otoliths have been referred to as continuous recorders of exposure to the environment. They are metabolically inert, unlikely to be resorbed, and grow throughout the life of the fish, and their annular structure produces a time scale that may be added to the record. However, previous studies indicate that only selected trace elements in otoliths are influenced by water composition, a relationship that is complicated by fish physiology and habitat of the fish. This study examines if the geochemistry of a habitat has an effect on otolith microchemistry, specifically, if otoliths retain a chemical signature that may be related to the geology of the watershed. Otoliths were taken from four geologically distinct areas in Manitoba that have been influenced by mining activity. In each case, a suite of elements indicative of the surrounding geology was chosen for LA-ICP-MS analyses across the annuli. Otoliths from fish captured near and downstream from a rare element pegmatite mine contain signatures of Li, Cs, and elevated Rb, whereas those from lakes distant to or upstream from the pegmatite do not have such concentrations of those elements. Otoliths taken from lakes adjacent to Cu, Pb, and Zn mining contain single peaks of the three metals that are interpreted to indicate when the fish came into contact with the tailings. Constant levels of Ni detected in otoliths from lakes near Ni mining operations suggest that the fish are exposed to consistent levels of the metal. Fish stocked in a closed open-pit Ni-Cu-Cr mine contain constant levels of these base metals throughout their life history. These cases indicate the effect habitat has on otolith microchemistry and highlight the possibility of using otolith microchemistry to develop baseline chemical signatures for environmental assessments.

Gagliano, Monica — Keynote Speaker

Monica Gagliano

James Cook University & Australian Institute of Marine Science

When the Going Gets Tough: Fish Populations in a Changing Climate

The urgent need for a rapid and quantitative assessment of the current status of species inhabiting our oceans, and specifically the physiological and ecological costs these species will incur as they attempt to adapt to the new global climate has been recently identified as a pressing research priority. Using the manifold characteristics of otoliths, recent studies have been able to examine the extent to which environmental stress experienced during the developmental history of individuals at current and predicted levels has broad-reaching ramifications for the dynamics of their population today and in the future. Here, I will review research on a model species of tropical reef damselfish, Pomacentrus amboinensis, to highlight the fundamental role of information recorded in otoliths play in providing an innovative approach to ecological theory and its application to the sustainable management of fish populations and the goods and services they provide.

Gao, Yongwen

Yongwen Gao[1]; David L. Dettman[2]; Kevin R. Piner[3]; Farron R. Wallace[4]

Makah Fisheries Management, P.O. Box 115, Neah Bay, WA 98357, USA[1]; University of Arizona, Department of Geosciences, Tucson, AZ 85721, USA[2]; NMFS Southwest Fisheries Science Centre, 8604 La Jolla, CA 92037, USA[3]; Washington Dept of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98563, USA[4]

Isotopic Correlation (d18O vs. d13C) of Otoliths in Identification of Groundfish Stocks

Genetic methods have not been successful in identification of marine fish stocks or regional subpopulations, particularly for the commercially important groundfish along the US Pacific west coast. In this study, we collected a large number of otolith samples (160 Pacific whiting, 128 sablefish, and 200 yelloweye rockfish) from the Washington and Oregon coast, and analyzed their otolith nuclei for stable oxygen and carbon isotope ratios (d18O and or d13C). The isotopic results and correlation of d18O vs. d13C indicated that most groundfish had two or more spawning stocks or subpopulations except for yelloweye rockfish, which might belong to a single stock coast-wide. As compared with the genetic methods in stock identification, the isotopic signatures of otoliths have unparalleled advantages in: (1) determination of a time series to separate the different life stages of marine fish; and (2) connection to the oceanographic and environmental conditions that the fish was exposed. Therefore, stable isotopic signatures in otoliths appear to be a supplement for genetic methods in marine fish stock identification. Overall this study may provide an example not only for the commercially important groundfish stocks along the US Pacific west coast, but for other marine fish as well.

Gao, Yongwen

Yongwen Gao[1]; Russell A. Svec[1]; Hap Leon[1]; Robert Jones[2]; Josie E. Thompson[3]

Makah Fisheries Management, P.O. Box 115, Neah Bay, WA 98357, USA[1];Northwest Indian Fisheries Commission, P.O. Box 1029, Forks, WA 98331, USA[2]; Oregon Dept of Fish & Wildlife, 2040 SE Marine Science Drive, Newport, OR 97365, USA[3]

Stable Isotopic Comparison in Otoliths of Yelloweye Rockfish and Canary Rockfish

Studies on groundfish stock structure indicated that yelloweye rockfish might have a single spawning stock along the Washington and Oregon coast. To test this hypothesis, we collected 120 canary rockfish otoliths and analyzed them for stable oxygen and carbon isotope ratios (d18O and d13C). Due to the extreme longevity and affinity for hard bottom substrates in canary rockfish we took two aragonite powder samples per otolith. One sample was taken from the nucleus of canary rockfish otoliths (the starting time of the life history), and the other taken from the 5th annual zone. Data from otolith nuclei can provide information on the natal sources and spawning stock separation, while the isotopic variation from age-1 to age-5 may indicate the fish growth and behavior. The d18O values of canary rockfish otoliths ranged from -0.21 to +1.71 VPDB (Vienna Peedee belemnite), while d13C values of same samples ranged from -5.36 to -1.44 VPDB. As compared with yelloweye rockfish otoliths, the correlation of d18O vs. d13C in canary rockfish did not show clear separation between Washington and Oregon samples. Significant isotopic differences were observed in d18O of otoliths, but not in d13C (t-test, p=0.001 for d18O and p=0.15 for d13C). From age-1 to age-5, canary rockfish showed substantial shift only in d13C values. These isotopic signatures appear in agreement with those of yelloweye rockfish otoliths. Our results do support the previous studies that both yelloweye rockfish and canary rockfish may have a single spawning stock or population coast-wide.

Garcia, Estrella

Estrella Garcia[1]; Trika Gerard[2]; Barbara Muhling[2]; John Lamkin[2]

University of Miami (RSMAS-CIMAS)[1]; NOAA NMFS[2]

Analyzing Habitat Linkages for Snapper (Lutjanidae) Using Otolith Microchemistry in Southern Florida

Ecologically important snapper species are believed to migrate to reefs from juvenile nursery areas such as sea grass and mangrove habitats including those in Florida Bay and the lower Florida Keys. Little is known about the migration corridors that exist between nursery and reef, and the timing of these migrations. Using stable isotope analysis in the otoliths of gray snapper we have been able to identify the nursery areas from isotopic trends. This study analyzes the juvenile portion of adult gray snapper otoliths collected on the Florida Keys National Marine Sanctuary in order to match them to one of the five nursery regions. Adult (n = 194) *L. griseus* and *O. chrysurus* were collected from nine sites along the Florida reef tract in 2004. Measurements of carbon and oxygen isotope ratios were obtained and compared to existing isotopic signatures of juvenile gray snapper from Florida Bay nursery. Preliminary analysis shows an overlap in isotope measurements for the juvenile portion of adult otoliths to isotope values for the Florida Bay region, thereby suggesting a migratory connection. Results from this study will help define regions and habitats of particular importance to fish successfully recruiting to the Florida reef tract. Furthermore, this will allow for the determination nursery use patterns in the adult snapper population and gain insight into the connections between regions, the relative importance of different habitats within those regions, and whether these patterns vary from year to year. Ultimately, this information will be useful for managers making decisions leading to the establishment and maintenance of protected areas which exist over years and decades.

Gerard, Trika

Trika Gerard[1]; Estrella Garcia[2]; Barbara Muhling[1]; John Lamkin[1]

NOAA NMFS[1]; University of Miami (RSMAS-CIMAS)[2]

Evaluation of Recruitment Connectivity Between the Florida Keys and Mesoamerican Reefs Using Otolith Microchemistry

Data identifying the extent of recruitment of local populations of reef fish is valuable information for effective marine fish conservation and management. Otolith microchemistry has proven to be an effective tool in separating snapper populations at regional and local levels. This study examines variability in the newly settled snapper recruits to make inferences about recruitment. Measurements of carbon and oxygen isotope ratios were analyzed from post settlement (12 -18mm standard length) and juvenile (58 -187 mm Standard Length) snapper (Lutjanidae) collected in 2002-2005 from the Xcalak Coral Reef National Park in Quintana Roo, Mexico and the Dry Tortugas Ecological Reserve, USA. Chemical signatures of newly settled coral reef fishes and juveniles were determined. There was a significant difference in d18O signatures between the Dry Tortugas and Mexico sampling sites (nonparametric MANOVA, $p < 0.001$). Oxygen isotope ratios were the driving force for significant variation. This baseline data, will provide managers with significant information for making sound management decisions that will contribute to the health of the ecosystem and management of coral reef fish stocks. Additionally, results will help in determining any connections between the region and Southern Florida and whether or not managers need to engage in cooperative efforts to encourage marine conservation efforts for all parties involved.

Gerber, Ruan

Ruan Gerber[1]; Nico Smit[2]; Ina Pieterse[2]

University of Johannesburg[1]; Centre for Aquatic Research, Department of Zoology, University of Johannesburg, Auck[2];

Age Estimation, Growth and the Size at Sexual Maturity of Southern African Tigerfish, (*Hydrocynus vittatus*)

The Okavango Delta is one of Africa's greatest wetlands, the largest Ramsar site in the world and home to 71 fish species. One of these, the tigerfish, *Hydrocynus vittatus* (Castelnau, 1861), supports a large and important commercial and recreational fishery in the Okavango Delta, Botswana. Suitable management plans are thus essential for its sustainable utilization. Appropriate fishery management plans are derived from knowledge of age structures, longevity and growth rate of the species in question. The aims of this study were to determine age, growth and maturation size of tigerfish in the Okavango Delta, and to contribute information to the establishment of a fisheries management plan. During August 2005, 2006 and 2007, 206 tigerfish were collected with rod and reel, fish were dissected and scales and lapillus otoliths removed and used to obtain age estimates from scales, whole otoliths and sectioned otoliths as well as to determine if individuals were sexually mature. Males were found throughout the age classes, indicating that they do not disappear from the population at a young age as was previously reported. To the contrary, results showed that they can outlive females, with males having a longevity of 20 years and females 16 years for individuals captured during this study. Males matured at a total length (TL) of 451mm and females matured at 522mm TL, corresponding to an approximate age of 4years for both sexes respectively. Results further showed that sectioned otoliths are the most appropriate method for ageing H. vittatus, since data obtained from sectioned otoliths more suitably fitted the von Bertalanffy model. It is the first study of its sort reporting on age determination of *H. vittatus* in the Okavango Delta and the first for this species that makes use of otoliths.

Gillanders, Bronwyn — Keynote Speaker

Bronwyn Gillanders

University of Adelaide

Using Otolith Chemistry to Determine Population Structure, Movements and Environmental History of Fish

Chemical analyses of calcified structures, especially otoliths, are now routinely obtained and used to answer a number of fisheries and ecological questions. Publications in otolith chemistry have increased greatly since the first otolith symposia in 1993. While chemical analysis of otoliths has become routine, we are now advancing more in statistical interpretations and comparisons with other techniques. I use examples from freshwater, estuarine and marine systems to examine advances in determining population structure, movements and environmental history of fish based on chemical marks. These marks may be natural or induced artificially into fish. I show that the conclusion obtained from chemical analysis of calcified structures can be supported and verified using a combination of approaches. For example, I show that molecular genetic, morphometric and chemical approaches provided similar information on population structure of the giant Australian cuttlefish. Similarly, I show that artificial (e.g. calcein marked) tags allowed hatchery fish to be definitively identified and therefore the success of natural chemical tags to determine stocking success could be ascertained. Likewise, the environmental history of fish could be estimated using otolith elemental chemistry and verified from acoustic tagging information on the same fish. I also highlight the significant advances being made in statistical models for assigning individuals to the population of origin, for clustering fish based on profile analyses across otoliths, and for determining past environmental history (e.g. salinity) of individual fish.

Godbout, Lyse

Lyse Godbout[1]; Chris Wood[1]; Ruth Withler[1]; Steve Latham[2]; John Nelson[3]; Lisa Wetzel[4]; James Irvine[1]; Rachel Barnett-Johnson[5]; M. J. Grove[6]; A. K. Schmitt[7]; K.D. McKegan[7]

Fisheries and Oceans Canada. Pacific Biological Station[1];Pacific Salmon Commission.[2]; SeaStar Biotech Inc.[3]; USGS Western Research Fisheries Center. [4] ;University of California . Institute of Marine Sciences.[5] ; University of Stanford, California[6]; University of California, Los Angeles[7]

Anadromous Sockeye Salmon (*Oncorhynchus nerka*) Reappear After Extirpation Nearly 90 Years Ago: a Case of Reverse Evolution?

We document the reappearance in 2007 and 2008 of anadromous sockeye salmon that were extirpated by the construction of hydroelectric dams on the Coquitlam and Alouette rivers, British Columbia, in 1914 and 1927, respectively. The return of these anadromous fish was not a complete surprise because unusual downstream migrations of smolts, had been observed during experimental manipulations of river flow in 2005 and 2006. We used genetic (microsatellite and mitochondrial DNA) markers and stable isotope (d34S and 87Sr/86Sr) patterns in otoliths to confirm that both the outmigrating smolts and returning adults were the progeny of non-anadromous sockeye (kokanee) that now inhabit the reservoirs formed by the dams. Samples of kokanee adults, smolts, and anadromous adults collected within the same river did not differ genetically, whereas samples of anadromous adults from the Alouette and Coquitlam rivers differed significantly from one another, and from other nearby populations from which the anadromous fish might have strayed. Probe-based stable isotopes analyses of otoliths indicated that the anadromous adults originated from non-anadromous parents. The mean concentration of d34S in the core of otoliths (which is derived from maternal yolk tissue) was not significantly different between anadromous adults and kokanee ($P<0.76$), but was 15 less than in other sockeye known to be the progeny of anadromous parents ($P<0.001$). Similarly, the mean 87Sr/86Sr in the core of otoliths was not significantly different between anadromous adults (0.70) and kokanee (0.70) ($P<0.08$), but was significantly lower than in other sockeye (0.71) known to be the progeny of anadromous parents ($P<0.001$). Low genetic diversity and a lack of evidence for alternative explanations, suggest that the anadromous sockeye runs that were extirpated by dams in both rivers persisted for several generations and evolved as kokanee. Given the opportunity for upstream and downstream migration, both populations appear capable of reverting back to the anadromous form.

Godbout, Lyse

Lyse Godbout[1]; James Irvine[2]; Marc Trudel[2]; Chris Wood[2]; Axel Schmitt[3]; Kevin McKegan[3]

Fisheries and Oceans Canada[1]; Fisheries and Oceans Canada. Pacific Biological Station[2];University of California, Earth and Space Sciences[3]

Successful Application of Stable Isotopes Measurements of Sulphur to Discriminate Among Alternate Life History Forms of Sockeye Salmon (*Oncorhynchus nerka*).

Oncorhynchus nerka occur in two main forms: anadromous sockeye salmon that spend most of their life in the ocean but spawn and rear for usually one year in fresh water, and non-anadromous kokanee that live in fresh water for entire life. The differentiation among the forms or nerka is not straightforward. They cannot be visually distinguished as juveniles, and the utility of DNA analysis is restricted if hybridization occurs. We assessed if sulphur isotopes (34S/32S, expressed as Î´34S) in otoliths allow to discriminate among forms of *O. nerka*. In addition, Î´34S in fish eggs, freshwater zooplankton from our study lakes in British Columbia and in marine zooplankton along the Pacific Coast allowed us to confirm the link between diet and the chemical life history of the fish as recorded in their otoliths. Î´34S was significantly (P<0.001) enriched in the core of the otoliths of anadromous sockeye by 10 - 14â€° compared to the core of kokanee otoliths. Conversely, sockeye eggs (18.6â€° Â± 0.28) (mean Â± 1 standard error) and the marine zooplankton (20.5â€° Â± 0.11) were also enriched by 10 - 14â€° compared to kokanee eggs (4.01 Â± 0.6 and 8.05 Â± 0.14, depending on the lakes) and freshwater zooplankton (6.2â€° and 9.4â€°, depending on the lakes), confirming that the core is derived from maternal yolk tissue and reflects the maternal diet. Conversely, d34S in the outer edge of the otoliths of sockeye (adult growth) was also enriched by 10â€° - 14â€° compared to kokanee. In conclusion, we were successful in discriminating among forms of *O. nerka* using the pattern of sulphur isotopes in otoliths.

Godiksen, Jane A.

Jane A. Godiksen[1]; Martin-A. Svening[1]; J. Brian Dempson[2]; Hans Nordeng[3]

Norwegian Institute for Nature Research (NINA), Arctic Ecology Department[1];Fisheries and Oceans Canada, Science Branch, St. John's NL, Canada[2]; Department of Biology, University of Oslo, Oslo, Norway[3]

Use of Otoliths as Data Storage Recorders in Arctic Charr: Understanding Consequences of Climate Variability and Change

In fish, as in all poikilotherms, several life history parameters are strongly dependent on water temperature. Especially in northern and arctic areas, any factor reducing the accumulation of energy of juveniles during the summer is likely to reduce their growth and thus their likelihood of survival during the winter. Thus, both growth and recruitment may be strongly affected by the length of ice-free season and summer temperatures. Arctic charr may reach up to 35 years of age, and analysis of retrospective annual growth over a long time period may be inferred by back-calculation from their otoliths. In the North-Norwegian stream, Salangen, otoliths of Arctic charr have been sampled at least once every decade from 1952 to 2007, providing the opportunity to back-calculate annual individual growth patterns over a period of more than 70 years. These calculations will be analyzed with respect to air temperature, ice-cover data, and snow depth. We hypothesize that individual growth will be positively correlated to length of the ice-free season and to summer temperatures, and negatively correlated to spring snow depth. We found that abiotic constraints strongly influenced both annual growth, variation in year class strength and anadromy in Salangen charr.

Gonçalves, Emanuel

Emanuel Gonçalves; Rita Borges; Gustavo Franco; Henrique Folhas

Eco-Ethology Research Unit - Instituto Superior de Psicologia Aplicada

Planktonic Larval Duration of Eleven Species of Temperate Cryptobenthic Reef Fishes - Relation With Possible Dispersive and Retention Patterns at the Arrabida Marine Park

Most benthic reef fishes present planktonic larvae that spend a variable amount of time in the water column. This variation may be an important factor determining larval growth and recruitment success for these species. The microstructure of the otoliths of recently settled juveniles is a powerful tool to estimate planktonic larval duration (PLD), pre-and post-settlement growth trajectories, age and size at settlement, among other early life-history traits. This is essential to understand patterns and processes regulating dispersal and retention mechanisms which might explain the distribution ranges and levels of connectivity among these reef fish populations. However, information for temperate cryptobenthic reef fishes is very scarce. We therefore investigated the pelagic larval duration (PLD), settlement mark types and age and growth trajectories of eleven temperate cryptobenthic reef species belonging to the families Gobiidae, Gobiesocidae, Blenniidae and Tripterygiidae. Based on data from nearshore plankton samples, we also collected information on the larval size, distribution and occurrence of some of these species and investigated possible retention or dispersal patterns at the Arrabida Marine Park (Portugal), where samples were collected. The gobiesocids presented the shortest PLD with an average of 13-14 days, whereas the investigated blenniid presented the longest PLD with an average of 33 days. The gobiids and the tripterygiid show in-between values. While gobiesocids, gobies and the tripterygiid are found in all stages of development in the nearshore plankton samples, the blenniid is only found as early-stage larvae. Growth trajectories, age and size at settlement were also investigated across species. These results are compared with the information available for other cryptobenthic species, both in temperate and tropical systems and the derived relationships discussed in the context of the possible pattern of retention and dispersal for these greatly overlooked rocky reef species.

Groenkjaer, Peter

Peter Groenkjaer[1]; Torben Ankjærø[1]; Jens Tang Christensen[1]; Henrik Kjeldsen[2]; Jan Heinemeier[2]

Dept. of Biological Sciences, Marine Ecology, Aarhus University, Denmark[1]; Department of Physics and Astronomy, AMS 14C dating Centre, Aarhus University, Denmar[2]

Stable N Isotopes in the Organic Matrix of Otoliths Reveal the Trophic Position of Individual Cod

Overfishing and climate change is likely to change the trophic structure of marine ecosystems. Here, we show that the ratio of the stable isotopes 15N and 14N (d15N) in the organic matrix of otoliths is a reliable indicator of trophic position, that can be used to document current and historical changes in trophic position of individual fish and, hence, the ecosystem structure. First, we developed an extraction method that allowed accurate estimation of the d15N based on less than 100 mg of otolith material. Secondly, we carried out a rearing experiment with juvenile cod to validate the link between prey and otolith d15N. In the experiment, 10 g juvenile cod were switched from a commercial pelleted food (d15N: 10.2 â€°) to a blue mussel (10.9 â€°), sandeel (12.5 â€°) or whiting (15.6 â€°) diet and reared for 4 months until a max size of 157 g. The corresponding average (Â±SE, n=5) d15N in the otolith matrix formed after the prey switch was 11.6Â±0.12, 12.7Â±0.09 and 15.5Â±0.06 â€°, respectively, suggesting a remarkably close coupling between prey and otolith d15N. Finally, we used the approach to document the ontogenetic change in trophic position of Faroese cod aged 2-7 years. A Oneway ANOVA followed by Ryans Q post-hoc test formed three significantly different groups consisting of 2 and 3 year old cod that had a d15N of 9.6 and 9.4, which increased to10.2 to 10.6 in 4 to 6 year old fish and 11.2 in 7 year old fish. This pattern reflects the offshore migration of 3 year old cod and increased piscivory in larger cod observed in the Faroese stomach sampling program. In conclusion, the study shows that the d15N of the fish diet, and, hence, the trophic level of the prey and predator can be estimated from the organic matrix of the otolith. The present approach will allow tracking changes in the trophic structure of marine ecosystems with very high spatial and temporal resolution by using the large inventories of otoliths collected over the last 100 years.

Haltuch, Melissa A.

Melissa A. Haltuch[1]; Owen Hamel[1]; Kevin Piner[2]; Patrick McDonald[3]; Craig R. Kastelle[4]; John Field[2]

Northwest Fisheries Science Center[1]; Southwest Fisheries Science Center[2];Pacific States Marine Fisheries Commission[3]; Alaska Fisheries Science Center[4]

A California Current Bomb Radiocarbon Reference Chronology and Petrale Sole Age Validation

The rapid increase in radiocarbon (14C) in the environment during the late 1950's and 1960's, due to atmospheric testing of nuclear weapons, can be used as a time specific reference for effectively validating fish ages. Petrale sole (*Eopsetta jordani*) is one of the highest value flatfish species harvested on the U.S. west coast. Therefore it is important to produce the best stock assessments possible for this species. Age data are often highly informative in fishery stock assessments, but ageing methods for petrale sole have not been validated. Additionally, the northern California Current (CC), a boundary current ecosystem, and petrale sole, both lack a reference radiocarbon chronology based on known age fish. This study presents the first bomb radiocarbon reference chronology for the CC along with age validation for petrale sole. The validation component of this study applies two recently published quantitative analysis techniques to evaluate ageing bias and one simpler method. Preliminary results suggest that break and burn and surface ages are negatively biased by about 1 year and 2-3 years, respectively. In comparison to previous studies both the reference and validation curves are more variable and show a notable lag in the rate of radiocarbon increase during what are generally considered the informative years of bomb radiocarbon increase in marine systems. The CC is a highly variable boundary current ecosystem dominated by wind driven upwelling with the period of strongest upwelling, typically the spring and summer months, coinciding with the pelagic period of petrale sole larvae and juveniles. Radiocarbon levels in deep upwelled waters are depleted and are expected to increase later and at a slower rate than those in surface waters. The more variable and slower rate of radiocarbon increase in the petrale sole data may be due to pelagic life stages spending a substantial portion of the first year of life in areas subject to variable strong upwelling. These results emphasize the importance of using reference curves in age validation studies that are region and if not species specific, at least from species with similar early life histories.

Hamel, Owen

Owen Hamel[1]; Craig Kastelle[2] ; Melissa Haltuch[1]; Kevin Piner[3]; John Wallace[1]

NOAA/NWFSC[1]; NOAA/AFSC[2];NOAA/SWFSC[3]

A Review and Evaluation of Methods for Comparing Reference and Validation Time Series in Bomb Radiocarbon Age Validations.

The bomb radiocarbon chronometer tracks the rapid increase in 14C which occurred in the earth's atmosphere and oceans due to atmospheric testing of nuclear weapons in the middle of the 20th century. The chronometer is increasingly popular as a tool for fish age validation since the signal can be seen in calcareous structures formed during the period of increase. Two recently published analytical methods suggest improvements for estimating ageing bias using bomb radiocarbon data. A simple method to estimate the timing of initial radiocarbon increase in a time series has also been proposed. The first analytical method utilizes a deterministic coupled-functions model to describe the increase and subsequent decrease in radiocarbon levels. The model describes the pulse of radiocarbon from nuclear testing as a Gaussian curve over time coupled with a continuous exponential decay process. The model estimates the timing and pattern of increase in 14C for each data set, allowing for estimation of ageing bias as well as observation of differences in pattern due to oceanographic factors affecting the rearing areas of different species or stocks. The second analytical method compares test chronologies to a LOESS smoothed reference chronology. To test for bias in ageing, the estimated birth years are shifted by 0, 1, 2 or more years while the best fit is obtained by calculating the sum of square differences between the test chronology and the smoothed reference chronology. To account for differences in the total increase between reference and test chronologies, the comparison is also made while allowing for modification in scale of the test data to better match the reference chronology. Both analytical models use fitting routines that assign all error and variation to the 14C values. The simple method involves finding the first data point for which the increase of radiocarbon from the lowest point in the series is greater than 10% of the total observed increase. Differences in the timing of first increase can indicate bias. These three methods for analysis of bomb radiocarbon validation data are compared and contrasted using a variety of published and unpublished data sets.

Hamer, Paul

Jodie Kemp; Simon Robertson

Department of Primary Industries, Victoria, Australia

Application of Multiple Otolith Techniques to Inform the Spatial Management of a Deepwater Fishery Species, Blue Grenadier *Macruronus novaezelandiae*, in Southern Australia

Blue grenadier is an important commercial trawl species targeted along the shelf slope of southern Australia at depths of 300-600 m. The fishery is structured around two main fishing regions; west Tasmania and east Bass Strait, with a third fishery developing in the Great Australian Bight. Management is under increasing pressure to implement finer spatial structuring of quota allocations and the need for greater understanding of fishery stock structure has grown significantly. A previous genetic study of population structure was inconclusive in this regard. This study compared otolith shape, trace element (laser ablation ICP-MS of otolith cores and margins) and stable isotope chemistry (d18O and d13C of whole otolith sections) for two cohorts of blue grenadier (aged 4 and 13 years) sampled concomitantly from the winter spawning fishery at each of the three major fishing regions. All techniques indicated significant variation among fishing regions for one or more of the pairwise comparisons. Patterns of significant variation among the regions were, however both technique and cohort dependent. Trace element chemistry (Mg:Ca, Cu:Ca and Ba:Ca) and stable isotopes displayed the most variation among regions, although there was some overlap of data among all regions. While actual stock boundaries cannot be defined based on this fishery structured sampling program, results of each of the three techniques in combination with previous studies are indicative that the Great Australian Bight fishery can be separated from the west Tasmanian and east Bass Strait fishery regions for the purpose of management. There was also support for separation of the east Bass Strait and west Tasmanian regions, and an indication from d18O that west Tasmanian fish were spending more time in colder water with increasing age. Life history d18O and trace element otolith transects are recommended to investigate migratory contingents within the Tasmanian and eastern Bass Strait fisheries. The study demonstrates the value of applying multiple techniques to improving understanding of fishery stock structure for management purposes.

Hansen, Michael

Michael Hansen[1]; Nancy Nate[1]; Charles Krueger[2]; Mara Zimmerman[3]; William Taylor[4]

University of Wisconsin - Stevens Point[1];Great Lakes Fishery Commission[2];Washington Department of Fish and Wildlife[3]; Michigan State University[4]

Life History Differentiation Between Deep-Water and Shallow-Water Forms of Lake Trout in Large Lakes of North America

Lake trout (*Salvelinus namaycush*) readily diversify in morphology to exploit diverse habitats (depth) in large lakes of North America. Historical morphological diversity of lake trout in the Laurentian Great Lakes was greatly reduced when stocks collapsed in the 19th and 20th centuries. To provide more realistic expectations for rehabilitation of lake trout morphotypes in the Great Lakes, we examined life history attributes of deepwater and shallow water forms of lake trout from unperturbed large lakes in North America (Great Slave Lake, Northwest Territories; Lake Mistassini, Quebec) and Lake Superior. Humper, lean, and siscowet morphotypes were differentiated with multivariate statistical models from standardized digital photographs of specimens. Growth histories of individual lake trout were estimated by back-calculating lengths at age from 1,693 otolith thin sections. Otoliths were prepared by mounting in epoxy, removing a thin section with a diamond saw, and mounting the thin section on a microscope slide. Sections were photographed and then annulus increments were measured using image-analysis software. Growth histories for each specimen were estimated from increment measurements using Campana's biological intercept model with a biological intercept from previous research in Lake Superior. Length-age models were fit to individual growth histories. Mean growth parameters were then compared among morphotypes within and among lakes to test the hypothesis that growth of similar morphotypes was more similar among lakes than growth of different morphotypes within or among lakes. Preliminary results suggest that growth was similar for similar morphotypes among different lakes but differed among morphotypes in the same lake and among different lakes. We suggest that these measures from unperturbed populations should help to clarify objectives for stock restoration in the Laurentian Great Lakes better than relying solely on similar measures from disturbed stocks in Lake Superior.

Harbitz, Alf

Alf Harbitz

Institute of Marine Research, P.O. Box 6404, N-9294 Tromso,, Norway

A Generic Ad-Hoc Algorithm for Automatic Nucleus Detection From the Otolith Contour

Automatic nucleus detection is required in a range of methods for automatic ageing, growth analysis, stock separation and others. A generic ad-hoc algorithm for automatic nucleus detection is developed where the otolith contour is the only data needed. The algorithm is applied to several thousand otoliths of cod, plaice and anchovy where the nucleus location annotated by experienced readers are used as true values. For the rather difficult species North East Arctic cod the standard deviation of the distance between the reader-based and automatic nucleus location was about 2% of the major half-axis of the best fitted ellipse to the domain enclosed by the contour. This was comparable with the standard deviation of the difference in core location between the two readers. Virtually all core predictions were in the domain enclosed by the first annual zone. As an example of the application, the images are circularized, standardized, and then superimposed on a haul by haul and age basis, the age being determined by experienced readers. The superimposed images of young fish of the same age from the same haul clearly show the annual zones in contrast to the much more blurred superimposed images of random fish of the same age. This indicates an interesting potential for using the otolith analysis for behavioural purposes. It also indicates a potential for applying clustering analysis to improve automatic ageing.

Harbitz, Alf

Alf Harbitz[1]; Hans Ingolf Hoie[2]

Institute of Marine Research, P.O. Box 6404, N-9294 Tromso,, Norway[1]; Institute of biology, University of Bergen, Norway[2]

Age Distribution of North East Arctic Cod Estimated From the Contour of Otolith Section Images

1,976 cross-section otolith images of reader-aged North East Arctic cod are analyzed by image analysis to investigate the potential of simple morphometric variables to estimate the age distribution from the contour. Contrary to the estimation of age distribution based on age-length keys (ALKs) or age-weight keys (AWKs), where the fish length, L, and fish weight, W, are strongly dependent, the three morphometric otolith variables considered here are not so dependent. These are: 1) the pixel area enclosed by the otolith section contour, 2) the ratio between the minor and major axis of the best fitted ellipse to the domain enclosed by the otolith contour, and 3) the angle (> 90 degrees) between the lines from the otolith core to the two largest distance modes from the core to the contour. All variables are correlated with age. The otolith-based age estimator, which is an optimized linear combination of the age estimation based on each of the three variables alone, appeared to be substantially better than that based on fish length and/or fish weight.

Harbitz, Alf

Arnt-Barre Salberg[1]; Alf Harbitz[2]; Hannes Baumann[3]; Hans Ingolf Hoie[4]; Christoph Stransky[5]

Norwegian Computing Center, Gaustadall 23, NO-0373 Oslo, Norway[1]; Institute of Marine Research, Sykehusveien 23, N-9294 Tromso,, Norway[2]; School of Marine and Atmospheric Sciences (SoMAS), Stony Brook University, Stony Brook[3]; Institute of biology, University of Bergen, Norway[4]; Johann Heinrich von Thanen Institute, Institute of Sea Fisheries, Hamburg, Germnany[5]

Rapid Differentiation of Norwegian Cod Stocks by Automatic Image-Segmentation of Internal Otolith Growth Structures

A method for automatic differentiation of the cod species North East Artic Cod (NEAC) and Norwegian Coastal Cod (NCC) using the two innermost translucent zones of the otolith is proposed. The method consists of four main steps:

i) Estimation of the otolith core location
ii) Segmentation of the two innermost growth rings
iii) Feature extraction from the segmented rings
iv) Classification based on the extracted features

The otolith core location is estimated by an automatic ad-hoc algorithm based on the otolith contour. Using the otolith core as a center point, a polar representation of the otolith image is constructed with angle along the horizontal axis and standardized radius along the vertical axis in order to obtain a rectangular image. The segmentation of the growth rings is based on a thin plate regression spline (TPRS) modelling of the profile of the angle slices from the otolith core to the boundary, providing a smoothed profile curve for each column in the rectangularized image. The TPRS representation facilitates noise robust estimation of the derivative of the profile curves, and the translucent zones are extracted by localizing the sections where the derivative is significantly different from zero. Feature vectors are constructed from the positions of each detected peak location of the two innermost rings. We model the sequence of extracted features using a hidden Markov model. The classifier then works on a sequence of extracted features, and is robust for spurious peak detections. The automatic classification procedure is evaluated on a collection of otoliths, and shows good agreement with the readings by experts.

Hastings, Mardi — Keynote Speaker

Mardi Hastings

Pennsylvania State University

The Extraordinary Inner Ear of Fishes

The inner ear of fishes appears remarkably simple, yet is exceptional in function. Fish detect the differential motion between otoliths and sensory epithelia in the saccule, utricle, and lagena through bending of the ciliary bundles atop the underlying hair cells. The hair cells do not respond directly to sound pressure, but rather to a single component of displacement. Because the body of a fish has about the same density as water, in the presence of sound it moves with the passing wave while the otoliths move less since their density is about three times higher than the density of water. In addition to this direct response to sound, further displacement may be induced indirectly by motion of the swim bladder (or other gas-filled chamber), which is excited by sound pressure. Either way, the displacement stimulus at threshold is incredibly small. Near threshold cilia are displaced by less than one ten-thousandth of a millionth of a centimeter -- much smaller than the diameter of a hydrogen atom! Otoliths are essential for hearing in fishes. Motion of the otoliths may also play a role in sound localization and frequency discrimination. Several species have evolved unique anatomy designed to provide additional motion directly to otoliths during passage of a sound wave. These specializations make the inner ear more sensitive to sound by lowering thresholds and broadening the range of detectable frequencies. There is also evidence that fish with unusually large otoliths have better hearing sensitivity. This makes sense because otoliths with more mass will move less with a sound wave and thus enhance relative motion with the sensory epithelium and bending of the apical cilia of the hair cells. These and other features of the amazing inner ear of fishes will be presented. Biomechanical analyses showing the relationships between structure and function will also be discussed.

He, Wenping

Wenping He[1]; Songguang Xie[1]; Brian R. Murphy[2]

Institute of Hydrobiology, Chinese Academy of Sciences[1];Virginia Polytechnic Institute and State University[2]

Validation of the Method of Estimating Age, Modeling Growth and Describing the Age Composition of *Coilia mystus* (Linnaeus) From the Yangtze Estuary, China

A total of 577 individuals of *Coilia mystus* were collected during April 2006 and April 2007 from the Yangtze Estuary area of China to estimate the age structure and growth patterns of the population. Examination of sectioned sagittal otoliths revealed a periodic straight/curved growth pattern. The straight zone occurred from April to November, and curved zone occurred from October to May, indicating an annual periodicity. Annual periodicity was also verified by marginal zone analysis. The shift from a curved-zone to the next straight-zone stanza was defined as an annulus. The collected specimens aged 0 to 5 years. The von Bertalanffy growth function was fitted to standard length (LS)-at-age data by LS = 215.16(1-e-0.53 (t+0.30)) (n = 577, r2 = 0.81, $p < 0.05$). The mature females included 5 age classes, with age-1 and age-2 individuals accounting for 74.3% of the population. The mature males included age-1 and age-2 individuals, with age-1 individuals accounting for 86.4% of the population. Mean length was smaller, and annual growth was less, for mature males than females of comparable ages. This study demonstrates that the Yangtze population of *C. mystus* is composed of more age classes than previously thought, and the age structure of the population should be considered in management decisions.

Hegg, Jens

Jens Hegg[1]; Paul Chittaro[2]; Brian Kennedy[1]; Rich Zabel[2]; Kerri Haught[2]

Dept. of Fish and Wildlife & Water Resources Program, University of Idaho[1]; Northwest Fisheries Science Center, NOAA-NMFS[2]

Resolving Natal Origins and Life History of Wild Fall Chinook Salmon (*Oncorhynchus tshawytscha*) Using Otolith Microchemistry and Geospatial Analysis

The development of divergent life history strategies in salmon is the result of variation in migratory behavior for individual fish and the effects of environmental fluctuation. It is fundamentally important to understand how these divergent life history strategies confer fitness advantages to individuals within the population and how changing environmental conditions over large scales affect individual fitness. Recent research has shown increased variation in the migration strategies of juvenile wild Snake River fall Chinook salmon (*Oncorhynchus tshwasytscha*) with marked increases in representation of juvenile migrants at older ages in a population that historically was dominated by sub-yearling juvenile migrants. Reconstructing the juvenile strategies and habitat origins of successfully returning adult fish can be difficult when tagging all individuals is not a feasible option. Using otolith microchemistry and geospatial techniques we are reconstructing the life history of individual fish with the goal of understanding the spatial representation and fitness consequences of alternate life history strategies of juvenile fall Chinook salmon in the Snake River. Our results show significant spatial differences in the geochemistry of key *O. tshawytscha* spawning locations. These chemical signatures are recoverable in the otoliths of returning wild fish and inform us of site-specific migratory strategies. To classify these otolith signatures we are using geospatial techniques to examine the link between geologic variation and microchemical signature within watersheds of the Snake River. This relationship has the potential to improve spatial classification of individual fish through the creation of a predictive framework to forecast our ability to discriminate natal origins within the system and to assign confidence intervals to the classification of fish. We are currently analyzing otoliths of adults from 2006-2008 in order to develop a spatially explicit understanding of juvenile migration strategy that could inform regional management practices and hydropower decisions.

Herzka, Sharon

Sharon Herzka; Sonia Valle

Center for Scientific Research and Higher Education of Ensenada (CICESE)

Differences in the Elemental Composition of the Otoliths of Pacific Sardines Caught in the Mexican Pacific and Gulf of California Using LA-ICPMS

The models of population structure for the Pacific sardine (*Sardinops sagax caeruleus*) in the California Current system and Gulf of California indicate the presence of three or four subpopulations. However, the degree of mixing among subpopulations has yet to be established. Otolith elemental analysis can be used to identify natal origin, infer migration patterns and evaluate geographic population structure. We used Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) to examine the chemical composition (Mg, Mn, Sr, Sn and Ba) of the otoliths of 6-18 month old sardines collected throughout their distribution in the Mexican Pacific. Subsamples were obtained from the otolith nucleus and near the margin. We evaluated weather there is evidence of ontogenetic variability in elemental composition and if otolith elemental signatures can be used to discriminate between sardines from the Pacific and Gulf of California. Samples were collected between May 2004 and May 2005 at three locations in the Mexican Pacific and six locations in the central gulf. There were significant differences between the calcium-standardized elemental ratios in the otolith nuclei and margins for most elements, suggesting an ontogenetic effect. Discriminant function analysis was applied to the data obtained from the otolith margins. Samples from the Pacific had clearly distinguishable elemental signatures from those collected in the central gulf. Jackknife classification analysis indicated over 90% of sardines were correctly classified to either the Pacific or Gulf of California. Some of the samples collected in Magdalena Bay exhibited a distinct elemental signature, suggesting residence within the bay may impress a unique chemical fingerprint in the otoliths. Manganese was the most useful element for discriminating between the populations of the Pacific and Gulf of California. Mn/Ca was consistently and significantly higher in the gulf, which may be due to the hydrothermal activity known to occur within the system. The results indicate LA-ICPMS can used to evaluate whether there is migration among the Pacific, Gulf of California and Magdalena Bay.

Hobbs, James

James Hobbs[1]; Rebecca Quinones[2]; Brian Hodge[3]; Peter Allen[4]; Donald Portz[5]

Interdisciplinary Center for ICP-MS, UC Davis[1]; Wildlife, Fish and Conservation Biology, UC Davis[2]; School of Fisheries, Humboldt State University[3]; Department of Biological Sciences, University of Manitoba[4]; U.S. Bureau of Reclamation[5]

The Use of Strontium Isotopes 87Sr:86Sr to Manage Threatened, Endangered and Commercially Important Species in the Western US.

The development of high precision strontium isotope measurements with laser ablation multi-collector ICP-MS has provided fisheries managers a state of the art tool to address issues related to the conservation and effective management of threatened, endangered and commercially important fish species. At the UC Davis Interdisciplinary Center for ICP-MS, we have been utilizing LA-MC-ICPMS for high precision strontium isotopes 87Sr:86Sr to address key issues in the management of threatened, endangered and commercially important species in the western US. In the San Francisco Bay-Delta Estuary we have been conducting research regarding freshwater management effects on natal origins and migration history for threatened longfin smelt and endangered delta smelt. In the Klamath River system we have been addressing issues regarding freshwater management and climate change effect on natal tributary origins and estuarine residency for the Chinook salmon, coho salmon, steelhead trout and green sturgeon. In the Columbia River we have been addressing issues with the effects of management actions on fish passage and the effects on habitat use and fish health for the Chinook salmon and steelhead trout. In the lower Colorado River we have been reconstructing habitat use and spawning migrations to identify key restoration sites for the endangered razorback and flannelmouth Suckers. The application of strontium isotopes rations in fish otoliths and fin rays can provide vital information for the protection and management of important fish species and may provide a cost effective alternative to traditional tagging studies in fisheries management.

Iimura, Kurin

Kurin Iimura[1]; Young-Jin Kang[2]; Archana Kanteti[2]; Emily Mills[2]; Yasuaki Takagi[1]; Richard Kollmar[2]

Hokkaido University[1]; University of Illinois[2]

Atlas of Otolith Formation in the Zebrafish

The otoliths of ray-finned fishes and the orthologous otoconia of tetrapods are essential structures of the inner ear that convey linear accelerations to sensory hair cells. Their displacement or absence results in disequilibrium, such as in benign paroxysmal positional vertigo. Otoliths and otoconia are completely acellular biominerals that contain at least 95% CaCO3 by weight and up to two dozen proteins, most of which have not been identified. Both nucleate early during embryonic ear development; otoconia grow until hatching or birth, while otoliths continue to grow throughout life. In fishes, the three otoliths-the lapillus in the utricle, the sagitta in the saccule, and the asteriscus in the lagena-have elaborate and species-specific shapes, whereas otoconia are innumerable, small, and generally barrel-shaped. Most importantly, the formation of both otoliths and otoconia is likely to be governed by their constituent proteins. The zebrafish is an excellent animal model for studies of otolith formation because its ear is highly similar to that of other vertebrates, including humans, and because it easily lends itself to embryological and molecular-genetic laboratory studies. As a reference for future studies, we have established an atlas of otolith formation in the zebrafish. Otolith size and shape were recorded by light microscopy, scanning electron microscopy, and X-ray computed tomography, and calcium content was measured by inductively-coupled-plasma mass spectrometry. Our results show that the size of zebrafish otoliths correlates more closely with fish size than with age; that otoliths are the first structures to calcify during development and initially contain up to two-thirds of the body's calcium; and that the transition from the smooth spheroids in the embryo to the extravagant organ-specific shapes in the adult coincides with the elaboration of the labyrinth at around two weeks of age.

Jackson, Gary

Stephen J. Newman[1]; Ian W. Wright[1]; Ben M. Rome[1]; Michael C. Mackie[1]; Paul D. Lewis[1]; Rick C. Buckworth[2]; Aaron C. Ballagh[3]; Rod N. Garrett[4]; Jason Stapley[4]; Damien Broderick[4]; Jennifer R. Ovendon[4]; David J. Welch[5]

Western Australian Fisheries and Marine Research Laboratory[1]; Department of Regional Development, Department of Fisheries, Australia[2]; Fishing and Fisheries Research Centre, James Cook University, Australia[3];Queensland Department of Primary Industries and Fisheries[4]; James Cook University[5]

Stock Structure of Grey Mackerel (*Scomberomus semifasciatus*) Across Northern Australia, Based on Otolith Isotope Chemistry

Otolith isotope chemistry was used to study the stock structure of grey mackerel, *Scomberomorus semifasciatus*.Otoliths were collected from grey mackerel at ten locations representing much of their distributional and fisheries range across northern Australia from 2005 to 2007. Across this broad range of sampling areas, fish from four broad regions: Western Australia, Northern Territory/Gulf of Carpentaria, Queensland east coast mid/north and Queensland east coast south had stable isotope values that were sufficiently different to indicate stock separation. Otolith isotopes differed more between locations than among years within a location, indicating temporal stability across years. These results indicate that optimal fisheries management may require different management units than are currently present, and that it is appropriate to manage these populations independently in these areas. Furthermore, as the population of S. semifasciatus in Western Australia exhibited high spatial separation from those at all the other locations examined, further research activities should focus on investigating additional locations within Western Australia for the possibility of supplementary stock separation.

Jackson, Gary

Gary Jackson; Ross Marriott; Dave Fairclough

Western Australian Fisheries and Marine Research Laboratories

Recent Initiatives in Otolith-Based Ageing for Assessments of Demersal Indicator Species in the West Coast and Gascoyne Coast Bioregions of Western Australia

Demersal scalefish resources along Western Australia's (WA) extensive coastline are characterised by high species diversity and relatively low biomass. While detailed biological information is available for only a small proportion of fished species, most are either moderately (20-40 yr) or long-lived (> 40 yr), and therefore vulnerable to over-exploitation. Within WA's integrated fisheries management framework, the Department of Fisheries Research Division is responsible for determining sustainable catch levels for the key target species. An indicator species approach has been adopted for assessment and management of the suite of demersal species based on a comprehensive risk assessment framework. Three such indicator species are currently being monitored in the West Coast (*Glaucosoma hebraicum*, *Pagrus auratus*, *Choerodon rubescens*) and Gascoyne Coast bioregions (*P. auratus*, *Pristipomoides multidens*, *Lethrinus nebulosus*). All of the assessment methods used to determine sustainable levels of catch and monitor exploitation levels, from a simple catch curve approach to 'weight-of-evidence' and integrated modelling, are reliant upon accurate and consistent otolith-based fish ageing. Factors including scale (8,000-10,000 estimates of fish age required per year), staff-turnover, need to improve efficiency and budget constraints have necessitated implementation of new approaches to ensure quality control in fish ageing. The Research Division has shifted from use of more conventional approaches requiring agreement between multiple readers and multiple otolith readings, to a single reader/reference collection approach. Recent initiatives include the development/documentation of ageing protocols for all indicator species, staff training (both for new staff and for experienced staff undertaking re-familiarisation prior to production reading) with reference to digitised/annotated images of reference collection sections and routine measurement of bias and precision. Innovative approaches include flexibility in the selection of suitable target ranges for measures of ageing precision for different species with otoliths of differing optical properties and readability.

Jones, Cynthia

Cynthia Jones; Stacy Beharry

Old Dominion University

Estimating Mortality with Natural Tags

The past five years have seen burgeoning interest in the use of otolith natural tags to measure population structure and connectivity. This has proven to be a valuable tool for fish ecologists, but its greatest promise will be its use in estimating mortality and fitness through its entire life history. Otolith-chemistry tags can be very specific at surprisingly fine scale and can provide measures of the value of these habitats to subsequent survival. I will summarize and evaluate the value of natural tags on such spatial scales. Once such a natural tag is present, then the real challenges occur, as estimation of survival and movement can be very problematic because of their high potential for bias. I discuss the use of statistical techniques that provide valid estimates of survival and show a proof of concept in a case study of spotted seatrout on the U.S. East Coast.

Jones, Cynthia — Keynote Speaker

Cynthia Jones

Old Dominion University

Exploring the Value of Life-History Patterns Revealed by Otolith Ageing

The importance of using otoliths to determine properties of fish populations is thoroughly documented in the scientific literature. Arguably the most powerful use of otoliths is in determining rates such as birth, death, growth, and fecundity with an extensive literature dating 30 years demonstrating that otolith-thin sections can provide the most reliable age readings of all hard parts. Reliable age-based rates are particularly important to the ever-growing suite of age-structured models, particularly those that incorporate uncertainty in input data. However, beyond these sophisticated age-structured models, we should not overlook the role that otolith ages play in revealing age-specific life history events important to species' and families' ecology and evolution. The fact that otolith ages can be validated and that otolith thin sections can subsequently be used to provide reliable estimates of the oldest ages allows us to compare and contrast life-histories of fish families through the study of life-history invariants. Life-history invariants are used to evaluate the absolute and relative ratios of major life events, such as the relation between the age-at-first maturity compared to mean maximum life span. I present examples from our extensive study of Sciaenidae (the drums and croakers) to illustrate how different their life histories are from the Gadidae, which have formed the paradigm for fish life histories so far, and how these differences offer insights to their response to harvest and management. Compared to gadids, sciaenids mature much sooner, thus they have a much longer period spent in reproduction. Although this confers higher potential productivity, it can also be interpreted as an evolutionary response to environmental uncertainty. Approaching life histories in the context of "how an animal lives its life" not only allows us to contrast life-history patterns, but also increases our knowledge about the resilience and susceptibility of animals to harvest and other anthropogenic challenges.

Kastelle, Craig

Craig Kastelle[1]; Melissa Haltuch[2]; Daniel Kimura[1]; Owen Hamel[2]; Patrick McDonald[3]; Delsa Anderl[1]

Alaska Fisheries Science Center, National Marine Fisheries Service[1]; Northwest Fisheries Science Center, National Marine Fisheries Service[2]; Pacific States Marine Fisheries Commission[3]

How Bomb Radiocarbon Fish Age Validation is Affected by Differences Among Marine Radiocarbon Reference Chronologies

Bomb radiocarbon (C-14) is a widely used fish age validation method. The bomb radiocarbon method relies on C-14 reference chronologies developed from known-age otoliths. For samples used in fish age validation, birth years are estimated from otolith growth increments, and C-14 is measured in otolith cores. If the time series of bomb-produced C-14 in the reference chronology and the validation sample are synchronous, the estimated ages and methods used to generate these ages are considered accurate. Our goal was to consider the use of reference chronologies in cases where they are not available specifically for a region and/or the species being validated. We examine several established C-14 reference chronologies and review the differences among them, calling attention to patterns across geographic regions. In addition to a northern hemisphere atmospheric reference chronology, we considered three geographically different North Pacific marine reference chronologies: yelloweye rockfish (*Sebastes ruberrimus*), Pacific halibut (*Hippoglossus stenolepis*), and petrale sole (*Eopsetta jordani*). In the marine bomb-produced C-14 reference chronologies, rates of increase during the era of atmospheric testing and their peak values were geographically different. Although these differences can be explained by basic oceanographic processes or early life history dissimilarities, they highlighted the concerns when using a non-species- and non-region-specific reference chronology. Age validation studies of yellowfin sole (*Limanda aspera*), Pacific ocean perch (*S. alutus*), and Dover sole (*Microstomus pacificus*) from the Bering Sea and Gulf of Alaska that use these bomb C-14 reference chronologies were considered as examples. We concluded that in the North Pacific, care should be exercised when using these reference chronologies. When possible, chronologies should be regionally specific, and from fish with similar early life histories.

Kemp, Jodie

Jodie Kemp[1]; Stephen Swearer[2]; Simon Robertson[1]; Greg Jenkins[1]

Primary Industries Research Victoria Fisheries Branch, Australia[1]; The University of Melbourne, Victoria, Australia[2]

The Potential Use of Otolith Shape and Microchemistry to Distinguish Cod Species (Genus *Pseudophycis*) in the Diet of Australian Fur Seals

Otolith shape is often used to facilitate the identification of teleost prey species in marine diet studies. However, fine-scale variation in otolith shape among different species, and the added effect of partial digestion of otoliths, can often limit the ability to identify prey species. The objective of this research was to evaluate the potential use of 1) fine-scale shape differences using Fourier shape analysis and 2) microchemical differences using laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS), in digested otoliths to identify fish prey species within the diet of predators. Belonging to the family Moridae, red cod *Pseudophycis bachus* and bearded rock cod *Pseudophycis barbata* are found in the shelf waters of south-eastern Australia and New Zealand. *Pseudophycis* species are important to a range of predators including the Australian fur seal (*Arctcephalus pusillus doriferus*) at Phillip Island Australia. *Pseudophycis* species from within the foraging range of the Australian fur seal at Phillip Island were examined for evidence of species-specific differences in otolith shape and microchemistry, with the objective of using these differences to identify prey species using otoliths collected from seal faecal and regurgitate samples at the Phillip Island seal colony. The results revealed that the use of otolith shape analysis techniques to identify prey species where otoliths have fine-scale shape differences should be used with caution as the effects of digestive processes can be significant. The use of core-region otolith microchemistry as a method to distinguish prey species was found to be effective, and shows potential to provide a means to establish more direct links between predators and the geographical source of their prey.

Kennedy, Brian

Kennedy Brian ; Gayeski Nick

University of Idaho

Otolith Microchemistry to Resolve Alternate Chinook Salmon Life History Strategies in Cedar River (WA, USA)

Identifying how different juvenile rearing habitats confer a survival advantage is crucial for protecting threatened species, conserving critical habitat and understanding the adaptive basis for life history variation. Juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in the Cedar River basin (Seattle, WA, USA) are known to use either river habitats or Lake Washington as their primary pre-smolt rearing environment. However, the relative representation of either life history strategy in the annual smolt cohort is not known. More importantly, we have no means by which to relate the specific juvenile strategy employed with its representation in those adult Chinook salmon that have successfully returned. Knowledge of both pieces of information is important for assisting resource managers to determine how best to invest limited funding for habitat preservation and salmon conservation. Smolt trapping efforts are quantifying patterns of outmigration within this population and otolith microchemistry analysis of returning adults is being used to quantify how these patterns of outmigration strategies relate to the representation of returning adults. We evaluate the ability of otolith microchemistry to distinguish among juvenile rearing strategy. In 2006 and 2007 we evaluated isotopic ratios (87Sr/86Sr) and elemental ratios (Ba, Sr, K, Mg and Na referenced to Ca) in water samples from throughout the watershed using ICP-MS and thermal ionization mass spectrometry (TIMS). Only dissolved Sr:Ca ratios showed significant and consisted differences between potential lake and river rearing sites. Juvenile fish sampled in these riverine and lacustrine sites supported our ability to distinguish these sites with lake fish having consistently higher Sr:Ca ratios. In 2008, the first cohort of adult otoliths were prepared and analyzed with all cases providing an unambiguous classification as river- or lake-rearing using discriminant function analysis.

Kerr, Lisa A.

Lisa A. Kerr[1]; David H. Secor[2]; Steven X. Cadrin[3]

SMAST, University of Massachusetts Dartmouth[1]; University of Maryland Center for Environmental Science[2]; NOAA/UMass Cooperative Marine Education and Research Program[3]

Partial Migration of Fishes as Exemplified by the Estuarine-Dependent White Perch

Partial migration defines the phenomenon of coexisting groups exhibiting migratory and resident behavior within the same population. In avian ecology, partial migration is a fundamental behavior that underlies the evolution of migration in general. Among fish, the terminology and theory associated with partial migration has predominantly been used to describe salmon ecophenotypes. We contend that partial migration is more widespread among fishes than previously recognized, and has important implications for population dynamics and persistence. Here, we document partial migration for the estuarine-dependent white perch (Morone americana), in the Patuxent River estuary (Chesapeake Bay, Maryland) using otolith strontium:calcium profile analysis. We then examined the consequences of partial migration to population productivity (spawning stock biomass), stability (variance in spawning stock biomass), and resilience (years to rebuild the population) using an age-structured simulation model. Divergence in the life history tactic of white perch occurred during the juvenile period in response to individual physiological condition, with resident or migratory behavior generally persisting over the lifetime of the individual. The representation of resident and migratory fish appears to change due to interannual environmental variability. In simulation models, increased representation of migratory fish resulted in increased population productivity and resilience, whereas increased presence of residents contributed to stability. Partial migration appears to play a role in mediating white perch population dynamics by mitigating population responses to unfavorable environmental conditions, thus contributing to long-term persistence. Our results highlight the importance of conserving spatial structure within fish populations.

Kingsford, Mike

Mike Kingsford[1]; Benjamin Walther[2]; Malcolm McCulloch[3]

James Cook University[1]; Australian National University, University of Texas Marine Science Institute[2]; Australian National University[3]

Fish Otoliths and Coral Cores as Environmental Loggers of Pulsed Environmental Events

Otolith chemistry is often used as a natural tagging technique that relies on spatial variation in various elements and isotopes. However, temporal variability in some chemical markers can be substantial in response to fluctuations in ecologically important parameters such as temperature, salinity, and nutrient availability. Thus, temporal variability in geochemical signatures can potentially reveal important information about the frequency and intensity of pulsed environmental events and their ecological effects. We present results from an on-going project to monitor water chemistry and associated variability in Ba:Ca recorded in otoliths of a resident fishes, a pomacentrid and a lutjanid, as well as coral carbonate at inshore and offshore locations on the Great Barrier Reef. Inshore, strong pulses of freshwater correlated with increases in Ba:Ca in sea water and in turn with carbonate Ba:Ca ratios in some taxa. Ba:Ca ratios in carbonates, therefore, act as an effective proxy for natural and anthropogenic influences on near shore habitats. In addition, the effects of upwelling varied at fine spatial scales both within a reef and with depth. Offshore reefs were exposed to regular upwelling events. Deep waters (> 150 m) were richest in Ba:Ca and temporal depositional patterns in fishes and coral are described. Temporal and spatial variability in otolith Ba:Ca has the potential to reveal ecological responses of fish populations to high-frequency fluctuations in oceanographic parameters and provide spatially explicit records of environmental variation.

Kollmar, Richard

Young-Jin Kang; Amy Stevenson; Peter Yau; Richard Kollmar

University of Illinois

Sparc is an Otolith Protein and Required for Normal Mineralization

Otoliths and the homologous otoconia serve to detect linear accelerations in the inner ear. In contrast to teeth and bones, these biominerals contain calcium carbonate and are acellular. There is little overlap between their known constituent proteins and those of teeth and bones. Their morphogenesis, unlike the well-studied mechanisms of tooth and bone formation, is barely understood. As a novel approach to identify otolith proteins, we employed tandem mass spectrometry to analyze crude soluble extract from rainbow trout (*Oncorhynchus mykiss*) and channel catfish (*Ictalurus punctatus*) otoliths. One new constituent we found was soluble protein, acidic, rich in cysteine (Sparc, a.k.a. osteonectin or BM-40), which in bone comprises up to 23% of total protein and links collagen to calcium phosphate. We then investigated Sparc's role in the zebrafish (*Danio rerio*). Sparc expression increased shortly before otolith formation commences and was strong in the developing ear. The presence of Sparc protein in otoliths was confirmed by immunoblotting. Blocking Sparc expression with antisense oligonucleotides led to smaller, additional, or fused otoliths with a reduced mineral phase. Our results indicate a requirement for Sparc during otolith mineralization, possibly by linking the collagenous otolin protein to the mineral phase, and suggest mechanistic commonalities with tooth and bone formation, despite the structural differences.

Krusic-Golub, Kyne

Dianne Tracey[1]; Peter Horn[1]; Ian Doonan; Kyne Krusic-Golub[1]; Simon Robertson[2]

National Institute of Water & Atmosphere NIWA[1];Fish Ageing Services Pty Ltd; Fish Ageing Services Pty Ltd[2]

Why Problems With Orange Roughy Ageing Precision Just Wont Go Away! An Inter-Agency Ageing Workshop and Protocol Testing

Orange roughy productivity, in particular recruitment variabilty, is poorly known, but knowledge of recruitment variability is becoming increasingly important for stock assessment and fishery management in New Zealand. Recruitment patterns are usually estimated from age frequency distributions, but previous orange roughy ageing studies have had poor precision and, consequently, relative year class strengths are obscured. More importantly, a potential bias or "drift" was noted in the most recent estimated ages of orange roughy in the region, which led to low confidence in the age frequency data, and resulted in age data being excluded from use in stock assessments since 2006. A workshop attended by scientists from 4 agencies was held in February 2007 to review orange roughy ageing, examine the consistency of ageing methodology between laboratories, determine best practice, improve the ageing precision, and establish if the data could be of use in stock assessments. Comparisons were made between otolith reading protocols, focusing on aspects which may have lead to differences in zone counts from the same otolith. The determination of the transition zone (TZ), believed to be associated with the switch from somatic growth to gamete production, was found to be a particular source of potential bias. A revised protocol was agreed to during the workshop, and a cross-ageing study followed to test the new protocols, and determine if accuracy and precision between and within readers and institutions was improved. Two readers from NIWA and two from CAF aged about 400 orange roughy otoliths (sister otoliths from 200 fish) from the largest stock on the Chatham Rise, covering the size range of orange roughy in this area. The new protocol solved some inter-institute problems, but it was found that there was still some relative reader bias, ageing imprecision remained relatively high compared to other species, and identification of a TZ or not influenced the estimated age of the fish, by up to 30%. Nevertheless, as a result of this research, the New Zealand Ministry of Fisheries is now looking at using the age data again in stock assessments.

Kuroki, Mari

Mari Kuroki

The University of Tokyo, Present Affiliation: University of Washington

Variation of Otolith Microstructure and Microchemistry Among Nine Species of Anguillid Glass Eels in Relation to Their Migratory Patterns

The variation of otolith microstructure and microchemistry among nine species of anguillid glass eels from various parts of the world was examined. The otolith increment widths of tropical eels were typically wider than those of temperate eels, which may be related to differences in the larval growth rates of each species and the environmental water temperatures in different regions. The values and the ages of otolith peaks corresponding to the onset of metamorphosis were significantly different among the nine species. No sharp increase in otolith increment widths or rapid growth zone was observed in glass eels collected in Iceland, as has been shown in other tropical and temperate eels. However, a Sr:Ca ratio decrease synchronized with metamorphosis was observed in all species examined. The mean duration of the larval period varied widely among species (108-194 d in four tropical species, and 203-351 d in five temperate species), and tropical eels generally metamorphosed and recruited much younger compared to temperate eels that live at higher latitudes. The mean age at metamorphosis and recruitment determined for sympatric glass eels of the European eel and hybrids of European and American eels that recruited to Iceland were not different, and these ages were generally intermediate between American eels in North America and European eels in Europe and North Africa. These species specific early history schedules related to their migratory patterns support the hypothesis that the timing of metamorphosis is a key factor for determining the place of recruitment of glass eels and for maintaining the geographic separation of anguillid eels.

Larsen, Kim

Kim Larsen[1]; Eric Beamer[2]; Karl Stenberg[1]; Lisa Wetzel[1]

USGS, Western Fisheries Research Center, Washington[1]; Skagit River System Cooperative, LaConner, Washington[2]

Otolith Microstructure Analysis Reveals Proportions of Life History Types for Ocean-Type Chinook Salmon of the Skagit River, WA

Ocean-type juvenile Chinook salmon utilize a number of habitats during smolt migration. One important habitat is the estuary, particularly tidal deltas, which provide a migratory corridor, protection from predators, and opportunity to forage, grow and develop osmoregulatory capacity. Puget Sound Chinook salmon populations have declined to precariously low levels (ESA threatened status) due to a variety of perturbations, including estuarine and coastal development. The Skagit River, which contains the largest tidal delta in Puget Sound, has lost ~80% of its historic tidal delta habitat. Data from tribal and other management stakeholders indicate density-dependent use of the delta, presumably as a result of these historic habitat losses. Our research has focused on the use of otoliths to determine residence times, growth rates, and the importance of estuarine utilization to juvenile Chinook salmon. This analysis has been a valuable tool for distinguishing between juvenile life history types that do or do not rear in the delta. We found that during low density outmigration years, the most common life history type used the delta for extended rearing and growth, which enhanced subsequent growth in other nearshore habitats. By contrast, during years of high density outmigration, delta residence time was shortened and there was an increase in the occurrence of outmigrants bypassing the delta. More recent efforts have focused on determining the proportional survival of each life history type in the returning adults. All of the juvenile life history types have been documented in surviving Skagit River adults. However, depending on outmigrant population size, not all types appear to contribute equally to adult survival.

Larsen, Kim

Kim Larsen[1]; Angie Lind-Null[1]; Christopher Ellings[2]; Sayre Hodgson[2]

USGS, Western Fisheries Research Center, Seattle, WA[1];Nisqually Indian Tribe, Olympia, WA[2]

The Use of Otolith Microstructure to Examine Estuarine Utilization and Life History Diversity in Natural and Hatchery Reared Fall Chinook Salmon of the Nisqually River, WA

The Nisqually Fall Chinook salmon population is one of 27 stocks in the Puget Sound evolutionary significant unit (ESU) listed as threatened under the Endangered Species Act (ESA). Preservation and extensive restoration of the Nisqually delta ecosystem is currently taking place to assist in recovery of the stock as juvenile Fall Chinook salmon are dependent upon the estuary. Furthermore, a Chinook salmon recovery priority of the Nisqually Tribe is to develop a self-sustaining, naturally spawning population. Currently, this population consists of offspring from both hatchery and natural spawners. A pre-restoration baseline that includes characterization of life history types, estuary residence times, growth rates, and habitat use is needed to evaluate the potential response of hatchery and natural origin Chinook salmon to restoration efforts and to determine restoration success. Otolith analysis was selected as a means to examine Chinook salmon life history, growth, and residence in the Nisqually Estuary. We will report on differential usage of the estuary by natural and hatchery reared juvenile Chinook salmon and their expression of life history diversity during mid-recovery of the population.

Lewis, Anna

Anna Lewis[1]; Audrey Darnaude[2]; Ewan Hunter[3]; Clive Trueman[4]

University of Southampton/CEFAS[1]; University of Montpellier II[2]; Centre for the Environment, Fisheries and Aquaculture Science (CEFAS)[3]; University of Southampton[4]

Development and Validation of Otolith Microchemistry Techniques in Support of the Retrospective Geolocation of Fully Marine Fishes

Otolith microchemistry is well-established as a tool for studying the movements of diadromous or estuarine fish, but is less frequently applied to fully marine species. This is partly because in the open ocean, fish rarely encounter temporally-stable, extreme physical-chemical shifts, and partly due to a limited understanding of the precise relationship between otolith chemistry and ambient conditions. Validation studies are crucial if we are to determine fish geolocation from otolith chemistry with any certainty, but these are notably lacking in situ. The relationship between environmental conditions and otolith microchemistry (trace elements and stable isotopes) was investigated in free-swimming plaice (Pleuronectes platessa L.) in the North Sea; their position determined through electronic data storage tags (DSTs). DSTs continuously record ambient conditions (temperature and depth) for periods of up to two repeat migration seasons, which, when coupled with advanced telemetry techniques provide an independent measure of location and therefore provide a platform for in situ validation of otolith microchemistry in a wholly marine species. Here we have integrated time series geochemical data with thermohaline models to produce GIS-based predictions of physical-chemical conditions in the North Sea. Correlations between environmental variables and observed trends in otolith microchemistry were used to assess whether predictive maps can retrospectively position fish in the North Sea based on the chemical signature of their otoliths.

Limburg, Karin

Karin Limburg

SUNY College of Environmental Science and Forestry

Apples and Oranges, Selenium and Barium: What Can be Learned about Otolith Chemistry from Comparing Different Analytical Techniques

Analysis of otolith chemistry has become an important method to determine a number of important characteristics of fishes, from provenance to migration patterns, to life history and physiology. In order to make correct inferences, one must understand the strengths and limitations of whatever analytical method one undertakes. Here I review several methods: non-destructive (EPMA, PIXE, and synchrotron-based XRF) and destructive (ICP-MS), pointing out their pros and cons, and call for a workshop or other mechanism to develop guidelines for preferred methodologies.

Limburg, Karin

Karin Limburg[1]; Darren Dale[2]; Hans HÃ¸ie[3]; Carina Olson[4]; Yvonne Walther[5]

SUNY College of Environmental Science and Forestry[1]; Cornell High Energy Synchrotron Source, Cornell University[2]; University of Bergen, Norway[3]; Dept. of Archaeology, Stockholm University, Sweden[4]; Swedish Fisheries Board, Karlskrona, Sweden[5]

Modern and Neolithic Baltic Sea Cod Otolith Chemistry: Potential to Track Juvenile Habitat Use and Other Life History Parameters

Baltic Sea cod *Gadus morhua* have been exploited since the Stone Age. Ajvide, a site on the island of Gotland rich in archaeological remains, yielded numerous Neolithic (ca. 4500 YBP) otolith. We used synchrotron-based X-ray fluorometry to map elemental concentrations in several of these otoliths as well as in modern Baltic Sea cod. As an out-group, we performed the same analysis on several otoliths of Norwegian cod whose rearing histories were known. In modern Baltic cod, strong seasonal patterns in Sr and Mn were observed, and were generally asynchronous. Mn appeared to peak during summer growth, following redox dynamics, and Sr peaks were observed in winter. Mn is highest, and Sr lowest, in the first 1-3 years of life, typically reversing thereafter. The signature is also seen in Neolithic otoliths, although diagenetic effects on Mn are evident. We interpret the high Mn/low Sr as an inshore signature, representing rearing in nursery areas. The switch to low Mn/high Sr appears to be a directed migration into deeper, offshore waters. Norwegian cod show different patterns; strikingly, Br is incorporated along certain growth axes of the Norwegian otoliths, suggesting a genetic component to the incorporation of this element. We discuss the potential for using these and other markers to identify nursery areas and life history events such as migration to adult habitats.

Linkowski, Tomasz B.

Tomasz B. Linkowski; Zofia E. Bystydzienska

Sea Fisheries Institute in Gdynia, Poland, Gdynia 81-332, ul. Kollataja 1

Otolith Microstructure in Lanternfishes (Myctophidae): a Revision of the Existing Nomenclature

Myctophids have evolved unique otolith microstructure among the all teleost species studied so far due to changes in vertical distribution and migratory patterns during early live history. A complex terminology was proposed by various authors to describe these features and the following terms have predominantly been used to describe zonal structure of sectioned myctophid otoliths in the recent literature: larval zone(LZ), post-larval zone(PLZ) and post-metamorphic zone(PMZ). Direct attribution of these terms to ontogenetic stages is misleading for several reasons. There are three major otolith microstructure patterns in the family Myctophidae but only one of them exhibits all three zones. Differentiation of the otolith microstructure appears primarily due to changes in vertical distribution and migration patterns rather than to ontogenetic traits. Moreover, the existing names of the zones contradict each other. For example, LZ does not cover the whole duration of the larval stage, at least in the majority of myctophid species, and PLZ is deposited during the period when larvae inhabit the lower mesopelagial with a non-migratory behavior of metamorphosing larvae as well as early juveniles. These inconsistencies of the present nomenclature are described and explained on the basis of numerous LM and SEM otolith images and results of enumeration and measurements of increment width in consecutive zones. These results are supported by recently published information on the vertical distribution and ontogenetic migrations of myctophid early life history stages. The three major types of myctophid otolith microstructure are suggested: type A; characterized by two sequences of growth increments in *Diaphus* spp. and *Notolychnus valdiviae*; type B with the aforementioned three zones, renamed into central, middle and external zone, observed in a vast majority of myctophid species and genera; and type C, characterized by a clustered pattern of accessory primordial found in some species without a conspicuous definition of central zone, observed in Gymnoscopelini tribe only.

Lochet, Aude

Aude Lochet[1]; Karin Limburg[1]; Dale Chess[2]

SUNY College of Environmental Science and Forestry[1];Cornell University[2]

Effects of Mercury on Selenium Incorporation into Fish Otoliths

Mercury and selenium interactions have been investigated for several decades, since the discovery of the protective effects of selenium against mercury toxicity. In fish, such interactions have been under study in organs like muscle, liver or kidney, but never in otoliths. However, selenium can be found in high quantity in otoliths of fish from areas highly contaminated in mercury, including Onondaga Lake (Syracuse, NY). The objective of the present study is to test the effects of mercury on selenium incorporation in fish otoliths. Simultaneously, the relationships between selenium uptake in otolith and in muscle are investigated. To do so, a lab experiment was designed: brown bullhead (*Ameirus nebulosus*) were kept in tanks at different levels (low, medium, high concentrations) of mercury and selenium during 25 days. A relatively rare isotope (Se78) was used for selenium enrichment in the experimental tanks. X-ray fluorescence spectrometry was used to analyze the concentrations of selenium incorporated in the otoliths during the lab experiment. Se uptake in muscle was measured using solution-based ICPMS, after muscle digestion. We discuss the uptake of selenium by the fish, either from the water and/or from its interaction with mercury and thus, we discuss the potential use of selenium as a marker of fish migration.

Loewen, Tracey N.

Tracey N. Loewen[1]; John A. Babaluk[2]; Neil J. Mochnacz[2]; James D. Reist[2]; Norman M. Halden[1]

Department of Geological Sciences, University of Manitoba, Canada[1]; Freshwater Institute, Fisheries and Oceans, Manitoba, Canada[2]

Characterizing Otolith Element and Geochemical Signatures: Descrimination of Dolly Varden (*Salvelinus malma*) Populations From the Yukon Territory North Slope and Northwest Territories, Canada

Dolly Varden (*Salvelinus malma*) that inhabit western Canadian Arctic waters are thought to be highly dependent upon thermal and non-thermal springs for critical spawning, rearing and over-wintering habitat. Evidence suggests that rivers fed by these springs have different geochemical and isotopic compositions. Trace element composition of otoliths from Dolly Varden utilising these critical habitats particularly for spawning and rearing should reflect distinct variation between thermal and non-thermal springs as well as variations in the geological character of the surrounding environment. We used laser ablation-inductively coupled-mass spectrometry (LA-ICP-MS) and secondary ion mass spectrometry (SIMS), to assess otolith micro-chemistry and isotopes in an attempt to discriminate between populations of Dolly Varden from six river systems in the Yukon Territory North Slope and Northwest Territories: Gayna River, Blackstone River, Rat River (tributary: Little Fish Creek), Big Fish River (Cache Creek), Babbage River (Fish Hole Creek), and the Firth River (Joe Creek). Sagittal otoliths will be analysed for a suite of 17 elements by LA-ICP-MS: lithium, beryllium, boron, nickel, copper, zinc, strontium, barium, sodium, magnesium, aluminum, silicon, phosphorous, sulphur, potassium, maganese, and iron. SIMS will be utilised to analyse otolith isotopes: oxygen/oxygen, hydrogen, carbon, and strontium/strontium in otoliths. For comparison to otolith elemental and isotopic analyses, water samples from study streams were analyzed for the same trace elements and isotopes. Independent multivariate analyses for otolith element and isotopes and geochemical signals will be used to discriminate between fish populations/river systems. Differentiation of Dolly Varden populations will provide further evidence of philopatry or dispersal and ultimately aid in determining origin of fish captured in mixed-stock coastal fisheries.

Lombarte, Antoni

Antoni Lombarte[1]; Miquel Palmer[2]; Jesús Matallanas[3]; Jesús Gómez-Zurita[4]; Beatriz Morales-Nin[2]

Institut de Ciencies del Mar-CSIC, Barcelona, Catalonia[1]; Institut Mediterrani d'Estudis Avançats (CSIC-UIB), Esporles, Illes Balears[2]; Universitat Autonoma de Barcelona, Bellaterra, Catalonia[3]; Universidad de Murcia, Murcia, Spain[4]

Ecomorphologic Comparisons of Otolith Sagittae on Nototheniidae

A quantitative ecomorphological study was carried out in the sagitta otoliths of Antarctic and Subantarctic nototheniids, a particularly interesting family because of its fast adaptive radiation into different life strategies. We analysed the otolith shape and size of 18 nototheniid species (the main Teleostean family in Southern waters) with the aim of testing the relationship between phylogeny, otolith characters and trophic niche. Size (weight) and shape, (biometric warp analysis based in homologous and pseudo-homologous landmarks) measurements were compared with phylogenic, habitat dwelling and food composition analyses. The results of the multivariant analysis of these factors indicates a weak relationship between otolith shape in nototheniids and phylogeny, instead there is a clear correspondence between relative otolith size and shape with their trophic niche. The most benthic feeding members of the family had larger saggitae in relation of the body size; instead pelagic species have smaller and rounder shape than benthic species. The rounded shape of pelagic species, such as *Pleuragrama antracticum*, is considered as a paedomorphic characteristic as many young nototheniids have rounded sagittae that become elongated as they grow.

The present results indicate that the relative size of the sagittae would appear to have an important functional significance. Consequently, in ecomorphological studies of the otolithic end organs, sagitta size is a suitable morphological trend to be analyzed.

Lombarte, Antoni

Antoni Lombarte[1]; Óscar Chic[1]; Amália Manjabacas[1]; Roger Olivella[1]; Vicenc Parisi-Baradad[2]; Jaume Piera[3]; Emilio García-Ladona[1]

Institut de Ciencies del Mar-CSIC, Barcelona, Catalonia[1];Universitat Politicnica de Catalunya, Catalonia[2]; Unitat de Tecnologia Marina-CSIC, Barcelona, Catalonia[3]

Six Years of the Interactive AFORO (Otolith Shape Analysis) Database Website (2003/2009)

AFORO (http://aforo.cmima.csic.es) is an interactive system for shape analysis of fish otoliths. It is a classification tool based on the unique characteristics of the otolith shape of different species. The system includes a database of images, complete morphometric information, Fourier, Wavelet analysis and Curvature Scale Space representation of the otolith contours of well identified samples. It was created in 2003, and since 2006 it has incorporated a search tool for automatic taxon identification of fishes. The system allows users to classify their own sample interactively by simply uploading an unknown otolith image as a query instead of as alphanumeric information. The user can obtain the classification output either by e-mail or at the web page, where an image is plotted showing the nine most similar otoliths in the database in order of greatest contour similarity. AFORO is currently changing its structure to become a data provider in the GBIF (Global Biodiversity Information) facility, a global network of interconnected biodiversity databases, and will now include geographical information of the otolith samples. The website and database are continually developing. New otolith images, with their corresponding shape analysis and classification system, are added each month. Since 2004 the otoliths in the database have increased in number of specimens uploaded (from 908 to 2510 images), in biodiversity representation (from 182 to 790 species, from 71 to 157 families, from 19 to 32 orders) and geographical extension. In 2004 there were basically only specimens from the Mediterranean and Antarctic seas. Currently, the otolith database also includes specimens from the central and north Atlantic, north-east Pacific and south-west Pacific. In 2008 AFORO was consulted by 4195 visitors from 105 countries, with a mean of nearly 9 pages per visit. AFORO can be considered an international otolith node.

Longmore, Craig

Craig Longmore[1]; Fogarty Kate[2] ; Neat Francis[3]; Brophy Deirdre[4]; Trueman Clive[5] ; Mariani Stefano[2]

University College Dublin, Ireland.[1]; UCD School of Biology & Environmental Science, University College Dublin, Ireland[2]; FRS Marine Laboratory, PO Box 101, 375 Victoria Road, Aberdeen, AB11 9DB[3]; Galway Institute of Technology, Dublin Road, Galway, Ireland[4]; National Oceanography Centre, European Way, Southampton SO14 3ZH, England[5]

A Comparison of Otolith Microchemistry and Otolith Shape Analysis in Unravelling Spatio-Temporal Connectivity in a Deep-Sea Teleost, *Coryphaenoides rupestris*

The Roundnose Grenadier *Coryphaenoides rupestris* (Pisces: Macrouridae), is a benthopelagic deep-sea species that is increasingly being targeted by commercial fisheries on both sides of the North Atlantic. Despite a number of studies documenting basic aspects of its biology and ecology, there remains a lack of knowledge on its stock structure, which is mainly based upon limited bio-geographical information and hydrological hypotheses. Otolith Microchemistry and Otolith shape analysis are fundamental tools in fish stock identification. Otolith microchemistry relies on the assumption that the microchemical composition of the otolith accurately reflects the chemical characteristics of the water inhabited by an individual at a given point in its development. The variation in shape of otoliths, which is the result of subtle interplays between intrinsic and extrinsic factors, can also be employed as a useful descriptor in identifying stocks. The relative efficiency of these methods in unravelling stock structure in deep-sea species is very poorly understood. Samples were obtained from the Skagerrak slope, the Rockall trough, the Irish Slope near Porcupine bank and the Mid-Atlantic-Ridge in the Azores, and microchemistry and shape analysis conducted on the same specimens. Preliminary analysis of otolith microchemistry suggests a greater intrapopulation variability in Rockall and strong similarities between the Irish Slope and the Azorean Mid-Atlantic Ridge. Shape analysis grouped Rockall and Skagerrak separately from the Irish slope/Mid-Atlantic-Ridge group. Despite the environmental homogeneity of the deep-sea habitat, both methods provided informative and reasonably consistent signals.

Lou, Dong C.

Dong C. Lou

School of Marine and Tropical Biology,
James Cook University, Australia

The Effect of Otolith Sectioning Position on Precision of Tropical Fish Age Estimation

Fish age determination is an important and routine procedure used in fisheries research to provide information for fisheries assessment and management. While there is a great degree of importance placed on the outcomes of age determination and large amounts of time and resources invested in this procedure, the outcomes can be undermined by error. Identifying the source of error and improving the reliability of age estimates is of key importance to those agencies dependent on precise and accurate ages. Fish otolith thin section is the key source of age determination in tropical fishes. The procedure of thin sections including otolith embedding, cutting and mounting is time consuming,where variation can occur in every stage. The variations in otolith processing can be reflected by errors in the precision and accuracy of age counts. This study has been designed to compare age estimates from a series of otolith sections from pro-nuclear to post-nuclear position in the same otolith to examine fish ageing error caused by errors during the otolith sectioning procedure. Fish otoliths were collected from various tropical fishes ranging from pelagic to demersal species in the Great Barrier Reef of Australia. Thin otolith sections were produced using a high precision saw and analysed with an image analysis system. The ageing errors were assessed from fish samples with a wide range of ages to investigate the impacts of variation in sectioning positions. This study provides useful information on the importance of otolith sectioning position, and thus improve the precision of tropical fish ageing.

MacLellan, Shayne

Shayne MacLellan; Darlene Gillespie

Fisheries and Oceans Canada

Cross-Dating: a Potential Tool for Assessing the Quality of Production Age Data Created From Rockfish Otoliths

Measuring the quality of age data produced by production methods has been problematic. Cross-dating, a dendrochronology technique, presents a tool that has the potential to improve precision and accuracy for large portions of any age data set where a master chronology can be applied. The Sclerochronology Lab has been successful in demonstrating this for Pacific geoduck clams (*Panopea abrupta*) and the results from rockfish otoliths are promising. The signature years (wide or narrow annual growth) from a master chronology produced for yelloweye rockfish (*Sebastes ruberrimus*) at Triangle, B.C., were found to be synchronous on otoliths across years and throughout the age range. Although not identifiable on all otoliths, signature years were present on enough samples to enhance age data quality and identify biases. There is, however, a trade-off involved as productivity is reduced.

Marohn, Lasse

Lasse Marohn[1]; Karsten Zumholz[1]; Enno Prigge[1]; Volker Hilge[2]; Andreas Klugel[3]; Reinhold Hanel[2]

Leibniz Institute of Marine Sciences, IFM-GEOMAR, Kiel, Germany[1]; Johann Heinrich von Thunen Institute, Institute of Fishery Ecology, Hamburg, Germany[2]; University of Bremen, Geosciences, Bremen, Germany[3]

Effects of Diet and Water Temperature on the Multi-Element Composition of European Eel (*Anguilla anguilla*) Otoliths

Otolith microchemistry is widely used as a tool to track individual migration pathways of diadromous fish under the assumption that the elemental composition of fish otoliths is directly influenced by the physicochemical properties of the surrounding water. Nevertheless, several endogenous factors are reported to affect element incorporation into fish otoliths and might lead to misinterpretations of individual life history studies. In two studies we experimentally examined the influence of diet and temperature on the microchemical composition of European eel (*Anguilla anguilla*) otoliths using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). In a first experimental set-up eight different diets, including seven natural prey types and one artificial diet, were fed during eight weeks in freshwater circuits. Results show for the first time that food has no significant influence on the incorporation of Na, Sr, Ba, Mg, Mn, Cu and Y into European eel otoliths. A second experiment was conducted to test the effect of water temperature on the element composition of *A. anguilla* otoliths. Therefore *A. anguilla* elvers were kept in freshwater at three different temperatures (14 degrees C, 19 degrees C and 24 degrees C) for 14 weeks. Multi-element otolith analyses revealed a significant temperature effect on the incorporation of several elements, including Sr, Na, Mg, Mn and Ba. Our results indicate that the influence of surrounding water temperatures might affect *A. anguilla* life history studies based on otolith element composition and could be responsible for still unexplained fluctuations of a variety of element concentrations in eel otoliths. As no diet effect could be found, we conclude that individual feeding behaviour will not lead to any misinterpretation of European eel migration studies.

Martin, Jean

Jean Martin[1]; Francoise Daverat[1]; Christophe Peycheren[2]; Thomas D. Als[3]; David Righton[4]

CEMAGREF[1]; CNRS UMR 5034[2]; DTU Aqua, National Institute of Aquatic Resources[3]; CEFAS[4]

Otolith Microchemistry Offers a New Insight on *A. anguilla* Panmixia Hypothesis and on the Transoceanic Migration Timing

The hypothesis that European eels constitute a single randomly mating population, the panmixia theory, is generally accepted. Yet, recent work suggested that the European eel population was genetically diverse, with discrete spawning populations. Our aim was to evaluate the panmixia theory with an otolith microchemistry approach. This work compared the elemental signature of the otolith core region of *A.anguilla* glass eels and leptocephali larvae collected in different sites to determine the extent to which larvae had shared the same environment. 180 specimens of *A.anguilla* glass eels (45 per site) were collected in four locations in Europe: SW Atlantic coast (France), Mediterranean lagoon (France), SW England and W coast of Sweden, from January to April 2008. Sixteen *A. anguilla* leptocephali, captured in the Sargasso Sea (Galathea 3 project) in April 2007 were also included in the analysis. The concentrations of fourteen isotopes were measured in the core region for each sample, using Femtosecond Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS). An annular ablation trajectory along the first feeding mark was applied on otoliths of glass eels and leptocephali, which permitted us to avoid the maternal influence (primordium) on the chemical signature. The results showed that the mean element ratios of 68Zn, 85Rb, 7Li, 25Mg, 24Mg, 138Ba, 57Fe of individual glass eel otoliths, varied between sites, but a multivariate analysis did not reveal any significant difference. Moreover, otolith elemental fingerprints of leptocephali differed significantly from glass eel otolith signature. The lack of discrimination of sites for the glass eel group supported the hypothesis of panmixia. However, the discrepancy between glass eels and leptocephali otolith fingerprints either suggested that leptocephali belonged to a different stock or alternatively that the otolith signature was not stable over years and that leptocephali collected in 2007 did not belong to the same cohort as the glass eels collected in 2008. This work opened the way for further investigation on the stability of the otolith fingerprint and on the timing of eel transoceanic migration.

Mateo, Ivan

Ivan Mateo[1]; Edward Durbin[2]; Richard Appeldoorn[3]; Aaron Adams[4]; Peter Swart[5]; Richard Kingsley[2]; Francis Juanes[6]

FAVS-University of Rhode Island[1]; GSO- University of Rhode Island[2]; Dept Marine Sciences University of Puerto Rico[3]; Mote Marine Lab[4]; RSMAS University of Miami[5];University Massachussetts Amherst[6]

Variation in Otolith Microchemistry Fingerprints of French Grunt (Haemulon flavolineatum) and Schoolmaster (*Lutjanus apodus*) in Nursery Habitats in Puerto Rico and St. Croix (USVI)

Juveniles of the economically important fish species French grunt (*Haemulon flavolineatum*) and schoolmaster (*Lutjanus apodus*) were captured in mangrove habitats and seagrass habitats in St. Croix and Puerto Rico in 2006 and 2007 to determine if fish from settlement and nursery areas can be discriminated from each other by otolith microchemical signatures. Concentrations of Rb, Co, Na, Mg, Ca, Mn, Mg, Sr, Ba, Pb, and Cu were determined in discrete regions of young-of-the-year fish otoliths representing the post-settlement period (30-60 days) using laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS). Oxygen (18O) and carbon stable isotopic ratios (13C) were also analyzed using isotope ratio mass spectrometry. Results of MANOVA for both years showed that elemental signatures for both species differed significantly ($P<0.001$) among the distinct mangrove and seagrass nurseries within Puerto Rico and St. Croix. In addition, univariate contrasts indicated that concentrations of six elements (Sr, Ba, Cu, Mg, Co, Na) and the two stable isotopes (18O and 13C) for both species within each year differed significantly among mangrove and seagrass nurseries within islands (ANOVA, $P<0.001$). Classification success for French grunt and schoolmaster nursery sites within St. Croix for 2006 and 2007 ranged from 87 to 92% and from 76 to 77%, respectively, whereas in Puerto Rico, classification success for French grunts and schoolmaster for the two years ranged from 80 to 84% and 84 to 87%, respectively. When stations were combined among habitats, classification success between mangrove and seagrass habitats in Puerto Rico for French grunt ranged from 84 to 91%, and for schoolmaster ranged from 94 to 99%. In St. Croix, classification success for French grunt was 95 to 96%, and for schoolmaster was 86 to 89%. The percentage of the French grunt subadults that were identified as having resided as juveniles in mangrove habitats was estimated to range between 40% and 70% for Salt River, St. Croix, and La Parguera, Puerto Rico, whereas for schoolmaster almost 100% of all fish resided in mangrove habitats in both islands.

Matta, Mary Elizabeth

Mary Elizabeth Matta[1]; Bryan A. Black[2]

Alaska Fisheries Science Center, NOAA Fisheries[1]; Hatfield Marine Science Center, Oregon Sate University[2]

Climate-Driven Synchrony in Otolith Growth-Increment Chronologies for Three Bering Sea Flatfish

Dendrochronology (tree-ring science) techniques were applied to the otoliths of three species of flatfish collected from the eastern Bering Sea: northern rock sole (*Lepidopsetta polyxystra*), yellowfin sole (*Limanda aspera*), and Alaska plaice (*Pleuronectes quadrituberculatus*). Within each species, otoliths were visually crossdated to ensure that the correct calendar year was assigned to each growth increment. Next, growth increment widths were measured in each otolith, crossdating was statistically verified using the program COFECHA, and chronologies were generated by averaging measurement time series after age-related growth declines had been removed. Final chronologies spanned 18 to 20 years and were significantly correlated with one another ($p < 0.001$). The high degree of synchrony between otolith growth chronologies corroborated age estimates obtained from counting growth increments. All three final chronologies strongly and positively related to bottom temperatures (e.g., $R2 = 0.81$ for yellowfin sole). Given the relationship between otolith size and body size, this study suggests that somatic growth is strongly influenced by environmental factors, either directly (metabolically) or indirectly (e.g., as a result of food availability), and occurs synchronously across species and broad spatial scales in the Bering Sea.

McCormick, Mark

Mark McCormick[1]; Mark Meekan[2]

James Cook University[1]; Australian Institute of Marine Science[2]

The Importance of Attitude: the Role of Behaviour in Influencing Survival at a Life History Transition

Personality traits can strongly influence fitness and survival and are theorized to be important mediators of life history trade-offs. This study explored the link between the mortality trade-offs associated with fast growth during the early life history and the behaviour of individuals during an important life history transition in a coral reef damselfish. Longitudinal sampling of a cohort of damselfish settling to a tropical reef at the end of their larval stage found that individuals with small otolith sizes at hatching, and low otolith growth were selectively removed from the local population over the first 24h after settlement, whilst there was no apparent selection for size or body condition at settlement. Selection against slow growth (initial larval growth and maximum growth), and small size at hatching and settlement, was accentuated over the first month after settlement. Detailed behavioural assessments of larvae settled onto habitat patches, and monitored for 24h, found that initial boldness aided survival whilst individuals that ventured larger distances from shelter suffered higher mortality. Correlations of growth with behavioural attributes were generally poor, however there was a weak correlation between boldness and maximum growth. A measure of flexibility in the maximum distance ventured trait among behavioural censuses was positively related to initial otolith growth. There was little consistency in behaviour over the first 24h, among assessments hours apart. The present study suggests that while fast early growth may lead to higher mortality later in life, and behavioural attributes influenced survival, there were poor relationships between previous growth and behaviour due to a strong selection pressure to learn novel behaviours rapidly after settlement. Evidence suggests that selection may promote behavioural flexibility at this ecological transition boundary.

McILwain, Jennifer L.

Jennifer L. McILwain; Brett M. Taylor

University of Guam Marine Laboratory, Mangilao, Guam

Marine Preserves Confer Little Benefit on a Fast-Growing, Heavily Targeted Parrotfish Species in the Western Pacific

A detailed demographic study was employed to test the assumption that Marine Preserves on Guam enable a build-up of older age classes for a common parrotfish, *Chlorurus sordidus*. Underwater visual census supplemented the demographic data providing valuable insights into the spatial composition of this and other parrotfish species on Guam and neighbouring islands. Otolith analysis confirmed earlier work from Australia that *C.sordidus* is short lived, with rapid initial growth, attaining a maximum age of 9 yrs. There were significant differences in the growth rates between sexes; males grew faster, and attained a larger maximum size compared with females. However sampling within Guam's Marine Preserves revealed an unexpected result. Despite being closed to fishing for nearly ten years, there was little or no significant build-up of older age classes within the Preserves. For either sex, there was no significant difference in the mean age or total length between areas open and closed to fishing. *Chlorurus sordidus* reached first maturity within the first 18 months of age. Mature active females reach their maximum reproductive potential within the first 3 years or >160 mm total length. Multivariate analysis of the census data indicated 'exposure' was the most influential variable in structuring parrotfish assemblages with a significant split between windward and leeward assemblages. Management regime had no apparent influence on assemblage structure with sites open and closed to fishing clustering together. Long-term catch and effort data revealed *C.sordidus* and other short-lived species have undergone little or no significant change in mean body size over 24 years despite a dramatic increase in fishing pressure. Conversely, parrotfish with greater longevities (t-max 10 yrs; e.g. *Scarus altipinnis, Cetoscarus bicolor*) suffered a significant decline in body size over the same time period. We suggest, fast-growing, short-lived species with higher population turnover such as *C.sordidus* are more resilient to heavy fishing pressure.

McMahon, Kelton

Kelton McMahon[1]; Marilyn Fogel[2]; Ivan Mateo[3]; Simon Thorrold[1]

Woods Hole Oceanographic Institution[1]; Carnegie Geophysical Laboratory[2]; University of Rhode Island[3]

Stable Carbon Isotope Analysis of Amino Acids in Otolith Protein: A New Tool for Tracking Fish Movement

Fish ecologists have used geochemical signatures in otoliths to address questions of habitat use, migration, and population connectivity for several decades. However, all studies to date have focused on the aragonitic inorganic fraction with little attention paid to the organic fraction that may constitute up to 5% of a representative fish otolith. We introduce a new application of compound specific-stable isotope analysis (CS-SIA) that uses d13C values of specific amino acids in otolith proteins to track fish movement through marine isoscapes. First we present results from a controlled feeding experiment examining patterns in stable carbon isotope fractionation (d13C) of individual amino acids from diet to consumer in a model fish species reared on isotopically distinct diets. We found that all essential amino acids (EAAs) showed no trophic fractionation between diet and consumer, representing direct isotopic routing of these amino acids from the diet. As such, the d13C values of EAAs, such as phenylalanine, represent the isotopic fingerprint of primary producers at the base of the food web. The fidelity with which EAAs reflect dietary sources makes CS-SIA a powerful tool for dietary reconstruction and tracking the movement of fishes between isotopically distinct food webs. To test the use of the approach we examined d13C values of otolith EAAs from fish collected along a mangrove-seagrass-coral reef continuum. We found that EAAs accurately recorded the d13C values at the base of the food web and served as unique residence tracers for fish moving between isotopically distinct habitats. This study introduces a valuable new tool for fish ecologists interested in using otolith chemistry to retrospectively assess diet and movement patterns of fishes.

Meekan, Mark

Mark Meekan[1]; Stephen Simpson[2]; Piers Bramhall[3]

Australian Institute of Marine Science[1]; University of Bristol[2] ; University of Edinburgh[3]

Rapid Climate-Driven Changes in the Demography of a Damselfish, *Stegastes obreptus*

Species ranges in many fishes extend over latitudinal scales that encompass substantial gradients in water temperatures. *Stegastes obreptus* occurs throughout the Indo-Pacific region, and its range extends from 30 degrees N in the Ryukyu Islands to 30 degrees S in Western Australia presenting a valuable opportunity to measure demographic responses of populations to water temperatures. We collected 1,344 individuals from 26 sites in Western Australia, from the tropical Dampier Archipelago (20 degrees S, annual mean SST=27 degrees C) and Ningaloo Reef, through the sub-tropical Abrolhos Islands to the temperate Rottnest Island (30 degrees S, mean SST=21 degrees C). Using fish length, sectioned otoliths (to measure age and back-calculate annual growth), and von Bertalanffy models, we derived growth parameters for each location. As expected, fish were larger in higher (colder) latitudes and growth was slower. Over the last 25 years all four locations experienced an increase in SST, with the higher latitude locations increasing 0.07-0.08 degrees C/yr. Water temperature in these locations is controlled by the mixing of the warm southward Leeuwin Current and the cold northward Capes Current, so is sensitive to climate-induced oceanographic change. In the sub-tropical Abrolhos Islands, where mean SST is greatest, there has been a significant increase in the early growth of fish (~0.4cm/yr, R2=0.73 for 2+ fish). This demonstrates plasticity in growth within a population, and indicates a rapid response in biomass production to a 1.6 degrees C increase in SST. If similar rapid responses occur in commercially targeted species, climate change will have important economic impacts on the value of fish stocks at a level more subtle than altered species distributions.

Mercier, Leny

Leny Mercier; Audrey M. Darnaude; David Mouillot

UMR 5119 ECOLAG, CNRS-UM2-IFREMER-IRD University Montpellier 2

Identification of Fish Origin Using Otolith Fingerprints: Classification Method Matters

Reliable assessment of fish origin is critical for exploited species since nursery areas must be identified and protected to maintain recruitment to the adult stock. During the last two decades, otolith chemical signatures (or "fingerprints") have been increasingly used as a tool to discriminate between coastal habitats. However, correct assessment of fish origin from otolith fingerprints depends on various environmental and methodological parameters, including the choice of the statistical method dedicated to fish assignment. Among all existing classification methods, Linear Discriminant Function Analysis (LDFA) is the most frequently used, although it requires data normality and homoscedasticity, which are rarely met by otolith chemical data. Other classification methods, both more powerful and less constrained, lack a comparative analysis in otolith microchemistry. Here we assess stock identification accuracy for 4 classification methods (LDFA, Quadratic Discriminant Analysis QDA, Random Forests RF and Artificial Neural Networks ANN), through the use of 3 contrasted datasets. In each case, all possible combinations of 1 to n chemical elements were tested to identify the minimal number of elements to be used for optimal accuracy in fish assignment to their actual origin. Our study shows that accuracy differs according to the model and the number of elements considered, with important differences (up to 26%) in the percentage of correct assignment reached. Among all models, RF and ANN perform best, especially for complex datasets (e.g. with numerous fish species and/or chemical elements involved). RF is less time consuming and more interpretable than ANN, and far more efficient and less demanding than LDFA. Therefore, we advise the use of this discriminant method for stock assessment and nursery identification based on otolith microchemistry.

Miller, Jessica

Jessica Miller[1]; Charles Simenstad[2]; Virgonia Butler[3]

Oregon State University[1]; University of Washington, Seattle, WA[2]; Portland State University, Portland, Oregon[3]

Reconstructing Juvenile Migratory History of Modern and Pre-Historic Columbia River Chinook Salmon (*Oncorhynchus tshawytscha*)

Chinook salmon (*Oncorhynchus tshawytscha*) displays a broad array of variation in numerous life history traits, including size- and age-at-ocean migration. The challenges are exacerbated in modified systems, such as the Columbia River in the western United States, where there is very little quantitative information on life history variation prior to extensive harvest, hatchery production, and the development of hydropower systems. Here, we reconstructed juvenile migratory history in Chinook salmon, specifically size-at-freshwater exit and brackish/ocean entrance, for a set of archaeological otolith samples from the upper Columbia River. In collaboration with the Confederated Tribes of the Colville Reservation, we acquired ten ~350-yr old Chinook salmon otoliths that had been recovered during excavation of an archaeological site. We obtained otoliths from modern populations of adult summer/fall and spring Chinook salmon in the upper Columbia River for comparative purposes. For archaeological and modern adult Chinook salmon, we used otolith structural and chemical analyses to reconstruct size-at-freshwater exit and brackish/ocean entrance, based on variation in Sr:Ca concentrations, and to explore potential source locations, based on 87Sr/86Sr. Additionally, we compared our size reconstructions with information on the size of modern juveniles from the mid-upper Columbia River stock: stock-of-origin was determined using a microsatellite DNA baseline. In general, the size-at-freshwater exit and freshwater residence time indicated by the archaeological samples appears to have been shorter than for modern, presumed wild, adult summer/fall or spring adult Chinook salmon. However, the size distribution of un-marked, modern summer/fall juveniles collected within the estuary is similar to the estimated sizes at freshwater exit for the archaeological samples. Overall, the evidence supports the contention that this archaeological site was comprised of primarily summer/fall run Chinook salmon and that, historically, juveniles migrated to the ocean at relatively small sizes.

Morat, Fabien

Fabien Morat; David Nerini; Yves Letourneur

Universite de la Mediterranee, Centre d'oceanologie de Marseille

Discrimination of NW Mediterranean populations of Two Fish Species (*Mullus barbatus* and *Solea solea*) by Otolith Shape Analyses

A study of otolith shape analysis was carried out on NW Mediterranean populations of two Teleosts fish species: a flatfish, i.e. the common sole *Solea solea*, and a "round" fish, i.e. the red mullet *Mullus barbatus*. Otolith shape analyses have been undertaken using elliptic Fourier analysis and otolith mean reconstruction, a new and powerful tool elaborated for such a purpose. The elliptic Fourier descriptors were characterised by several harmonics. The coefficients issued from Fourier harmonics were used for multivariate analyses (principal component analysis and canonical discriminant analysis) and for mean otolith outline reconstruction. For both species, multivariate analyses clearly demonstrated a significant discrimination between local populations, i.e. between each of the 8 sites for the red mullet and between the 5 sites for the common sole. The otolith mean reconstruction has highlighted shape differences between the different sites and different fish class-sizes. For the red mullet, areas of differential accretion were observed near the sulcus acusticus ending ("the notch") for fishes coming from different depths. Indeed fishes from shallow depths presented less marked notches than did deeper individuals. This accretion area and the width of the dorsal face varied according to size-class. Indeed, the large specimens presented wider rostrums and narrower dorsal faces. Juvenile common sole inhabit shallow depths whereas adults live deeper (70-100 m). For this species, a reduction of the dorso-ventral width and an increase of the antero-posterior length were observed with increasing fish size. For both species, otolith shape variations between local populations and between size-classes were discussed with respect to abiotic conditions (depth, anthropogenic perturbations, river runoff...) in different environments and as a function of variations in diet.

Mosegaard, Henrik

Lotte Worsoe Clausen; Dorte Bekkevold; Asbjorn Christensen; Peter Lewy; Henrik Mosegaard

Technical University of Denmark, National Institute of Aquatic Resources

Otolith Shape Development in Herring and its Application in Stock Assessment and Population Ecology

The origin and reproductive interactions of sympatric, spatially separated spawning components of Atlantic herring (*Clupea harengus*) have received long-standing interest. For stock assessment and management purposes, the herring populations in the North Sea and adjacent areas are split into seasonal spawning types (winter, spring and autumn). Each type is made up of one or several local stock components. Otolith shape analysis has been used to discriminate between populations for a variety of species and for herring this approach has had increasing success with development of imaging techniques and statistical methods. Environmental differences and geographical separation of populations give rise to variation in the shape of otoliths. These variations may suggest differences in the spawning area and environment of populations within a species. Both genetic and environmental influences have been reported as important in determining the shape of the otolith and that different genotypes induce important differences in otolith shape. Sagittal otoliths have certain morphological features that are laid down early in the ontogeny of the fish, and measurements of internal otolith shape in adult herring has proven a powerful tool for stock discrimination. To develop and validate otolith shape as a fast and robust stock identifier for all life stages of herring, knowledge of the ontogenetic development of otolith shape within all stock components is necessary. Image based data of outer and inner contours are analysed by different optimisation algorithms for best shape transformation from juvenile till spawning stage to separate individual variation from stock specific shape development. Different statistical approaches are explored for the two major objectives, stock assignment of individuals and estimation of stock proportions in mixed aggregations. Precision and accuracy in relation to parameterization of shape based assignment is analysed and discussed in relation to application.

Mosegaard, Henrik

Karin Hussy; Henrik Mosegaard

Technical University of Denmark

Using Otolith Microstructure to Infer Age of Adult Eastern Baltic Cod (*Gadus morhua* L.)

One of the longstanding problems with stock assessment of Baltic cod is the lack of validated age determinations. Since the visual contrasts within the otoliths of this stock is very low and annuli not easily discernible, confidence in ages from traditional expert readers is limited. The objective of this study was to develop a new ageing method based on increment patterns observed in transversal sections of the otoliths. These patterns are thought to originate from annual variations in temperature. Otoliths from fish < 40 cm were selected from the Baltic International Trawl Survey, first quarter of the years 2001 and 2004. Transversal sections of otoliths were ground to reveal narrow growth increments. The widths of these increments correspond to daily increments from fish with known otolith growth rates, and were therefore assumed to be daily increments. Their widths reveal a distinctive pattern: a series of zones with clearly distinguishable increments, with increasing/decreasing widths in a dome shaped pattern, interrupted by zones where no regular increment structure is visible. Increment width seems tightly coupled to the annual cycle in environmental temperature at a depth of 30-60 m, where cod predominantly reside. Between 135 and 200 increments occur within the different zones, with a non-significant trend towards lower increment numbers and widths with distance from the center of the otolith. Increment formation apparently ceases at temperatures below 5-6 degrees C, but growth during the cold months corresponds closely with estimated growth rates. The increment patterns observed seem to reflect annual cycles in environmental temperature and may thus be used to develop a promising fool for the determination of Baltic cod's true age. But proper validation of their annual periodicity is still needed.

Munro, Andrew

Andrew Munro[1]; Bronwyn Gillanders[2]

Alaska Department of Fish and Game[1]; University of Adelaide[2]

Reconstructing Environmental History and Movement of Fish Inhabiting Estuarine and Hypersaline Waters Using Multivariate Analyses

Knowledge of the environmental history and movement of fish is critical for the proper management and conservation of fish and fisheries. Reconstruction of the past environmental history of individual fish using natural otolith signatures has generally been limited to single element profiles or analysing the profiles of multiple elements independently. We investigated the potential of otolith chemistry for reconstructing the environmental history of seven species of fish in The Coorong, an estuary in South East Australia with salinites that range from brackish to hyper-saline. Samples of fish collected throughout the estuary were used in conjunction with water samples to develop otolith chemistry-salinity relationships for multiple elements including Mg, Mn, Sr, and Ba. We then used these relationships to reconstruct salinity profiles (with confidence intervals) of individual fish based upon multiple elements using Classification and Regression Tree (CART) analysis and Canonical Analysis of Principal coordinates (CAP). Examination of salinity profiles of individual fish revealed that some followed expected life-history patterns for their species, while others exhibited unexpected profiles. For example, some fish appeared to have spent their entire lives in hyper-saline waters (i.e salinity > 50), even though it is generally thought that they move between freshwater and marine waters. The ability to quantitatively reconstruct the past environmental histories of fish using multiple elements will allow for a better understanding of the variety of life-histories exhibited by a species and enable estimation of the proportion of each strategy (or contingent) present in a population. Mechanisms for differences in migratory patterns could then be investigated.

Murie, Debra

Debra Murie; Daryl Parkyn

University of Florida

Age and Growth of Greater Amberjack in the Gulf of Mexico, With Application of Finrays for Non-Lethal Aging of Tag-and-Released Fish

Greater amberjack (*Seriola dumerili*) in the Gulf of Mexico are considered to be overfished based on the most recent stock assessment, yet there continues to be a lack of age and growth information for the Gulf stock over most of its exploitation range. In cooperation with state and federal fisheries agencies in the southeastern U.S., a total of 1,838 greater amberjack ranging in size from 74 to 1829 mm fork length were collected during 1989 to 2008 and sagittae were extracted for aging. Ages and growth of greater amberjack were modelled and compared for major fisheries in the Gulf of Mexico, including charterboat, private recreational, headboat, and commercial. Overall, greater amberjack ranged in age from young-of-year to 15 years of age and were sexually dimorphic in size, with females >4 years larger at age than males. Comparatively, growth of greater amberjack was similar for private, charter, and headboat fisheries. The commercial hook-and-line fishery caught the largest individuals in a cohort for ages 1-4, reflected in a larger size at age in that fishery in conjunction with a greater minimum size regulation. In addition to sampling amberjack for otoliths, a subsample of amberjack in 2006-2008 had pectoral finrays removed for aging to develop both a quicker method of port-sampling these large fish, as well as a non-lethal aging method for this species for tag-and-release studies. Comparison of ages assigned using finrays versus otoliths indicated that finray aging was relatively precise (average percent error = 7.8%, Lin's correlation coefficient = 0.908) and, with further development for older fish, it could be used as an alternate method to age amberjack.

Neubauer, Philipp

Philipp Neubauer[1]; Jeffrey S. Shima[1]; Steve Swearer[2]

Victoria University of Wellington[1];University of Melbourne[2]

Statistical Considerations for Inference of Demographic Connectivity From Natal Otolith Microchemistry - Optimal Scaling and Improved Allocation.

Natal otoliths of fish have recently been advocated as potential tracers of natal origin of fish, allowing assignment of settlers and/or recruits to putative source locations. Given the importance of demographic connectivity in the marine environment, such a tool could be extremely valuable for disentangling present day dispersal in coastal marine metapopulations. The applicability of this technique to open coast settings has been sparsely tested, and results to date indicate scale dependency with respect to sampling effort and the geographical extent of the study. We assessed variability of natal otolith signatures of the Common Triplefin *Forsterygion lapillum* in various environments around Cook Strait in a hierarchical sampling design. Scaling relationships are modeled with respect to sampling effort and geography to maximize allocation success of unknown signatures using linear discriminant analysis and an improved variant thereof. We find that useful scales of variation in natal otolith chemistry differ from open coast to estuarine environments. The scaling relationships presented allow finding useful scales with respect to desired allocation success in a given environment or across different scales in a hierarchical design. These developments show that the applicability of this technique depends largely on the question being asked and the useful groupings that can be found with respect to this question.

Niklitschek, Edwin J.

Edwin J. Niklitschek[1]; David H. Secor[2]; Mario George-Nascimento[3]; J. Pamela Toledo[4]; Alejandra Lafon[4]

Universidad Austral de Chile, Centro Trapananda, Chile, and Programa Copas Sur-Austral[1]; University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory[2]; Universidad Catalica de la Santa-sima Concepcion, Chile.[3]; Universidad Austral de Chile, Centro Trapananda, Chile.[4]

Segregation of SE Pacific and SW Atlantic Blue Whiting Stocks: Evidence From Complementary Otolith and Parasite Natural Tags

Blue whiting (*Micromesistius australis*) support one of the largest industrial fisheries in South America. Two main spawning/nursery grounds are known: one in the SW Atlantic Ocean, south from the Falkland (Malvinas) Islands (53 degrees S); and other in the SE Pacific Ocean, south from the Taitao Peninsula (47 degrees S). Spawners from both grounds are believed to return to common feeding areas in the Scotia Sea. Although management of this resource has been conducted under the hypothesis of one single stock, differences in mean length from commercial catches and recent evidence from otolith microchemistry have challenged this hypothesis. In the present paper we measured d13C and d18C and Sr/Ca ratio in otolith cores corresponding to spawners from both grounds, and compared these to sea surface temperature and first year growth rate. We also analyzed and compared parasites composition between spawners caught at each ground, as a way to assess a possible segregation between feeding areas. We found significant differences in mean d13C and d18O ratios between otolith cores from the two spawning grounds; each isotope discriminated >90% of the samples, but together supported a 100% classification rate. Higher d18O and Sr/Ca ratios in the SW Atlantic samples agreed with lower mean temperature, higher d18O and higher salinity in sea water from this spawning/nursery region. Parasite species composition in adults also showed significant differences between grounds, indicating segregation in feeding grounds might exist as well. Our results do not support the single stock hypothesis, but rather provide evidence for at least two ecologically distinct sub-populations of blue whiting in South America.

Nishimoto, Mary

Mary Nishimoto[1]; Libe Washburn[2]; Robert Warner[3]; Milton Love[1]

Marine Science Institute[1]; Department of Geography[2]; Ecology Evolution and Marine Biology[3]

Otolith Elemental Signatures Reflect Residency in Coastal Water Masses

We examined variability in otolith chemistry of wild caught fish in relation to in situ temperature and salinity within the California Current System. Barium, magnesium, and iron from the most recent growth zone in otoliths differentiated pelagic juvenile shortbelly rockfish (*Sebastes jordani*) residing in water masses with distinct temperature and salinity properties from central and southern California spanning nearly 500 km of coastline. The 3-element signature also discriminated fish that resided in different water masses that were associated with mesoscale cyclonic eddy circulation in the Santa Barbara Channel. Variability in otolith chemistry reflected the spatial patterns of both horizontal gradients and vertical gradients in water mass properties related to circulation. Although we found that the concentrations of particular elements in otoliths were correlated to ambient temperature or salinity, we suggest that these parameters are more useful as an identifying signature of distinct water masses associated with unique otolith signatures rather than as factors directly affecting otolith chemistry. Other factors varying among the water masses or among the fish populations residing in the water masses may also affect otolith chemistry. We discuss how oceanographic phenomena associated with the 1997-1998 El Nino and the persistent, recirculating eddy in the Channel may have affected coastal ocean conditions and variation in otolith chemistry of fish in the study area.

Oxman, Dion

Dion Oxman[1]; Rachel Barnett-Johnson[2]; Michael Smith[3]; Allison Coffin[3]; Diane Miller3; Ron Josephson[1]; Arthur Popper[3]

Alaska Department of Fish and Game[1]; NOAA Fisheries, Santa Cruz[2]; University of Maryland[3]

The Effect of Vateritic Sagittae on Sound Reception, Otolith Morphology, and Inner Ear Sensory Epithelia in Chinook Salmon

The inner ear of teleost fishes contains three calcareous structures (otoliths) that are part of the organs for hearing and balance. The largest of these structures, the sagitta, is usually composed of calcium carbonate crystals in the form of aragonite, but the calcium carbonate also occurs less frequently in a clear crystallized form called vaterite. Recent reports indicate vateritic sagittae occur more frequently in captive populations than in their wild counterparts, but the functional impact of this polymorph has remained unknown. Using auditory brainstem response (ABR) techniques, we investigated the functional consequences of otolith crystal structure on hearing in captive juvenile Chinook salmon (*Oncorhynchus tshawytscha*) reared at the Coleman National Fish Hatchery in Battle Creek, CA. Of the 40 juveniles tested, 50% had normal (aragonitic) sagittae, 30% had vateritic sagittae, and 20% had one otolith of each crystal type. Measures of hearing using ABR indicated a significant loss of sensitivity (2.5-6.5 dB) occurred within the primary hearing range (100-300 Hz) among salmon that had at least one vateritic sagitta. Auditory thresholds were not significantly different in fish with one vs. two vaterite sagittae. Crystallized sagittae were significantly larger and less dense than their aragonite counterparts. Saccular epithelium shape, as defined by its length-to-width ratio, and hair bundle orientation patterns did not differ between saccules with different crystal types. There was, however, a propensity for the saccular epithelia from vateritic sagittae to have fewer sensory hair bundles. We conclude that significant hearing loss was associated with the occurrence of vateritic sagittae and suggest that hearing loss is caused by the lower density of the vaterite otoliths.

Panfili, Jacques

Jacques Panfili[1]; Audrey M. Darnaude[2]; Yu-Chia Lin[3]; Mikael Chevalley[1]; Yoshiyuki Iizuka[1]; Wann-Nian Tzeng[2]; Alain J. Crivelli[4]

IRD[1]; CNRS[2]; IFS-NTU[3];SBTV[4]

European Eel Movements During Continental Life in the Rhone River Delta (South of France): High Level of Sedentarity Revealed by Otolith Microchemistry

Migrations between estuarine and freshwater environments are still unclear in the European eel (*Anguilla anguilla*) due to the multiplicity of water bodies colonised by the species. Within the Rhone river delta, only one freshwater habitat, the Fumemorte canal, communicates with the brackish ecosystem connected to the sea, thus offering a good opportunity to test eel sedentary behaviour during its continental life. For this, 58 silver eels were captured between 1997 and 2007 in the lower part of the freshwater canal and otolith Sr:Ca ratios, widely recognised as a proxy of salinity history of fish, were used to reconstruct individual past migratory behaviour. Variations in Sr:Ca ratios were measured on sagittal sections, along a transect covering the whole continental life history, i.e. going from the nucleus transition mark (arrival in continental waters) to the posterior edge (capture). For technical comparison, 28 otoliths were analysed using LA-ICPMS, and 30 with EPMA. Mean Sr:Ca ratios on otolith edges were identical (t = -0.345, df = 56, p = 0.731) for LA-ICPMS (2.72 Â± 0.32 10-3) and EPMA (2.67 Â± 0.59 10-3), indicating that measurement accuracy and precision are reliable for both tools. For each transect, the first and the last Sr:Ca values were used as references for the Sr:Ca signatures in the brackish (mean 5.22 Â± 1.39 10-3) and the freshwater (mean 2.70 Â± 0.47 10-3) ecosystems respectively. Using these signatures, a linear discriminant analysis (LDA) was built to assign each Sr:Ca value of the transect to either the freshwater or the brackish ecosystem. Six distinct types of migratory behaviour were identified for the population of the freshwater canal: eels entered the canal either directly (67 %) or after one to two years in the lagoon (33 %), with a subsequent majority of freshwater residents (55 %), but also some occasional migrants (< 3 intrusions in the lagoon, 31 %) and a few regular migrants (> 2 intrusions in the lagoon, 14 %). These results stress the value of LDA for reconstruction of eel inter-habitat use during the continental life, which is fundamental for population management and conservation.

Panfili, Jacques

Jacques Panfili[1]; Audrey M. Darnaude[2]; Laurent Vigliola[1]; Amandine Jacquart[1]; Sylvain Gilles[1]

IRD[1]; CNRS[2]

Test of the Relationship Between Otolith Sr:Ca and Salinity Using a Euryhaline Species Submitted to a High Salinity Gradient

Fish otolith Sr:Ca ratio has been widely recognised as a proxy of water salinity. To investigate further the relationship between these two variables, the euryhaline tropical species *Sarotherodon melanotheron heudelotii* (Cichlidae) has been submitted to a high salinity gradient (10-100). Experimental and control individuals, reared from birth in a closed system at a constant salinity of 10, were randomly separated into two groups after otolith labeling with oxytetracycline (OTC): control fish (N = 27) were maintained for 75 days at salinities of 10-20 while experimental fish (N = 27) were submitted to a salinity of 100 and supported a subsequent decrease in salinity (10 units per week until a final salinity of 20). In both cases, water salinity was controlled daily and water strontium concentrations were measured weekly by SB-ICPMS. At the end of the experiment, otolith transverse sections were prepared and Sr:Ca ratios were analysed using LA-ICPMS. Otolith growth rates (distance between the OTC mark and the edge) were not significantly different between control and experimental groups (ANCOVA, SC = 30.46, p = 0.634), confirming that the experimental design did not affect fish growth. Water Sr concentrations closely reflected ambient salinity (positive linear regression, R2 = 0.963). For most of the fish tested (~80%), the relationship between otolith Sr:Ca and salinity was positive but non linear (power regression, R2 = 0.677). Moreover, a few individuals from both the control and the experimental groups (~20%) showed very low Sr:Ca ratios during the whole experiment, indicating that they strongly regulated Sr incorporation into their otoliths. It is the first clear demonstration that elemental incorporation in the otolith can be regulated differently among individuals, at least for a species adapted to hypersaline conditions. These results imply that special attention is required when analysing otolith elemental concentrations for ecological applications.

Parisi, Vicenc

Vicenc Parisi[1]; Sebastien Carbini[2]; Jose Antonio Soria[1]; Ronan Fablet[3]

Technical University of Catalonia (UPC)[1]; French Research Institute for Exploitation of the Sea (IFREMER)[2]; TELECOM Bretagne[3]

Otolith Image Classification and Conditional Models for Fish Ageing: Plaice,Cod and Anchovy Case

This paper presents an automated fish age estimation tool based on two different approaches: a classifier that estimates individual ages based on intensity profiles along radials of the images of otolith sections, and a conditional model that estimates age proportion based on the morphological features of fish and otoliths. The estimation of individual ages from otolith images involves a series of image processing methods, specifically designed for the considered case studies (morphological segmentation and nucleus detection, 2D ring detection, contrast enhancement) and a nearest neighbour classification scheme. The angular sectors, that a priori contain the best growth marks, are selected. An intensity profile is computed in each sector and the fish's age is estimated by searching for the k most similar intensity profiles among those stored in a reference database (RDB), which has been calibrated by experts. To reduce the effects of non-linear growth the profiles are aligned elastically before measuring the differences between them. A conditional model is trained to estimate the probability that a fish belongs to a certain age group based on morphologic descriptors of the fish and its otolith. This probability is computed from the distance between the descriptors of the fish of unknown age and the ones with known ages in the calibration set.For a given production set, the age-class proportions are estimated by the sum of the individual classification probabilities. The proposed methodologies have been evaluated for five case-studies (Eastern Channel and Icelandic plaice, North Sea and North-East Artic cod and Bay of Biscay anchovy). The validity of the methods was determined with two tests: leave one out (LOO) and random partitions (RP) of the databases. The results obtained with LOO (percentage of correct classifications) range from 90.9 % for Icelandic plaice to 33.2 % for NE Arctic cod.The RP method was used to create random partitions of the databases (production and calibration set) and the estimated age proportion shows strong coincidence to the groundtruthed age structures for all species and stocks.

Paul, Katrin

Katrin Paul; Rainer Oeberst; Barbara Deutsch; Cornelius Hammer

Institute of Baltic Sea Fisheries, Rostock, Germany

Otolith Shape Analysis as a Tool for Cod Stock Discrimination in the Baltic Sea

Cod (*Gadus morhua* L.) is the commercially most important demersal species in the Baltic Sea. Currently two spawning stocks are distinguished by spawning time and spawning area. The "Spring spawners" spawn from March to April in the western Baltic Sea (Kiel Bight (ICES SD 22), Mecklenburg Bight (ICES SD 22) and Arkona Basin (ICES SD 24)) while "summer spawners" spawn from June to September also in the Arkona Basin and east of Bornholm (ICES SD 25). Migration leads to intensive stock mixing, which restrains the stock allocation of single individuals and result in problems in stock assessment. In the past, the discrimination of Baltic cod stocks was attempted for groups by inter alia meristics and morphometry, genetics and tagging experiments, but until now it is not possible to assign a single, non-spawning individual to a certain stock. Since otolith shape analysis is a common method for stock discrimination and is successfully applied for horse mackerel and Atlantic cod stocks, it is tested as a tool for Baltic cod stock discrimination. To obtain baseline values, spawning cod were sampled in February - March 2007 to 2009 in the Mecklenburg Bight and in June - August 2005 to 2008 in the Bornholm Basin. To minimize size effects, only fish of defined length groups were used. The outer shapes of left sided otoliths were digitized and elliptical Fourier descriptors were analyzed statistically. Preliminary results suggest the presumption of outer shape differences between "spring spawners" and "summer spawners".

Pecquerie, Laure

Laure Pecquerie[1]; Ronan Fablet[2]; Anne Lorrain[3]; Elise Dufour[4]; Daniel Gerdeaux[5]; Sebastiaan A.L.M. Kooijman[6]; Roger M. Nisbet[1]

University of California Santa Barbara[1]; Telecom Bretagne/LabSTICC[2]; IRD/ LEMAR,France[3]; Museum National d'Histoire Naturelle, France[4] ; INRA, Station d'Hydrobiologie Lacustre, France[5]; Vrije Universiteit, Amsterdam,The Netherlands[6]

Dynamics of d13C Isotope Ratio in Fish Otoliths and Bivalve Shells in the Context of the Dynamic Energy Budget (DEB) Theory

The carbon isotopic composition (d13C) of biogenic carbonates such as fish otoliths and bivalve shells can yield relevant information on the environmental conditions experienced by an organism (e.g., past CO2 levels, phytoplankton dynamics) as well as individual life traits (e.g., migration). An increasing body of evidence shows that metabolism controls the variations of the carbon isotope ratio at the seasonal level and throughout ontogeny in both otoliths and shells. Yet, it remains a challenge to interpret the d13C signal of such structures as the relative contributions of the two carbon sources - dissolved inorganic carbon (DIC) and respired CO2 derived from food remain poorly understood. In the present study, we investigate the underlying mechanisms that control the d13C in bio-calcified structures from a modeling perspective. In particular, we aim to model the relative contributions of the respired CO2 and the DIC as a function of the state of the organism and its environment. Our approach is based on the Dynamic Energy Budget (DEB) theory. This general theory describes the uptake and use of energy by an organism throughout its life cycle to achieve growth and reproduction according its environment. In this context, different hypothesis are tested for the contribution of DIC to biogenic carbonates as the individual grows. We applied the model to whitefish otoliths in Lake Annecy, France and scallop shells off Western Brittany, France. By using (i) appropriate parameter values and environmental conditions to simulate growth of fish and bivalve and (ii) two different hypotheses for the contribution of DIC to (internal) otoliths and (external) shells. We model d13C patterns both throughout ontogeny and at the seasonal level that fit well with the data. We suggest in particular that entrance of DIC might be proportional to a surface area in bivalves and to a volume in fish. Further study of the mechanisms involving DIC entrance is required but we show how modeling fish and bivalve metabolism within the same conceptual and quantitative framework help reveal common mechanisms underlying observed d13C biocarbonate patterns across taxa.

Pecquerie, Laure

Laure Pecquerie[1]; Pierre Petitgas[2]; Patrick Grellier[2]; Sebastiaan A.L.M. Kooijman[3]

University of California Santa Barbara[1];IFREMER, France[2]; Vrije Universiteit, Amsterdam, The Netherlands[3]

Resolving Environmental Effect on Stage Transitions in Anchovy Early Life History Using Dynamic Energy Budget (DEB) Theory

Recruitment in fish populations is partly controlled by the environmental conditions experienced by the individuals during the larval stage. Reconstructing the environmental conditions that allow fish to survive until metamorphosis would substantially improve our understanding of the factors that control recruitment variability. In the present study, we aim to study (i) the age and otolith radius at metamorphosis of juvenile anchovy sampled in 1999 and 2003 in the Bay of Biscay area and (ii) environmental scenarios that could explain these patterns using a bioenergetic model based on the Dynamic Energy Budget (DEB) theory. In this theoretical context, variations in food and temperature levels encountered by the individuals result in variable age and length at metamorphosis. We interpret the peak of otolith growth rate as the onset of metamorphosis. Age and otolith radius at metamorphosis are studied according to the date individuals were spawned. An individual model of growth, development and otolith formation is then developed in the DEB theory framework. We investigate the impact of different simulated environments on individual traits at metamorphosis. Temperature conditions are provided by a hydrodynamic model applied to the Bay of Biscay area for the 1999 and 2003 spawning seasons. We then study food scenarios that reproduce both the inter-annual and the seasonal patterns of individual traits at metamorphosis. We first show that individuals hatched in 2003 were on average older at the onset of metamorphosis compared to 1999. We also provide evidence that the spawning date influences the age and the otolith radius at metamorphosis: individuals hatched late in the season metamorphose at a younger age with a smaller otolith radius. Although the temperature over the spawning season was higher in 2003 compared to 1999, older ages at metamorphosis could be explained by lower food densities in 2003. We discuss the fact that lower food availability in 2003 could have led to the lower recruitment level observed in 2003 compared to 1999.

Phillis, Corey

Corey Phillis[1]; Frances Malamud-Roam[2]; Axel Schmitt[3]; Lynne Ingram[2]; Peter Weber[4]

University of California, Santa Cruz[1]; University of California, Berkeley[2]; University of California, Los Angeles[3]; Lawrence Livermore National Laboratory[4]

Life History Diversity Within Imperiled Chinook Salmon Populations Determined by Otolith Strontium and Oxygen Isotopes

Degradation and removal of freshwater habitats in the southern extent of the Chinook salmon range has led to a drastic decline in stock abundance and diversity. In the California Central Valley (CCV) 80% of historical spawning habitat has been blocked by dams, disproportionately extirpating many (spring run) or all (winter run) historical populations with life histories adapted to cold, high-elevation streams that can support juvenile rearing during the warm summer months. Remaining rearing habitat has been severely altered, particularly in the Sacramento-San Joaquin Delta where channelization, introduction of predators, and water exports has been intense. Here we investigate the rearing strategies of spawning adults from the extant spring and winter run populations utilizing otolith microchemistry. Sr isotopes (87Sr/86Sr) from otoliths of ~100 fish were analyzed by LA-MC-ICP-MS with a temporal resolution of 1-2 weeks. The 87Sr/86Sr ratio provides a good natal tributary and downstream migration signal; however, habitat assignment beyond the Delta is poor due to the highly non-linear 87Sr/86Sr mixing curve produced by tidal marine water. Therefore, we collected oxygen isotopes (d18O) by SIMS from select otoliths in an attempt to increase habitat use resolution within the San Francisco Bay Estuary (SFBE). Total time to ocean entry ranged from 2 to 11 months, however >70% of individuals spent 6 months or less in the freshwater system. Residence time in natal streams after first feeding ranged from <2 to 8 months, with most leaving either before 100 days or after 180. Juveniles spent very little time in the Delta (<45 days), even though this is often assumed to be an important rearing habitat. While the SFBE is not normally considered rearing habitat for juvenile salmon, otolith 87Sr/86Sr ratios indicate residence times of >45 days in this region. However, preliminary d18O results suggest 87Sr/86Sr ratios may overestimate the duration spent in this estuarine habitat.

Pilling, Graham

Andrew Harwood[1]; Paul Dennis[2]; Alina Marca[2]; Richard Millner[3]; Graham Pilling[3]

School of Environmental Science, University of East Anglia, UK[1]; Stable isotope Laboratory, University of East Anglia, UK[2];CEFAS, Pakefield Road, Lowestoft, Suffolk, UK, NR33 OHT[3]

Can Stable Isotopes Help Reveal Behavioural Differences in Individual North Sea Cod?

North Atlantic cod (*Gadus morhua*) may move to temperature zones that optimise physiological processes. Understanding these environmental influences on fish ecology often relies on relatively expensive Data Storage Tags (DSTs). However, the use of otoliths and oxygen stable isotope analyses allow temperature histories of wild fish to be derived. This study used the approach to investigate ambient temperatures experienced by individual cod in the North Sea over discrete time periods. Resulting temperature estimates were used to identify ecological patterns and thermal preferences of individual cod. Otoliths from 28 cod caught in the central North Sea during cold and warm periods were analysed. Carbonate samples were taken using micro-mill equipment within the region of the second to fourth years of age, resulting in between 7 and 15 samples per otolith. Individual carbonate samples were measured using a stable isotope ratio mass spectrometer. Temperatures were reconstructed using published equations for North Atlantic cod and seawater d18O values for the North Sea. Otolith-derived ambient water temperature histories were compared against both observed sea surface temperature records and modelled bottom water temperatures (BWT) for corresponding periods of zone formation. Estimated temperature experience suggested that fish could be placed into one of two classes: a) fish experiencing temperatures within the modelled BWT range, and hence which had either remained in or migrated to bottom waters during warm periods; and b) fish experiencing temperatures exceeding respective BWT ranges, and hence had spent at least some time in shallow/surface waters. These two groups showed different patterns in the temperatures experienced during opaque and translucent zone formation. Results are examined relative to existing knowledge of North Sea cod ecology developed through data storage tag studies and thermal preference observations. Implications of findings for the management of fisheries, which ignores potential meta-population structure within the North Sea, and implications of future climate-driven temperature changes within this Sea, are discussed.

Pilling, Graham

Alex Tidd[1]; Audrey Geffen[2]; Hans Hoie[2]; Richard Millner[1]; Francis Neat[3]; David Righton[1]; Peter Wright[3]; Graham Pilling[1]; Ulysses S. Ninnemann[4]

Cefas, Pakefield Road, Lowestoft, UK[1]; Department of Biology, University of Bergen, Norway[2]; FRS Marine Laboratory, 375 Victoria Road, Aberdeen[3]; Depart. Geo Sci, University of Bergen Norway[4]

Climate and the Carbon Footprint: What Can we Learn From Oxygen and Carbon Isotope Measurements?

The use of oxygen isotopes (d18O) in otolith carbonate to estimate thermal experience of fish has become a frequently used tool. However, some uncertainty remains over the relationship between isotopic signature and the physical properties that fish actually experience. More recent studies have suggested that carbon isotope (d13C) signatures could also be used to assess physiological processes like metabolism, although the parameterization of metabolic formulae is challenging. For example, carbon isotope levels may be affected by seawater dissolved inorganic carbon levels, dietary components, and metabolic modification. To improve the parameterization of temperature/oxygen isotope relationships in North Sea cod (*Gadus morhua*) otoliths, and to investigate how carbon isotope signature varies with temperature and oxygen isotope levels, we used electronic tags to record directly the ambient temperature that individual cod experienced under natural conditions, and coupled this information with oxygen and carbon isotope levels from their otoliths. Carbonate samples were obtained from sectioned otoliths using a New WaveTM MicroMill system. Samples were milled from the otolith edge to the inner region, ensuring that the period representative of the time at liberty with the data storage tag was covered. Samples were then measured for isotope levels using a Finnigan 253 stable isotope ratio mass spectrometer, and temperatures reconstructed using published equations for North Atlantic cod. The results confirm that d18O levels can be used to reconstruct thermal experience of cod, although discrepancies were observed, primarily due to differences in resolution of the stable isotope signal and uncertainties in interpretation of the temporal pattern. In contrast, the relationship between carbon isotope levels and temperature and oxygen was more complex. The results are discussed in relation to future climate change, and further studies to elucidate the relationships between isotope ratio and metabolism are suggested.

Popper, Arthur — Keynote Speaker

Arthur Popper; Xiaohong Deng

Department of Biology, University of Maryland, College Park, MD

Why Otoliths? The Rest of the Story!

Otolith organs are found in all vertebrates, including in ancestral fishes. In modern vertebrates the otolith organs subsume two major roles: that of hearing and of the detection of movement of the organism relatively to the environment. Thus, while otoliths hold their own inherent interest for many reasons discussed at this meeting, the role of otoliths in the life of vertebrates is to serve as a mass in a system that functions much like an accelerometer.

Rankin, Tauna

Tauna Rankin; Su Sponaugle

RSMAS/University of Miami

Behavioral Basis for Selective Mortality in a Coral Reef Fish

Fast growth and large size are thought to increase survivorship during the early life stages of marine fishes (growth-mortality hypothesis, GMH). Further, growth-related early life history traits (ELHTs) can carry over to juvenile survival. Recently we analyzed the otoliths of 13 monthly cohorts of settling larvae and early juveniles of the bicolor damselfish *Stegastes partitus* and found that mortality was selective for several ELHTs. Controlling for temperature, comparison of overall mean traits among cohorts indicated that survivors generally grew faster during the larval period and were larger at settlement. However, in contrast to the GMH, juveniles that survived to 2-3 wks exhibited slower juvenile growth during the first week. To test the underlying behavioral mechanism, we paired behavioral observations and otolith analysis with manipulated and naturally settled juvenile *S. partitus*. We collected and tagged 52 settlement stage larvae and placed them on the reef in pairs with one large and one small settler. Daily 5 min observations of total sheltering time, number times shelter was sought, and maximum vertical and horizontal distances traveled were made over approximately one week and survivors were collected at the end for their otoliths. Daily observations and collections of 236 naturally settled juveniles were taken over the same interval. The survivors of the experimental manipulations did not reveal significant trends among risk-taking behaviors and juvenile growth, however, larger settlers spent less time sheltered and traveled higher in the water column.

Rowell, Kirsten

Kirsten Rowell[1]; David Dettman[2]; Robert Dietz[2]

Universtiy of Washington[1]; University of Arizona[2]

Reconstructing the Marine Food Chain: Nitrogen Isotopes in Skeletal Remains

The ratio of 15N/14N (D15N) from consumer and prey tissue is commonly used in ecological studies to determine trophic level, food web structure, and mean trophic level in aquatic ecosystems. Tracking food chain length or mean trophic level in a system over time provides insights about biodiversity and ecosystem resilience. Yet the absence of baseline information before anthropogenic disturbances makes comparative studies addressing ecosystem responses difficult. We test if organic matter encapsulated in ancient fish otoliths and clam shells can define the food web structure and mean trophic level in the Gulf of California before overfishing. This approach uses skeletal remains (>1000 ybp) to establish the first baseline assessment of the food chain length from before human alterations to the system. Our calibration results indicate that otolith D15N is on average 1.6 lower compared to muscle tissue. Our results from otoliths of four fish species and 2 clam shells demonstrate that nitrogen in aragonite remains can reconstruct food web structure from the past. A past/present comparison of nitrogen isotope ratios in otoliths of Totoaba, a top predator, suggests that one full trophic level has been removed from the food chain since human disturbances to the upper Gulf of California.

Ruano, Miguel

Miguel Ruano; Ichiro Aoki

School of Agricultural and Life Sciences, Tokyo University

Early Life History Traits of Two Black Rockfish (*Sebastes inermis*) Populations in Japan, Using Otolith Microstructure Analysis: a Multivariate Approach

Sebastes inermis is a commercially important demersal species in Japan. The management of this species depends directly on the knowledge of the traits and ecological pathways established in early life. Juvenile black rockfish collected from Miura Peninsula (Sajima bay and Aburatsubo) central Japan (N=60), were aged by microstructure analysis of sagittal otoliths, in order to analyze the ecological structure of the populations and understand the adaptive strategy of this species during early life. It was possible to determine temporal events: extrusion date, planktonic stage and settlement period. Hatching occurred from late December till early March with January considered the main hatching period for both populations. In the present study, December hatched fish presented a higher growth rate in both planktonic and settlement periods, and had higher ages and sizes at settlement. Fish establish longer planktonic periods when conditions are favourable and in this case temperature seems to have high influence, with December having higher mean temperature. One explanation for the different values along hatching seasons is related to the period needed to maximize the competent size. Both places were distinguished by differences in duration and growth rate of settlement period where Aburatsubo population presented the higher values. These values are related with the differences shown on temperature between places, habitat substrate with higher seagrass and algal beds canopy and also the lower exposure to environmental conditions. For spatial comparison the planktonic period assume a lower importance on the analysis and settlement and post-settlement periods were determinant to establish patterns. Through principal component analysis was possible to confirm the contribution of the referred variables to determine the main differences in hatching season differentiation and both population's characterization. This study confirm *S. inermis* early life stages, showing a clear transition moment from larvae to juvenile that is coincident with their settlement in protected and shallow coastal nursery areas after a planktonic stage offshore. Although, further research is needed to understand clearly all pathways evolved in the observed effects.

Ruggerone, Greg — Keynote Speaker

Greg Ruggerone[1]; Jennifer Nielsen[2]; Bev Agler[3]

Natural Resources Consultants, Inc.[1]; U.S. Geological Survey, Alaska Science Center[2]; Alaska Department of Fish and Game: Mark, Tag, and Age Lab[3]

The Use of Salmon Scales to Test Hypotheses About Salmon Growth, Climate, and Ocean Carrying

Studies have shown that ocean climate shifts can influence salmon survival and abundance, but questions remain about the mechanism(s) of influence because we have few long-term biological time series. Furthermore, questions about ocean carrying capacity to support salmon arise because approximately 5 billion hatchery salmon are released into the ocean each year and studies have documented trends toward smaller adult salmon. These questions are difficult to examine because salmon migrate long distances in the ocean and sampling at sea is difficult. We review evidence from our recent studies involving annual and seasonal growth of salmon scales to test the following hypotheses: 1) greater early marine growth of Alaska sockeye salmon led to increased survival and abundance after the 1977 ocean regime shift, and to density-dependent growth during later life stages when size-related mortality was less likely; 2) competition for prey between Asian pink salmon and Alaska sockeye salmon led to reduced growth at sea and survival of sockeye salmon, and 3) competition occurs primarily after peak sockeye salmon growth and prey availability in spring. We also present new scale growth data indicating that 1) marine growth of Chinook salmon is dependent on growth in freshwater, and 2) coho abundance in western Alaska is related to their early marine growth and to abundance of larval pollock (salmon prey). These studies provide examples of how scale measurements can be used to reconstruct salmon growth trends in the ocean as a means to test otherwise problematic hypotheses.

Satoshi, Katayama

Katayama Satoshi

National Research Institute of Fisheries Science, Japan

Two Types of Otolith Opaque Zone

Altenative formations of opaque and translucent zones in the otolith are widely used for age determination, however, the mechanisms of annual periodicities of the zone formations has been unknown. Therefore there are various interpretations and explanations about the opaque zone. In order to reveal the mechanisms, I examined optical and structural characteristics of the opaque zone. Through microscopic and SEM observations of otolith section of natural and reared flatfishes, two types of opaque zones with heterogeneous in formation pattern and in aragonite structures were found as below. Type A: This type of opaque zone displays dense and minute crystals, that is usually formed around the opaque core and when the fish grows rapidly in the young period.Type B: This type consists of aggregation of grooves, discontinuous crystals, and is formed in spawning season and growth stagnant period. This opaque zone in the transverse section often shows directional change of otolith growth that the direction along dorso-ventral swelled to proximal. Otoliths of older fish only have type B of opaque zones. Opaque zones which have been utilized as an annual structures includes different structures with opposite nature in the life history. It is necessary to recognize these types in interpreting the annual structures for age determination.

Saunders, Richard

Richard Saunders[1]; Anthony Fowler[1]; Bronwyn Gillanders[2]

SARDI Aquatic Sciences, PO Box 120, Henley Beach SA 5024[1];Southern Seas Ecology Laboratory, University of Adelaide, SA, 5005[2]

Otolith Microstructure Reveals Recruitment Processes for Snapper (*Chrysophrys auratus*)

The daily increments in the otoliths of a young fish remain an extraordinarily powerful tool to reconstruct its life history. This study used otolith microstructure in conjunction with data on spawning of adults and environmental variables to enhance the understanding of the recruitment dynamics of snapper (*Chrysophrys auratus*) in South Australia. The population dynamics of this species are driven by interannual variation in recruitment. The sagittal otoliths of 0+ snapper have exceptionally clear microstructure evident in transverse sections prepared by grinding and polishing. These can provide estimates of age, spawn date, settlement date, pre-settlement duration and growth rate. The impact of spawning activity, water temperature and lunar cycle on the timing and strength of recruitment were investigated. Dramatic interannual variation in the recruitment of 0+ snapper was observed in trawl sampling. Spawning was continuous from November to early February but peaked in December each year. From otolith microstructure, birth dates showed that most successful recruits were spawned from mid-December to mid-January. Strongest recruitment resulted from spawning during December and January on days when water temperatures were between 21 and 23 degrees C but spawning on days in this range did not necessarily result in recruitment. Evidence of lunar periodicity was detected in both the spawn and settlement date frequencies. The spawn date frequency distributions of successful 0+ recruits did not correspond with the measured spawning activity of adults as considerable parts of the spawning season in each year did not produce successful recruits. The information from the otolith microstucture provided insight into the relationship between spawning, recruitment and environmental characteristics in this important fishery.

Schill, Daniel

Elizabeth Mamer[1]; George LaBar[2]

Idaho Fish and Game[1]; University of Idaho Emeritus[2]

Validation of Scales and Otoliths for Estimating Age of Redband Trout in High Desert Streams of Idaho

Studies validating aging structures for rainbow trout are sparse and none have been conducted for redband trout in either desert or montane environments. Oxytetracycline mark-recapture methods (M-R), marginal incremental analysis (MIA), and comparisons across multiple populations were used to evaluate the accuracy of three structures for aging redband trout in high desert streams. We assessed periodicity of annulus formation on paired scale and otolith samples from all age classes of trout residing in two streams, identified the location of the first annulus on otoliths from these waters, and compared age estimates and between-reader coefficient of variation on nine additional streams. Edge analysis revealed that Age 0 redband trout in both study streams grow two translucent bands in their otoliths during their first year of life, concurrent with growth cessation likely induced by the cycling annual temperature regime. Our results demonstrate that scales were an unacceptable aging structure for desert redband trout. A combination of MR and MIA methods successfully validated otolith age estimates for fish 1-9 years old. Whole otoliths were validated to be 100% accurate to within one year over the entire length range of redband trout sampled in both streams, and sectioned otoliths for Age 2 and older trout also proved to be 98-100% accurate within one year. Between-reader CV for scales was unacceptably high (11.5%), while that observed for sectioned otoliths with whole otoliths used as corroboratory structures averaged only 2.3%. The lack of cohesive, multi-species study designs evaluating otolith growth patterns and zonation via formal research hypothesis testing has resulted in longstanding confusion about the timing and meaning of otolith zone formation. Several formal hypotheses are proposed for future evaluation.

Schulz-Mirbach, Tanja

Tanja Schulz-Mirbach[1]; Friedrich Ladich[2]; Martin Plath[3]

Ludwig-Maximilians-University, Dept. of Earth Environ. Sciences[1]; University of Vienna, Dept. of Behavioural Biology, Althanstr. 14, A-1090 Vienna[2]; University of Frankfurt, Germany[3]

Otolith Morphology and Hearing Abilities in a Cave- and a Surface-Dwelling Form of the Atlantic Molly (*Poecilia mexicana*)

Cave fish have rarely been investigated with regard to their otolith morphology and hearing abilities. Here, we compare a cave form of the Atlantic molly, *Poecilia mexicana*, inhabiting a cave system in south-eastern Mexico, with a surface-dwelling population from north-eastern Mexico. The cave fish display several differences in morphology (e.g., pale body pigmentation, smaller eyes) and behavior. We tested the hypotheses that (i) the sense of hearing is less important in the cave due to the lack of avian and piscivorous predators, resulting in poorer hearing abilities and (ii) otolith morphology differs due to different habitats. We utilized the auditory evoked potential (AEP) recording technique in order to determine auditory sensitivities between 100-1500 Hz. Left lapilli, sagittae, and asterisci of each individual were weighed and SEM images of each otolith were taken in order to study the structure of the face oriented towards the corresponding macula, to quantify the otolith area, and to analyze overall contours by conducting Fourier shape analysis. We found very similar hearing abilities in cave- and surface-dwelling fish, with greatest sensitivity between 200 and 300 Hz. The contours of each otolith type, however, differed distinctly between the two populations. In addition, sagittae of surface-dwelling fish were characterized by large, circularly arranged crystals in the centre of the sulcus, a pattern lacking in sagittae of cave fish. No difference was found in the mass-to-area ratio of the three otolith types. Our results indicate that differences in otolith morphology such as otolith contour and sulcus morphology do not result in different hearing sensitivity in cave- and surface-dwelling Atlantic mollies.

Secor, David H. — Plenary Speaker

David H. Secor

University of Maryland Center for Environmental Science

Otoliths Speak Volumes on Fish Migration

How does one explain to the lay person why fish otoliths are important? Undoubtedly, otolith science has increased geometrically in methods and applications, but thinking beyond "Otolith Research and Application" ,how have otoliths improved our understanding of fishes and their environment? I use Harden Jone's 1968 Fish Migration, as a benchmark of fish migration concepts prior to Panella's 1971 breakthrough paper on otolith microstructure. For case study species I will show how otolith science has informed past migration concepts including, (1) ecological traps due to maladaptive life cycles (European eel), (2) parent stream theory (bluefin tuna), (3) adoptive homing (Atlantic herring), and (4) partial migration (Atlantic cod). Harden Jone's overall conclusion that life cycle closure leads to population structure (aka the migration triangle) is a first principle in fisheries science, but in recent years has been challenged by otolith science. In particular, a transformative discovery attributable to otoliths is that life cycles vary substantially within populations. New avenues of otolith science are now exploring the causes and consequences of this life cycle diversity. I highlight some common approaches for addressing the consequences of life cycle "portfolios" as they relate to population and metapopulation stability and persistence.

Shcherbich, Zhanna

Zhanna Shcherbich; Paul Brickle; Alexander Arkhipkin

Fisheries Department, P.O. Box 598, Stanley, FIQQ 1ZZ, Falkland Islands

Growth in Evolutionary Exile: Morid Fishes (Gadiformes) in the Southwest Atlantic

The family Moridae represents a separate group of gadiform fishes that were excluded from the centers of their speciation on the shelf by the more successful Gadidae and Merluccidae to deeper water habitats, where they were probably outcompeted by evolutionary progressive Macrouridae. As a result, morids radiated only over the upper slope (codlings) occupying the niche of medium-sized benthopelagic predators, and in bathypelagic waters of the open ocean (antimoras and codlings) as medium to large opportunistic predators. Only in South America, Australia and New Zealand do morids (red cods) occupy the eco-niche of large benthopelagic predators on the shelf. It is likely that these niches had been left vacant by other large gadoid fishes. Otolith analysis showed that all morids studied were long lived with maximum age ranging from 15 to 30 years. Living constantly in cold waters bathypelagic (*Antimora rostrata, Lepidion ensiferus, Halargyreus johnsonii*) and upper slope benthopelagic (*Notophycus marginata*) morids grow slowly throughout their entire life cycle. In contrast, shelf benthopelagic *Salilota australis* takes an advantage of warmer ambient temperatures in summer growing fast in their juvenile stage and achieving the largest known size for morids (~90 cm). Evolutionary trends in growth in different morid lineages are discussed.

Shepard, Katherine E.

Katherine E. Shepard[1]; William F. Patterson, III[2]; Doug A. DeVries[3]

Louisiana State University, Department of Oceanography and Coastal Sciences[1]; University of West Florida, Department of Biology[2]; National Marine Fisheries Service, Panama City Laboratory[3]

Estimating the Contribution of Atlantic Stock King Mackerel (*Scomberomorous cavalla*) to Mixed-Stock Winter Landings in South Florida with Otolith Markers

King mackerel (*Scomberomorous cavalla*) is a coastal migratory fish that supports important commercial and recreational fisheries in the US Gulf of Mexico (GOM) and south Atlantic (Atlantic). GOM and Atlantic populations (stocks) are genetically distinct, but migrate south each fall to overwinter in the waters off southern Florida. Understanding the relative contribution of each population to the mixed winter landings is essential for designing effective management policies. We analyzed otolith chemical (elemental and stable isotope) signatures for fish collected in 2006 and 2007 from each stock's summer spawning grounds to derive sex- and population-specific otolith markers. Computed quadratic discriminant functions for data had mean jackknifed classification accuracies ranging from 66.0% to 67.4% for elemental chemistry, 76.8% to 81.1% for stable isotope signatures, and 79.0% to 84.3% for combined chemical signatures. Data collected in 2007 is currently being analyzed. Maximum likelihood stock mixing models were parameterized with the stock-specific chemical signatures and applied to otoliths sampled from 2006-07 and 2007-08 winter landings in three south Florida sampling zones. Results indicated a gradient existed in estimated Atlantic stock contribution to winter landings, with lower contribution in the west and higher contribution in the east. In the easternmost zone, which was sampled monthly, the proportion of Atlantic fish increased from December to March. This temporal trend likely reflects the beginning of the spring migration northward. Our results suggest Atlantic contribution is greater than 0% (the historical assumption for management purposes), and, furthermore, assuming a set mixing rate does not accurately reflect the spatial and temporal variability of Atlantic contribution to winter landings.

Shiao, Jen-Chieh

Jen-Chieh Shiao[1]; Kotaro Yokawa[2]; Shi-Wei Wang[1]; Yue-Gau Chen[3]

Institute of Oceanography, National Taiwan University[1] ; National Research Institute of Far Seas Fisheries, Japan[2]; Institute of Geosciences, National Taiwan University[3]

Discriminating the Natal Origin of Pacific Bluefin Tuna *Thunnus orientalis* by Otolith Stable Isotope Signature

Otolith oxygen (O) and carbon (C) stable isotopic compositions were analyzed to discriminate the natal origin of young Pacific bluefin tuna (PBT, *Thunnus orientalis*) collected in the Sea of Japan, Tsushima Strait and Pacific coast of south-eastern Japan. All specimens (n = 60) showed relatively stable but depleted d18O (-3.5 to -2.5pm) and d13C (-10 to -11pm) values from the otolith core to around 600 - 1000 mu m, which corresponded to the larval, juvenile, and young stages of approximately 2 - 4 months of age. The values of d18O varied from -2.0pm to -3.0pm and d13C varied from -9.0pm to -11.0pm during this stage among the locations. Then, the isotope values dramatically enriched to approximately -1.5 to -1.0pm for d18O and around -7.0 to -8.0pm for d13C at the otolith edge, except some smaller PBT. The stable isotopes of PBT collected in Sakaiminato were significantly depleted than the PBT collected in Tosa Bay (canonical discriminant analysis, Wilks Lambda = 0.32, $p < 0.01$), believed to result from their hatching in the Sea of Japan and northwestern Pacific Ocean, respectively. Furthermore, the discriminant analysis results suggested that most PBT collected in Tsushima Strait and Pacific coasts were hatched in the northwestern Pacific Ocean and some of them can migrate into the Sea of Japan during the first year. The mean otolith growth rate during the larval stage was slightly slower for PBT hatched in the Sea of Japan than for those hatched in the northwestern Pacific Ocean although the statistical analysis was only significant at day 8 (t-test, $p < 0.05$). These results suggested that otolith microstructure and stable isotopic composition are useful natural markers for determining the natal origin of PBT hatched in different spawning grounds.

Shiao, Jen-Chieh

Shelly Cruz[1]; Jen-Chieh Shiao[2]; Bo-Kai Liao[3]; Chang-Jen Huang[4]; Pung-Pung Hwang[3]

Institute of Fisheries Science, National Taiwan University[1]; Institute of Oceanography, National Taiwan University[2]; Institute of Cellular and Organismic Biology, Academia Sinica, Taiwan[3]; Institute of Biological Chemistry, Academia Sinica, Taiwan[4]

Plasma Membrane Calcium ATPase Required for Semicircular Canal Formation and Otolith Growth in the Zebrafish Inner Ear

Fish otoliths consist of >90% calcium carbonate, the accretion of which depends on acellular endolymph. This study confirms the presence of plasma membrane calcium ATPase 1a isoform (Atp2b1a) in the auditory and vestibular system of a teleost fish. As shown by in situ hybridization, zebrafish atp2b1a is expressed mainly in larval otic placode and lateral-line neuromast as well as in the hair cells within the adult zebrafish inner ear chamber. Zebrafish atp2b1a knockdown by antisense morpholinos reduced the number of hair cells and produced malformation of semicircular canals and smaller otoliths. These defects coincide with unbalanced body orientation. The formation of smaller otoliths in atp2b1a morphants may stem from an impairment of calcium supply in the endolymph. However, otolith formation persists in most morphants, suggesting that other zebrafish Atp2b isoforms or paracellular pathways may also transport calcium into the endolymph. These results suggest that Atp2b1a plays an important role for normal development of the auditory and vestibular system as well as calcium transport in the inner ear of zebrafish.

Shirai, Kotaro

Kotaro Shirai[1]; Kodai Yamane[2]; Yosuke Amano[2]; Takaomi Arai[2]; Tsuguo Otake[2]

Department of Earth and Planetary Science, The University of Tokyo[1]; Ocean Research Institute, The University of Tokyo[2]

Assessing the Usefulness of Pressed Powder Pellet Standard Prepared From Three Biogenic Calcium Carbonate Certified Reference Material for Improving the Accuracy of Otolith Chemistry Using LA-ICP-MS

Otolith chemistry has a great potential for studying the fish migration and stock structure. LA-ICP-MS is one of the most useful methods to analyze otolith chemistry because of its merits such as high sensitivity, and high spatial resolution. For accurate quantitative analyses, LA-ICP-MS require matrix-matched standard to eliminate matrix effect. One promising technique is probably pressed powder pellet prepared from powdered calcium carbonate. However, previous studies using limestone CRMs suffered from impurity. In this study, three biogenic calcium carbonate CRMs, JCp-1 (coral), JCt-1 (giant clam) provided by AIST Japan, and NIES No. 22 (otolith) provided by Environment Agency of Japan, were examined to assess their availability as standard for LA-ICP-MS calibration. Three CRMs were compressed by 400 kgf/cm2 in an oil cylinder, then reinforced by infiltration of pure epoxy resin under vacuum. Chemical compositions were analyzed by ICP-MS (Agilent, 7500cs) connected with Laser Ablation system (New Wave, UP213). Obtained data were calculated off-line by using Pepita software and spreadsheet, and were then calibrated against both NIST 612 glass standard and JCp-1. Sr/Ca ratios of all CRMs showed consistent results among one another calibrated against both NIST 612 and JCp-1. However, obtained JCt-1 and Jcp-1 compositions calibrated against NIST 612 showed systematically lower values for B, K, Mn, Cu, Zn, and Ba, whereas it showed higher values for Mg and Rb, compared to certified/information values. Obtained JCt-1 compositions were consistent in all elements when they were calibrated against JCp-1. Obtained NIES No. 22 compositions calibrated against JCp-1 showed slightly lower values for Na, Mg, and Ba, whereas it showed significantly lower values for Mn, Cu and Zn. These results indicate that NIST 612 and NIES No. 22 are not adequate for quantification by LA-ICP-MS, except for Sr/Ca ratio. Thus, JCp-1 and JCt-1 are recommended for LA-ICP-MS calibration.

Sinnatamby, Niloshini

Niloshini Sinnatamby[1]; J. Brian Dempson[2]; James Reist[2]; A Storm-Suke[1]; Michael Power[1]

University of Waterloo[1];Fisheries and Oceans Canada[2]

The Use of Delta-18O Analysis of Young-of-the-Year Arctic Charr, *Salvelinus alpinus*, Saggital Otoliths to Infer Thermal Habitat Use Within Quttinirpaaq National Park, Nunavut Canada

Arctic charr, *Salvelinus alpinus*, is the most northern of all freshwater and anadromous species and is the only fish species located within Quttinirpaaq National Park (QNP), Nunavut, Canada (about 82 degrees N). Polar regions have already experienced the greatest regional warming, and face the largest projected temperature increases as a result of predicted climate change effects. While temperature is known to influence juvenile growth rates, little is known about the thermal habitats used by young-of-the-year (YOY) Arctic charr at high latitudes. Remote sites at high latitudes often provide unique challenges in obtaining temperature records for lakes and an understanding of thermal habitat use by fish within those lakes. Here otolith-inferred temperatures and associated fish lengths obtained from YOY from various sites within QNP, including multiple sites within Lake Hazen, in August 2007 and 2008 are compared to assess spatial variability in thermal habitat use and infer its influence on size. In addition, otolith-inferred temperatures from YOY obtained from Lake Hazen in 2001 are compared with those from 2007 and 2008 in order to assess whether YOY thermal habitat use varies temporally with climate. Mean temperatures experienced by YOY were estimated from delta 18 O signatures of otoliths using a species-specific fractionation equation. Results indicate a wide range of thermal habitat use within and among sites, including some surprisingly warm areas. Evidence for metabolic variation is also examined using coincidentally-derived otolith carbon isotope signatures.

Soria, J. Antonio

J. Antonio Soria[1]; Antoni Lombarte[2]; Vicenc Parisi-Baradad[1]

Technical University of Catalonia (UPC). Barcelona (Spain)[1]; Institut de Ciencies del Mar CMIMA - CSIC - Barcelona (Spain)[2]

Otolith Identification of Merluccius Populations and Sympatric Species with Local Discriminant Bases

The species of the genus *Merluccius*, commonly called hakes, contributes to significant catches from the Gadiformes order that represent a quarter of the world catch of commercial marine fish. Fisheries management of the Merluccius spp. requires determination of population units or precise species identification in the case of close sympatric populations. Over the last years, otolith contour images have been used as indicators in taxon and geographical populations. The selection of objective features from otolith images has been one of the main concerns in order to enhance the performance of classification methods and, subsequently, to improve identification results. For these tasks, the Local Discriminant Bases (LDB) and a standard classification procedure scheme is used in this work to determine intra-specific variability and differences between some sympatric species of *Merluccius* populations. First, wavelet packet coefficients are selected automatically by a class separability measure and then the accuracy of the classifier is determined in a cross-validation process of test and training. Since LDB is based on discrimination of the wavelet coefficients among populations, affinities and differences among fish groups can be determined in terms of contour irregularities and their position. Its suitability has been tested developing intra-specific and inter-specific identifications using different *Merluccius* species from the AFORO database (aforo.cmima.csic.es). Simulations have been carried out achieving an average estimation of 85% accuracy in four sympatric comparisons (*M. gayi* vs *M. australis*, *M. albidus* vs *M. bilinearis*, *M. capensis* vs *M. paradoxus* and *M.polli* vs *M.senegalensis*), and 77% in four intra-specific comparisons (North American Pacific *M. bilinearis* and Atlantic *M.productus*, iberian *M. merluccius* and South American Pacific *M. gayi*). Although the selection of accuracy estimation methods according to real fish sampling settings need to be studied, results are promising and motivate the use of class discrimination approaches, such as the LDB, in future tools for otolith identification based on wavelet descriptors.

Sponaugle, Su — Keynote Speaker

Su Sponaugle

Marine Biology & Fisheries, RSMAS, University of Miami

Life Histories and Fisheries Management: The Otolith Toolbox

Information obtained from fish otoliths has been a critical component of fisheries management for decades. The nature of this information has changed over time as management goals and approaches have shifted. The earliest and still most pervasively used data is that of annual age and growth rates used to calculate the demographic rates of populations in single species management strategies. Over time, the absence of simple stock-recruitment relationships has focused attention on the youngest stages, where otoliths again serve as a valuable tool. As management has shifted to more ecosystem-based approaches, the need to understand ecological and oceanographic processes has been advanced through the use of otolith data resolved on a daily basis. In particular, spatial management requires an understanding of population connectivity (sources and sinks), the resolution of which benefits substantially from otolith data. Daily otolith-derived data collected at an individual level has enabled the development of individual-based models, which in turn allow the modeling of complex systems and provide information on which individuals survive over time and why. Such a mechanistic understanding of the ecology of young stages is particularly necessary in light of a rapidly changing ocean environment. Future advances in our understanding of population replenishment will rely on the creative (and increasingly complex) combination of otolith-derived data with data from other disciplines such as oceanography, physiology, chemistry, behavior, genetics, and genomics.

Starrett, Lindsay

Lindsay Starrett[1]; Brian K. Wells[2]; Churchill B. Grimes[2]

University of California, Santa Cruz[1]; NMFS, Santa Cruz[2]

Barium as an indicator of upwelling exposure in the otoliths of Central California juvenile rockfish.

The transport, survival and growth of juveniles are crucial to maintaining adult rockfish populations. It is recognized that these factors may be linked to upwelling conditions, however the effects of upwelling have not been clearly demonstrated. Cold upwelled waters, brought to the surface by wind-driven Ekman transport, are typically nutrient rich and have a different chemical signature than warmer offshore, or surface waters. The element Barium is likely a key indicator of upwelled water masses, as it quickly drops out of surface waters and is at a much higher concentration in deep ocean waters. The open coastal system of Central California exhibits two such regions where intense upwelling occurs (e.g. Pt. Reyes & Ano Nuevo). To address whether Barium can be used as an indicator of exposure to upwelled water masses along Central California, we concurrently collected water samples and juvenile rockfish otoliths (*Sebastes jordani* & *Sebastes entomelas*) in the spring months of 2007 and 2008. A standardized set of transects were set up at a spatial resolution designed to capture meso-scale oceanographic features. Different pelagic juvenile rockfish habitats (i.e. water masses) were defined using satellite sea surface temperature imagery. Water and the last days of otolith growth were analyzed for Barium:Calcium ratios along with a suite of other elements. Increased Ba:Ca ratios in water samples correlated with the upwelled water masses. Higher Ba:Ca ratios in the otolith during the time of upwelling was also demonstrated. An “upwelling tag” in the otolith may allow for a direct measure of upwelling importance with regards to transport, survival, and growth of juvenile rockfish off Central California.

Steer, Mike

Mike Steer[1]; Tony Fowler[1]; Bronwyn Gillanders[2]

SARDI Aquatic Sciences, West Beach, South Australia[1];Adelaide University, Adelaide, South Australia[2]

Southern Garfish (*Hyporhampus melanochir*) - Analysis of Stock Structure From Multiple Otolith-Based Techniques

The southern garfish, *Hyporhamphus melanochir* (Hemiramphidae), is endemic to the coastal waters of southern Australia and is commercially and recreationally fished throughout its distribution. Fishery production is highest in South Australia usually exceeding 400t per annum, which accounts for approximately half of the total national catch. Currently this fishery is assumed to consist of two separate stocks, one in each of South Australia's two gulf systems, however, there has been no evidence to support this spatial separation. This study aimed to resolve this issue by delineating potential garfish sub-populations, and determining the extent of mixing within South Australian coastal waters, through the integration of multiple otolith-based techniques. Otoliths can be used as 'natural tags' as their chemistry, shape and internal structure are influenced by the ambient environment. Therefore fish living in different environments can be discriminated on the basis of the chemical or physical properties of their otoliths. This study examined regional, age-related, differences in the chemical composition of the otolith, in terms of their trace element and stable isotope concentrations, as well as exploring discrepancies in their overall shape and internal microstructure.

Stransky, Christoph

Hans-Werner Ruessmann; development team WebGR

Federal Agency for Agriculture and Food, Germany

Web Services for Support of Growth and Reproduction Studies

WebGR is an open source project for supporting calibration workshops. The software includes a set of web services to support the organization and data analysis of calibration workshops, both for age and maturity information of fish. The most common exercises carried out during these workshops are counting otolith growth rings or classifying gonads, with subsequent analysis of the results in order to build age-length keys or maturity ogives. This should be possible to do online using WebGR services. WebGR includes procedures for training purposes, like browsing images, reading expert's annotations or simulating a calibration exercise. The services are installable as a website. All workshop participants have access to a repository of images grouped or classified by workshop (species, date, area, etc.). Each image could be annotated by several scientists. The annotations include fields for the classification (age x or maturity stage y, etc.), observations, scientist, etc. This information is stored in a database so that the statistical analysis of the results can be automated as far as possible and made public as online reports. The software is licensed by an Open Source license to promote transparency, technology transfer and peer review; in addition this allows the scientific community to get involved in further developments, like linkage to statistical analysis engines, or any other specific features. As a second part of the presentation I want to show a small piece of the software: 1)How to make an annotation to image, 2) How to make a calibration exercise, 3) How to compare the results.

Stransky, Christoph

Christoph Stransky

vTI, Inst. of Sea Fisheries, Germany

Supporting Adaptive Management of European Fisheries by Otolith-Based Stock Identification

Stock identification is one of the prerequisites for adaptive fisheries management incorporating optimum harvest strategies for a particular stock. In this context, otolith-based techniques have increased in importance, delivering a wealth of life-history information for investigating stock-specific characteristics. Improvements in microchemical analysis of otolith constituents and image analysis of otolith outlines and growth structures have clearly supported this development. At the same time, rapid and practical allocation of individual fish to stock units demands for time- and cost-efficient techniques for the analysis of stock differences. Several otolith-based methods have proven to fulfil these objectives. Based on a series of recent case studies, the utilization of stock-specific information from otolith analyses in the assessment and management of European fisheries is being reviewed. In many cases, these studies were part of multidisciplinary projects employing a range of other stock identification methods. Apart from the target outcome of these studies, several biological and ecological features of the stocks and species under investigation were revealed. A perspective is given on future research needs and potential for broad-scale application of otolith analyses in fisheries management.

Sun, Chi-Lu

Chi-Lu Sun; Hsiao-Ling Lin; Su-Zan Yeh

Institute of Oceanography, National Taiwan University

Evaluating Age and Growth of Young Swordfish, *Xiphias gladius* L., in Taiwan Waters Using Otoliths

Swordfish, *Xiphias gladius*, is a cosmopolitan species found in the tropical, subtropical and temperate waters of the world's oceans and adjacent seas. In the waters of Taiwan, the swordfish is an incidental catch of the offshore tuna longline and harpoon fisheries. Both fisheries contributed an estimated 1,372 metric tons, or 99% to the total swordfish landings from Taiwan waters in 2007. A previous study on the age and growth of swordfish in Taiwan waters using anal fin rays indicated that juvenile swordfish grow very fast from birth to age one, reaching approximately 90 cm in lower jaw fork length (LJFL) at the end of year 1. However, knowledge on the growth of swordfish in young stage is extremely limited. In this study, we evaluate the age and growth of young swordfish in Taiwan waters by examining the growth increments on the otoliths. Sixty young swordfish were collected from Taiwanese offshore longline landings at three local fish markets from September 2000 to January 2002. Sagittae, the largest of the three otoliths in billfishes previously shown to be the most accurate for age determination, were successfully recovered from 29 of the 60 fish sampled. The growth increment counts on the section of sagittae, presumed to be daily, were made for age estimation. Estimated ages for the 29 swordfish, varying in size from 71.2 to 96.2 cm LJFL, ranged from 145 to 354 days. Estimates of spawning dates, based on the otolith analysis, ranged from February to October. A power function seems to best describe the relationship between LJFL and age estimates in days for the young swordfish. Average growth rate within the size interval of 71.2 to 96.2 cm was estimated to be 0.98 mm per day. The intercept is zero, and the estimated size at 365 days (age one) is 94 cm LJFL which is consistent with earlier results.

Suthers, Iain

Iain Suthers[1]; Jack Fife[1]; Mike Power[2]; Rob Stephenson[2]

University of New South Wales[1]; Dept. of Fisheries and Oceans, New Brunswick, Canada[2]

Larval and Juvenile Growth Rates From Atlantic Herring Otoliths, in Relation to Plankton, Fishing Effort and Year Class Strength

The growth rate of larval fish may predict the annual supply of young fish, but fisheries science has not exploited this remarkable finding. Using a 28 year archive of herring otoliths from the Bay of Fundy off eastern Canada, with year class strengths determined from a virtual population analysis, we tested the hypothesis that strong year classes were produced from wider growth increments at age (i.e. faster growth), and weak year classes were produced from narrower increments. Two normal year-classes and two strong year-classes with abundances five-fold greater were selected. We examined otolith size (diameter and area) at approximately 18 months of age of the 4 year classes at 2, 3, 4, and 5 years old as an index of growth rate. We also examined sagittal and transverse sections of 2 and 3 year-old otoliths respectively, and compared the daily increment widths at approximately 4 weeks, 8 weeks, and 14 weeks post-hatch, corresponding to the first few months of larval life in late summer. In 2 year-old fish, the area of the otolith at ~15 months old was significantly greater for the two strong year classes, The otolith area at ~15 months old was not significantly different among year classes, as the cohort became 3, 4, and 5 years old and recruited to the fishery; Measures of daily larval increment growth in 2 year olds and the independently sampled 3 year-olds one year later (i.e. of the same cohort) were significantly correlated. Only one strong year-class had larger increment width series. Remarkably, the larval increment widths at 4 weeks were significantly correlated with length at 2 years (although this varied among year-classes). The two strong year classes were associated with a lower abundance of zooplankton particles <1 mm diameter. Over the full 26 year series (1972-1998), the zooplankton particle size distributions were correlated with the year class strengths. Our approach of using larval growth from 2 and 3 year old fish may be confounded by fishing intensity, even in these young year classes. Faster larval growth did result in one strong year class, but not in another. Larger 2 year old fish also had larger otolith radii as larvae. Size of juvenile fish is however a strong (and pragmatic) correlate of YCS.

Svedang, Henrik

Henrik Svedang[1]; Patrik Jonsson[1]; Mikael Elfman[2]; Karin Limburg[3]

Swedish Board of Fisheries, Institute of Marine Research Lysekil[1]; Lund University, Department of Nuclear Physics[2]; State University of New York[3]

Fine-Scale Population Structure in Atlantic Cod (*Gadus morhua* L.) Suggests Very Precise Homing Behaviour

The question whether temperate marine fishes consist of self-sustaining populations or "open" populations remains yet to be resolved. At the heart of the connectivity problem lies the nature of the stock separation mechanisms. Marine fish populations could either be segregated by environmental forcing, i.e. retention during early life stages with accompanying opportunistic recruitment of juveniles to spawning, or by philopatric behaviour, i.e. tendency of an individual to return to, or stay in, its home area. Numerous examples of spatial genetic differentiation have been found in the last decades. For populations connected by a moderately high migration rate (<10% a year) but still constituting demographically distinctive entities, genetic enquiries might be fruitless or ambiguous. In this study, cod (*Gadus morhua*) migrations in the eastern North Sea were investigated by archival taggings. The observed migratory patterns indicated three closely located spawning sites in the Kattegat-Ãresund area. The natal relatedness to the spawning sites was investigated by analysing the contents of trace elements of the otolith core for retained fish. Similarity in natal origin was assumed to be detected by estimating the contents of various trace elements. The contents of Ba, Br, Co, Cr, Cu, Fe, Mn, Mo, Ni, Sr, Ti, Zn were determined by using PIXE combined with a nuclear microprobe. Both discriminant analysis and repeated MANOVA, using year class as covariate, indicated unequivocally natal origin of fish to be of highest explanatory value. As the proposed natal origin was founded on the independently inferred migratory behaviour, philopatric behaviour is suggested to be an essential stock separating mechanism also over short distances.

Swearer, Stephen

Stephen Swearer[1]; Steven Morgan[2]; Michael Sheehy[3]; Robert Warner[3]

University of Melbourne[1]; University of California at Davis, Bodega Marine Laboratory[2]; University of California at Santa Barbara[3]

Nature vs Nurture: is Otolith Core Chemistry a Marker of Natal or Maternal Origin?

The utility of otolith core elemental signatures to identify the origins of dispersing fish larvae is dependent on the extent to which elemental incorporation reflects the natal environment. The often unique chemistry of otolith cores as well as recent evidence for maternal transmission of enriched stable isotopes, suggest that maternal effects may dominate otolith core chemistry. If maternal effects are variable within a source population, otolith core chemistry will not be a reliable marker of larval origins. In order to investigate the relative importance or maternal versus environmental effects on otolith chemistry, we cultured recently spawned cabezon eggs in 15 environmental treatments (3 temperatures and 5 seawater concentrations) using enriched stable isotope spikes. We found that environmental effects dominated maternal effects for most elements indicating that otolith core chemistry is a reliable indicator of the natal environment in this demersal egg laying species.

Szedlmayer, Steve

Stephen Szedlmayer[1]; Sabrina Beyer[2]

Auburn University[1]; Monterey Bay National Marine Sanctuary[2]

Validation of Annual Periodicity in Otoliths of Red Snapper, *Lutjanus campechanus*

The periodicity of otolith growth rings from adult red snapper was examined through a mark and recapture study. In 2005-2007, red snapper (n=251) were caught with hook-and-line, injected with oxytetracycline (OTC), and released 15-40 km south of Dauphin Island, Alabama. Fish were recaptured up to 2.5 years after release (n=19) and sagittal otoliths were dissected, sectioned and examined under blue-violet light. The number of growth rings past the OTC mark was compared to time at liberty of the fish and supported an annual periodicity of growth ring formation. However, all recaptured fish were less than 10 years of age and validation of older red snapper (>10 years) is still needed. Based on known timing of OTC marking, otoliths showed opaque ring formation in late summer or early fall, in contrast to the generally accepted concept of late winter formation for this species.

Tahara, Daisuke

Asuka Kurakami[1]; Jinro Nagatomo[2]; Masahiro Ono[2]

Fukui Prefectural University[1]; Wakasa Wan Energy Research Center[2]

Migratory History of the Fourspine Sculpins (*Cottus kazika*)

Fourspine sculpins (*Cottus kazika*) have a catadromous life style; they migrate from the middle and lower reaches of rivers to the coastal seas for spawning in late autumn and winter. However, little is known about the migratory history of this species, the timing of migration, and the factors influencing the downstream migration from rivers. We studied the migratory history of one- and two-year-old fourspine sculpins collected from freshwater environments by examining the strontium (Sr) and calcium (Ca) concentrations in their otoliths by means of wavelength dispersive X-ray spectrometry with an electron microprobe. During the rearing examination, we observed that individuals, which were collected from freshwater and acclimatized to a seawater environment, had an increased Sr:Ca ratio in the otoliths. This result indicates that otolith microchemistry analysis is an effective method to clarify the migratory history of fourspine sculpins. The Sr:Ca ratio in 13 of 14 one-year-old fourspine sculpins remained high in the regions surrounding the core; however, it reduced drastically at a distance of ca. 0.5 mm from the core. The Sr:Ca ratio in 1 of the 14 specimens was high in 2 narrow regions: up to 0.7 mm and between 1.0 - 1.3 mm from the core. This suggested that this fish had migrated downwards to the sea and then migrated upwards to the river from the coastal sea. In contrast, the Sr:Ca ratios in all two-year-old fourspine sculpins (n = 9) were high from the core up to a distance of 0.5 mm, and thereafter remained low up to the edge of the otolith. Most of the fourspine sculpins (22 of 23 specimens) had consistently low Sr:Ca ratios in regions outside the high ratio area, i.e., from the core up to a distance 0.5 mm, suggesting long-term residence in a freshwater habitat after upstream migration. These findings indicate that most fourspine sculpins only migrate downstream to the coastal seas for spawning during their entire lives.

Taylor, Brett M.

Brett M. Taylor; Kevin Rhodes; Jennifer L. Mcllwain

University of Guam Marine Laboratory, Guam, USA

Is Bigger Really Better? A Detailed Demographic Analysis of a Grouper Spawning Aggregation in Micronesia

Although the potential for overexploitation of fish spawning aggregations (FSA) is well recognized, rarely is this phenomenon incorporated into fishery management plans. The global depletion of FSA highlights the need to monitor their timing and location, as well as quantify associated biological characteristics. Demographic data collected from otoliths of aggregating individuals provides valuable information on 1) size and age at first participation, 2) age structure, 3) possible differences in individual age- and sex-specific growth rates and 4) individual age- and size-specific reproductive output. In this study, we test the assumption that larger, older fish make a disproportionate contribution to spawning for the camouflage grouper, *Epinephelus polyphekadion*. Research-associated sampling occurred at a FSA site in Pohnpei, over four combined reproductive months in 1998 and 1999. FSA samples were compared to market samples from non-reproductive periods. Like other tropical groupers, we found *E. polyphekadion* is relatively long-lived (20+ years) and slow-growing (K = 0.23/yr). Ages for FSA-derived fish ranged from 4 to 22 yrs. There were no apparent sex-specific growth differences and the oldest year classes had equal sex ratios. The FSA had higher mean ages (10.7 yrs) and a greater proportion of older fish than market samples (mean = 6.9 yrs). The mean age from the 1999 FSA was significantly lower (9.8 yrs) than that of 1998 (11.6 yrs). We discuss the need for a better understanding of the relationship between size, age and reproductive potential in this and other tropical reef fish.

Taylor, Matt

Matt Taylor; Iain Suthers

University of New South Wales

Puberty Blues: Ontogenetic Changes in Sub-Adult *Argyrosomus japonicus* (Sciaenidae)

Mulloway, *Argyrosomus japonicus* (Sciaenidae), develop protuberant concretions on the distal surface of the sagitta, which become smoother and less lobular with increasing size until c. 400 - 500 mm total length (TL). After 500 mm TL, concretionary smoothness does not further increase with size. The potential role of these structures have not yet been evaluated for juvenile and sub-adult fish. Otolith shape was described using a perimeter:surface area ratio (PSA) of transverse otolith sections, and this was related to changes in morphology of the caudal fin, changes in habitat use and migration, and changes in dietary piscivory. Caudal aspect ratio increased abruptly between 401 - 500 mm TL, coinciding with an increase in percentage of fish in the diet. This was followed by a change in otolith morphology, and a change in habitat use and migration patterns. Significant differences in PSA between 100 mm size classes of mulloway occurred for fish < 500 mm TL, whilst CAR was significantly different for fish < 400 mm TL and > 400 mm TL, confirming the transition commenced with a change in fin shape, prior to otolith morphology. Principle component analysis of morphology revealed a transition at 500 mm TL, consistent with an observed shift in the diet from invertebrates to fish, and a shift in foraging habitat from deep riverine to shallow riverine habitat. These factors indicate a major ontogenetic change occurring in pre-mature fish between 300 - 500 mm TL. Results are compared with otolith morphology and ecology of other Australian Sciaenidae.

Terwilliger, Mark

Mark Terwilliger; Douglas Markle; Tamal Reece

Oregon State University

Annual Growth and Production of Lost River Suckers From Upper Klamath Lake During the Last Century

The Lost River sucker (*Deltistes luxatus*) is endemic to the Upper Klamath Basin of northern California and southern Oregon. Upper Klamath Lake in south-central Oregon is the primary refuge for the species. Although historically abundant, Lost River suckers were listed as endangered in 1988 due to ageing and declining populations, caused by apparent recruitment failure since the early 1970s. These population declines were due, in part, to the existence of a sport fishery on spawning adults. We examined otolith microstructure of adult Lost River suckers from two periods: historical collections made during spawning runs in 1970, and contemporary collections made by the U.S. Geological Survey from 2001-2006. Validated annuli indicated that Lost River suckers aged in this study were long-lived; the maximum age observed was 57 years, 13 years older than the previously reported maximum age. Significant differences existed in length and age distributions between historical and more contemporary collections. Age and birth-year distributions of contemporary collections showed a lack of diversity when compared to historical collections; few fish were born prior to 1988, indicating that the closure of the sport fishery in 1988 was a key step in protecting the species from extinction. Growth appears relatively rapid up to age 10, after which growth slows considerably and appears determinate for both sexes, such that a 650 - 700 mm fish can be from 10 to 57 years old.

Thompson, Josie E.

Josie E. Thompson; Robert W. Hannah

Oregon Department of Fish and Wildlife

Using a Dendrochronological Approach to Examine Possible Relationships Between Redbanded Rockfish (*Sebastes babcocki*) Growth and Climate in Waters off the Coast of Oregon

Fishery management regulations have recently shifted much of the groundfish trawl effort in the eastern Pacific from the continental shelf to the slope, potentially increasing fishery impacts on demersal slope rockfish species. Understanding the life history of these species and how they may be affected by climate are critical pieces of information for developing sound fisheries management strategies. The redbanded rockfish (*Sebastes babcocki*) is a slope rockfish species for which life history information is quite limited, though it is commonly found in commercial trawl landings along the west coast of the U.S.. In this study we apply dendrochronology (tree-ring) methods and the cross-dating approach to otolith growth increments in order to develop a growth chronology for redbanded rockfish found off the coast of Oregon. The master chronology will be developed by averaging the detrended time series of growth increment measurements from individual specimens. The final result will be correlated with the average annual sea surface height, Northern Oscillation Index, and Pacific Decadal Oscillation. A significant correlation between the master chronology and climate indices will not only provide information about how redbanded rockfish growth may be affected by climate, but it can also help to validate the assumptions of the age reading method. Finally, we will present some comparisons between the redbanded rockfish master chronology and growth chronologies which have been developed for other west coast rockfish species in this same latitudinal region, including splitnose rockfish (*Sebastes diploproa*) and aurora rockfish (*Sebastes aurora*). Preliminary growth parameters will also be presented.

Thorrold, Simon

Simon Thorrold[1]; Lisa Natanson[2]; Leah Houghton[1]; Gregory Skomal[3]

Woods Hole Oceanographic Institution[1]; NOAA National Marine Fisheries Service[2]; Massachusetts Marine Fisheries[3]

Integrating Ecogeochemistry and Satellite Archival Tagging to Resolve Migratory Connectivity of Basking Sharks in the Western Atlantic Ocean

The world's second largest fish, the basking shark (*Cetorhinus maximus*), is broadly distributed in boreal to warm temperate latitudes of the Atlantic and Pacific oceans from shallow coastal waters to the open ocean. We present new data from popup satellite archival transmitting (PSAT) tags and a novel geolocation technique that demonstrates that basking sharks range much further than previously thought and are seasonal migrants to mesopelagic tropical waters. Tagged sharks moved from temperate feeding areas off the coast of southern New England to the Bahamas, the Caribbean Sea and onward to the coast of South America and into the Southern Hemisphere. When in these areas, basking sharks descended to and, in some cases, remained at mesopelagic depths for weeks to months at a time. However PSAT tags cannot provide information on lifetime movements of basking sharks. We are therefore determining if compound specific stable isotope analyses of vertebrae may shed light on migration pathways of basking sharks throughout their lives. Stable C and N ratios of amino acids in vertebral bands, along with radiocarbon analyses of vertebral collagen, can provide information on diet and, perhaps, geographic location at specific life history stages. The approach may also prove useful for determining the frequency of basin-scale migrations in adult basking sharks. We hope that the integration of PSAT tagging and ecogeochemistry will shed new light on the remarkable migrations of basking sharks and highlight the need for global conservation efforts throughout the species range.

Thorrold, Simon

Simon Thorrold[1]; Serge Planes[2]; Geoffrey Jones[3]; Michael Berumen[1]

Woods Hole Oceanographic Institution[1]; Ecole Pratique des Hautes Etudes - CNRS, Universite de Perpignan[2]; James Cook University[3]

Tracking Dispersal of Clownfish Larvae in a Network of Marine Reserves Using TRAnsgenerational Isotope Labeling (TRAIL) and DNA Parentage Analysis

Direct estimates of larval dispersal in marine environments are rare due to the logistical difficulties associated with tagging tiny larvae that quickly diluted in vast volumes of water and suffer extremely high mortality rates. Here, we describe two new tagging methods that aim to directly measure local retention and dispersal of reef fish larvae. The first technique, TRAnsgenerational Isotope Labeling (TRAIL), relies upon maternal transmission of enriched barium isotopes to embryonic otoliths of reef fishes. Otoliths from juvenile fish are then screened for the unique isotope tags using laser ablation inductively coupled plasma mass spectrometry (ICP-MS). The second technique assigns recently settled juveniles to their parents using DNA microsatellite loci. In clownfish (*Ampriprion percula*), where adults inhabit a single anemone for their entire adult lives, the approach allows for remarkably precise estimates of dispersal distances. Estimates of self-recruitment to a small marine reserve were remarkably high (40-60%), but varied significantly between years. We have also tracked larvae for distances up to 35km from their natal reef, suggesting that at least some individuals do indeed disperse long distances. Together, the techniques are providing unique descriptions of population connectivity among coral reef reserves in a network of marine reserves along the north coast of New Britain, Papua New Guinea.

Tomaro, Londi

Londi Tomaro; Jessica Miller

Department of Fisheries and Wildlife, COMES, HMSC, Oregon State University

Survival of Mid-Upper Columbia River Spring Chinook Salmon: the Effects of Size and Growth During Migration.

Survival to recruitment in Pacific salmon is of interest to scientists studying population regulation and managers focused on predicting future abundance. Certain populations are of particular interest, such as mid-upper Columbia River (MUCR) spring Chinook salmon (SpCS), because they are included in an evolutionarily significant unit (ESU) listed as endangered under the Endangered Species Act. Evidence is accumulating that salmon survival is dependent on ocean conditions during early marine residence. However, this stock overwinters in freshwater and moves quickly downriver, through the estuary, and into the ocean as yearlings. Therefore, their survival may be more dependent on the interaction between river and ocean conditions than other stocks. To test this we examined the relationships between survival of MUCR SpCS and size-at-freshwater exit, and growth rates during migration and estuarine residence. Yearling SpCS used in this study have been collected off the coast of Washington and Oregon from 1998-2008, and were identified as part of the MUCR ESU using a coastwide microsatellite DNA baseline. The pairing of otolith chemical and structural analyses is an ideal methodology to differentiate between freshwater and brackish/ocean residence, back-calculate growth rates and size-at-freshwater exit, and determine dates of freshwater exit for individual fish. We used otolith structural and chemical (Sr:Ca and Ba:Ca) analyses to collect the above mentioned data for fish sampled in four years (1999, 2003, 2004, 2006). Juvenile Chinook salmon catch in the nearshore ocean was positively correlated with the abundance of 3-yr old SpCS at Bonneville Dam, the lowest mainstem dam, lagged two years (Rsq = 0.79). Mean back-calculated size-at-freshwater exit was positively related to the abundance of 3-yr old SpCS at Bonneville Dam lagged two years. Mean back-calculated growth rates during juvenile brackish/ocean residence were positively related to the catches of interior SpCS juveniles in the near shore ocean. Therefore, conditions that facilitate growth in both freshwater and brackish/ocean habitats are important factors influencing smolt-to-adult survival of this stock.

Trueman, Clive

Clive Trueman

University of Southampton

Metabolic Rates and Life Histories in Deep Water Fish

Deep water fish communities are adapted to low light, low nutrient availability, low temperature, high pressure environments. The physiological adaptations to these conditions are diverse, but difficult to study as animals cannot be raised experimentally. Life histories of deep water fish are particularly interesting but direct observation of behaviour and determination of metabolic rates is extremely difficult in these inaccessible environments. The carbon in otolith aragonite is derived from dietary (isotopically light) carbon and dissolved inorganic carbon. The isotopic composition of carbon in otoliths is therefore controlled in part by the proportion of metabolically derived carbon within the blood, and consequently metabolic rate. While the precise relationship between activity, metabolic rate and d13C values is uncertain, large variations in the proportion of metabolically derived carbon in otoliths are seen both between species and ontogenetically within individuals, and have been used as a proxy for relative (field) metabolic rates. Here I present isotopic reconstructions of ontogenetic depth migrations and relative metabolic rates in a range of fish caught between 500 and 1500m depth on the NE Atlantic slope, as derived from the stable isotope composition of sub-sampled otoliths. Slope dwelling fish exhibit a range of depth migrations and metabolic rates, suggesting a diversity of life history and metabolic patterns. Orange roughy (*Hoplostethus atlanticus*) undergo complex vertical migrations, revealed by oxygen isotope patterns. In all fish, carbon isotope ratios and presumably relative metabolic rates decrease with increasing depth, but the assemblage of fish found at any single depth exhibit varying carbon isotope compositions, generally corresponding to behavioural traits predicted from body morphology and flesh composition. The stable isotope composition of otoliths appears to be a promising store of evidence for the study of elusive deep water fish.

Tsukamoto, Katsumi

Katsumi Tsukamoto; Tsuguo Otake; Michael Miller; Yukio Yamasaki; Kenji Mochizuki

Ocean Research Institute, The University of Tokyo

Migratory Ecology of Amphidromous ayu in the Coastal Waters of Japan Revealed by Otolith Aging

The ayu, *Plecoglossus altivelis*, is an amphidromous osmeriform fish that lives in East Asia, and has one of the most beautiful otoliths of all fish species in the world. An extensive study was conducted to learn about the distribution and larval migration of ayu in the Pacific coastal waters in Wakayama, Japan, using otolith analyses of larvae collected during three years of surveys. The density of larvae decreased from the estuary to offshore and the distribution of larvae was limited to only within 2.5 km of the shore, where there was an effect of freshwater from rivers, with no larvae being collected in intensive surveys 2.5-5.0 km offshore. An aging technique with ayu otoliths was used to examine their larval migration patterns and habitat shifts during their oceanic phase, which has been poorly understood so far. Comparison of frequency distributions of age and body size of the larvae suggested clear habitat shifts from the surface layer of coastal waters to the surf zone and then into the estuary just before their upstream migration in spring. The individuals that were born earlier in the spawning season of the last autumn recruited to the surf zone earlier in the next spring, and vice versa for later spawned individuals. The age and body size of larvae collected in the surf zone increased from October to April, while their growth rate decreased during the sampling season. A similar correspondence between recruitment timing and hatching date, age, size and growth rate was observed in estuarine and freshwater habitats, suggesting that this pattern was an important characteristic of their larval development and migration. A gap in the age and size distributions of the early born fish suggested that other habitats were used during the transitions from the coastal surface layer to the surf zone, and from the surf zone to the estuary, which were determined to be in the bottom layer near the surf zone by collection of larvae in those habitats. The precise age determination using otoliths in the ayu was a key factor that enabled the whole migration route of larvae of the species in coastal areas to be revealed.

Tzeng, Wann-Nian

Wann-Nian Tzeng[1]; Nien-Tzu Yeh[2]; Kang-Ning Shen[2]; Yoshiyuki Izuka[3]

Department of Life Science, National Taiwan University, Taipei, Taiwan[1];Institute of Fisheries Science, National Taiwan University, Taipei, Taiwan[2]; Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan[3]

The Larval Dispersal of Giant Mottled Eel *Anguilla marmorata* as Indicated by Otolith Daily Growth Increment and Sr/Ca Ratios

The tropical eel *Anguilla marmorata* is a catadromous fish, growing in the river and spawning in the ocean. Mitochondrial DNA study indicated that this species in the adjacent waters of the Philippines, Taiwan and Japan may be a panmictic population coming from the same spawning ground. However, how they populate these countries and the process of their larval transport are not clear. This study attempted to determine the age at metamorphosis from leptocephalus to glass eel (Tm), and the age of glass eel at estuarine arrival (Tt) by their otolith growth increment by using scanning electron microscope (SEM). Tm was determined with reference to metamorphosis check and the Sr/Ca ratio in otolith measured by electron probe micro analyzer (EPMA). Five spatial and temporal samples of *A. marmorata* glass eel were collected from the Philippines, Taiwan and Japan. Mean (±SD) Tm and Tt were 95.36±14.09 days and 131.21±15.2 days for the specimen from the Philippines, 104.38±12.34 days and 126.99±15.35 days for Taiwan and 109.17±16.79 days and 137±17.83 days for Japan, respectively. The duration from metamorphosis to estuarine arrival (Tt-m) were 35.85±80.67, 22.61±6.64 and 27.29±8.9, respectively. Analysis of variance (ANOVA, P 0.05) indicated that Tm, Tt-m and growth rate before metamorphosis (Gm) were all significantly different among locations. These indicated that the age of leptocephalus at metamorphosis, which was correlated to their growth rate, may play an important role in determining the latitudinal distribution of *A. marmorata*. Mean (±SD) Tm and Tt of the three temporal recruitment samples from Taiwan were 104.38±12.34 days and 126.99±15.35 days in May, 119.38±14.52 days and 129±15.18 days in July and 125±10.7 days and 145±6.01 days in November, respectively. ANOVA indicated that Tm and Tt were significantly different between May and November samples but no difference between May and July, and between July and November. These suggested that the difference in growth rate of different leptocephalus cohorts and oceanic current speed at different seasons of the year may also contribute to the differences in Tm and Tt of temporally-different leptocephalus cohorts.

Vasconcelos, Rita

Rita Vasconcelos; Patrick Reis-Santos; Maria Jose Costa; Henrique Cabral

Instituto de Oceanografia - Faculdade de Ciencias da Universidade de Lisboa

Connectivity Between Estuaries and Marine Areas: Integrating Metrics to Assess Multiple Species Nursery Role of Estuaries

Estuaries provide putative nursery grounds for many marine fish species and play a fundamental role in supporting coastal adult stocks. Considering the ecological and economic relevance of nursery function and its likely variation among systems, due to both differences in habitat quality and quantity, it is essential to promote comprehensive assessments of nursery function and identify the estuaries that fulfil the nursery and effective juvenile habitat definitions, in particular by quantifying their connectivity with coastal populations. Nursery function of the main estuarine systems along the Portuguese coast (NE Atlantic) were assessed for four economically important fish species that use these areas simultaneously (*Solea solea, Solea senegalensis, Platichthys flesus* and *Dicentrarchus labrax*), based on the integration of data on: 1) juvenile condition - proxy for habitat quality; 2) coverage of high density juvenile areas - measure of habitat quantity; 3) juvenile densities as well as estimated total juvenile abundances - measure of potential juvenile export from estuarine to coastal environments; and 4) retrospective identification of nursery origin of fish from coastal marine habitats via otolith elemental chemistry - measure of effective connectivity and juvenile export. Otolith elemental fingerprints, combined with the remaining metrics, were a fundamental tool in the identification of the differential nursery role of the analysed sites. Estuaries fitting the nursery, sensu stricto, and effective juvenile habitat concepts were identified. These varied with species and identifying an area as an effective nursery for a species did not imply that it will be of equivalent importance for the remaining present species. Overall estimates of potential juvenile export, accomplished through the combination of habitat quantity and juvenile data, concurred with the effective connectivity estimates carried out with otolith chemistry. Results highlighted the significance of multi-species assessments towards evaluating the importance of these estuarine systems for marine populations and prioritizing management and conservation strategies.

Vasil'kov, Valeriy

Valeriy Vasil'kov

Vladivostok State University of Economics and Services, Russia

Computer-Aided Age Estimation Techniques Using Calcified Structures

The major objectives of this study are to find methods and algorithms for mass age estimation, to automate the process and to improve quality control. Image analysis systems and specially developed software packages were applied. Computer-aided aging techniques (CAAT) were developed and tested on fish scales, whole and broken and thin-sectioned otoliths, thin-sectioned shells from 15 fish and non-fish species. The variety and the heterogeneity of growth patterns, the multiple quasi-periodicity of bands, the unstationary nature and the noisiness of brightness profiles were some of the primary problems. A few mathematical approaches, such as spectral power function, and the adaptive joint interpolation of transects have been developed to manage these problems. The advice on how to overcome these problems are given. There is a clear-cut distinction in the image enhancement algorithms between Rockfish and Gadidae otoliths, and between whole and broken otoliths. Algorithms for anomalous and imperfect specimens should be set up specially. Due to image enhancement, destructive otolith burning can be avoided. Computer-aided technique applications allow age validation, precision control, and more accurate aging in older Rockfish and imperfect specimens (checks, double rings, etc.) are shown. The true Pacific Halibut otoliths ages proven by tagging-recaptured data have been obtained. Statistical tests on the discrepancy between halibut routine age reading by human readers and the true ages indicated a significant discrepancy. Halibut age estimates by CAAT were very reliable. Three kinds of CAAT have been compared. Fully automatic age reading, although many times faster than human age reading, produces errors in anomalous and imperfect specimens. Computer-aided anomalous and imperfect specimen analysis, though quite slow, produces a greater benefit in quality. Interactive semi-automatic age reading, including increment verification in imperfect specimens, produces a compromise between speed and quality.

Villacorta-Rath, Ana Cecilia

Ana Cecilia Villacorta-Rath[1]; Mark McCormick[1]; Mark Meekan[2]

James Cook University[1]; Australian Institute of Marine Science[2]

Environmental Determinants of Growth and Selective Mortality of the Fast-Growing Clupeid, *Spratelloides delicatulus*

Larvae and juveniles of the fast-growing clupeid *Spratelloides delicatulus* were collected during November and December of 2006 at Lizard Island (14 degrees 40 minutes S, 145 degrees 28 minutes E) using light traps. To examine the selectivity of mortality, monthly cohorts were sampled twice, with each collection separated by a week. (n = 50 fish per month). Otolith analysis was then used to back-calculate growth rates and size-at-age. These variables were compared between successive samples of the same cohort to determine if selective mortality had taken place over the summer. During November larvae attained mean standard lengths (SL) and growth rates of 18.08Â±0.22 mm and 0.59Â±0.01 mm.d-1, respectively, while mean juvenile SL and growth rates were 29.3Â±0.85 mm and 0.52Â±0.08 mm.d-1, respectively. In December, SL and growth rates averaged 19.72Â±0.2 mm and 0.68Â±0.02 mm.d-1 in larvae; while juveniles averaged 28.43 mm SL and growth rates of 0.51Â±0.07 mm.d-1. Repeated-measures MANOVA comparisons suggested that the intensity of size-selection experienced by *S. delicatulus* larvae depended on size-at-hatching and growth rates during the early larval stage. The slow growing cohort underwent size-selective mortality at the late larval phase, corresponding from 15 to 21d of age. There was a strong relationship between growth rates of these fish from 9 to 21d of age and temperature and chlorophyll a concentration, suggesting that slow growing larvae were more vulnerable to variability in environmental conditions. These findings highlight the importance of growth rate triggering size-selective mortality of *S. delicatulus* during the late larval stage.

von Biela, Vanessa R.

Vanessa R. von Biela[1]; Christian E. Zimmerman[1]; Lawrence L. Moulton[2]

U.S. Geological Survey, Alaska Science Center[1]; MJM Research[2]

Long-Term Variability of Arctic Cisco Growth Rates: Using Otolith Growth Rates to Test for Evidence of Environmental Control

Arctic cisco (*Coregonus autumnalis*) are an important resource in northern Alaska and subsistence users have expressed concern over declines in harvest and size of Arctic cisco from the Colville River. We measured otolith growth of 901 individuals captured in subsistence fisheries in the Colville River between 1986 and 2007, representing 25 year classes (1978 - 2003), to compare growth with environmental variables. Otolith growth was linearly related to somatic growth (linear regression, $r2 = 0.84$, $P < 0.0001$). The first 8 annual growth increments exhibited significant inter-annual variation in growth (one-way ANOVA for each annulus, $P < 0.05$) with most growth occurring in the first annulus. Young-of-the-year (YOY) otolith growth rates were analyzed separately from other years in relation to environmental variables. In all cases, comparisons were made using linear regression weighted by sample size and significance was set at 0.05. YOY growth was positively related with the winter Arctic Oscillation index (Nov-Mar, $r2 = 0.19$), mean summer air temperature at Inuvik in the Mackenzie River Delta (June-July, $r2 = 0.15$), mean speed of east wind at Barrow, Alaska (July-Aug, $r2 = 0.16$), and mean Mackenzie River discharge at Ft. Simpson lagged 2 years (April-June, $r2 = 0.50$). The residual growth of older juveniles (annuli 3-8) was positively related to the winter Arctic Oscillation index ($r2 = 0.16$), summer air temperature at Barrow (June-September, $r2 = 0.47$), and the mean Kuparuk River discharge at Deadhorse in the current year (May-September, $r2 = 0.22$). The lagged river discharge relationship may represent the time needed for prey resources to react to increased nutrient availability associated with increased river discharge, while the unlagged correlation is more likely to index the nearshore salinity. These results suggest that YOY growth is most strongly related to nutrient discharge (lagged river discharge) while older juvenile growth is most strongly related to the current physical environment (temperature and current discharge). Growth curves are also being examined for changes in the pattern of growth across the entire juvenile stage.

Walther, Benjamin

Benjamin Walther[1]; Mike Kingsford[2]; Malcolm McCulloch[1]; Mark O'Callaghan[2]

Australian National University, UT Marine Science Institute[1]; James Cook University[2]

Validating Otolith Ba/Ca as a Proxy for Environmental Change in Marine Habitats

Temporal variation in otolith chemistry may be used to reconstruct time series of fluctuating environmental parameters in the marine environment. This approach has been successfully employed with carbonate skeletons of corals to track shifts in temperature, salinity, and terrigenous or upwelled nutrient pulses to coral reef habitats. We describe an experimental validation of elemental uptake in otoliths of a site-attached damselfish. We experimentally manipulated temperature and food intake for juvenile, subadult and adult fish. We show the influence of life history stage growth rates on discrimination coefficients for Ba/Ca and other elemental ratios. We compare our results to Ba/Ca discrimination coefficients reported for other species and systems, and discuss the requirements that must be met before this method is employed in natural settings. This experiment lays the groundwork for a reconstruction of river runoff and upwelling events on the Great Barrier Reef using paired otolith and coral elemental profiles.

Walton, Joanne K.

Joanne K. Walton; Joe Scutt-Phillips; Graham Pilling; Sally Songer

CEFAS, Lowestoft, UK

Otoliths and Maturity: Using Otolith Features to Examine the Impacts of Fishing on Plaice Populations

It has long been known that intensive fishing pressure may lead to both phenotypic and genetic changes to the life history of an exploited population. European Plaice (*Pleuronectes platessa*) is one such population where intensive exploitation may have caused a reduction of the length and or age at maturity. We used images of sectioned plaice otoliths from Irish and Celtic sea stocks caught between 1998 and 2008 to analyse the formation of annual increments in combination with biological information (e.g. length, maturity, whole body weight) recorded at capture, with the aim of looking for evidence of changes in maturation patterns. These changes will be related to environmental and anthropogenic covariates in an attempt to identify potential relationships. The use of images as opposed to traditional microscope methods provides an easily accessible record that can be compared, layered and manipulated in order to identify the trends in otolith features. Images of otoliths from same age individuals of known maturity, captured during each year of the time series were super-imposed upon each other resulting in a combined image. This highlights common features in the otolith macrostructure. In order to achieve this, images required scaling to take account of individual variability in growth. These images were compared between years to identify any macro-structural variance that has occurred. The study also identifies further work determining age at maturity from otolith formation alone, so that even fish caught outside of the spawning season where maturity may not be so easily determined, can be used in life-history studies. By correlating this information with available temperature data, and data on changes in fishing effort across the time series, the most likely cause of phenotypic changes that have taken place in the life history of the species will be identified. Changes in maturity, along with the age structure, will affect the fecundity of individuals and therefore a population's ability to recover in the event of collapse; for this reason accurate biological parameters for commercially exploited stocks are essential for the sustainable management of a species.

Weber, Peter

Peter Weber[1]; Rachel Barnett-Johnson[2]; Corey Phillis[3]; Bruce MacFarlane[4]; John Wikert[5]; Michelle Workman[6]

Lawrence Livermore National Laboratory[1]; University of California, Santa Cruz[2]; University of California, Berkeley[3]; National Marine Fisheries Service[4]; U.S. Fish and Wildlife Service[5]; East Bay Municipal Utility District[6]

Otolith Sulfur Isotopes and Microstructure Demonstrate that Hatchery Salmon Dominate Spawning on the Mokelumne River, California.

Impacts of hatchery-produced salmon on the long-term sustainability and persistence of naturally spawned salmon have been difficult to assess. In California's Central Valley (CCV), population estimates of natural origin salmon are inferred from survivorship estimates of coded wire tag (CWT) marked hatchery fish recovered in commercial and recreational fisheries, spawning ground surveys, or when adults return to hatcheries to spawn. Due to the small proportion of CWT marked fish (historically <10% of hatchery releases), population estimates rely on large expansions from few returned tags introducing substantial error with an underlying assumption of equal survival rates for wild and hatchery fish. This study seeks to increase the accuracy and precision of current estimates. We previously developed otolith-based microchemistry (sulfur isotopes) and microstructure (growth patterns) methods to identify hatchery and naturally produced salmon in the CCV. These methods rely on signatures that result from the feeding and rearing differences between the fish in a hatchery and the wild. For this study, we have applied both methods to determine the relative abundance of hatchery and naturally reared adult spawners in the CCV Mokelumne River and the associated hatchery. The methods agree well, and based on validation included during the study, the microchemistry data provide higher accuracy (>95% vs. 90%). Our results show that in the total population 3% (1 to 8% 95% CI) of adults returning to spawn are naturally reared, which is within error of the relative proportion of natural and hatchery juvenile Chinook salmon production in the system. The microchemistry data for the river and hatchery show a higher proportion of natural origin spawners in the river as compared to in the hatchery (approximately three-fold).

Wells, David

David Wells[1]; Jay Rooker[1]; David Itano[2]

Texas A&M University[1]; University of Hawaii[2]

Nursery Origin of Yellowfin (*Thunnus albacares*) and Bigeye Tuna (*Thunnus obesus*) in the Hawaiian Islands

Refining our understanding of population structure and varying degrees of stock mixing is critical to the effective management of Western Central Pacific Ocean (WCPO) tuna stocks. The purpose of this study is to determine whether chemical signatures in the otoliths of yellowfin and bigeye tuna in the WCPO are sufficiently distinct to be useful as "natural tags" indicating nursery origin. Chemical signatures (stable isotopes and trace elements) in the otolith cores of age-0 yellowfin and bigeye tuna from six areas in the WCPO were assessed in 2008. Significant differences (MANOVA $p < 0.01$) in otolith composition were found among all areas for both species. Otolith cores of yellowfin tuna from the Hawaiian Islands showed differing chemical signatures (i.e., enriched 18O) relative to conspecifics from equatorial nursery areas with overall cross-validated classification success of 87%. In addition, otolith cores of bigeye tuna from the central Equatorial Pacific had different chemical signatures than fish collected from western Equatorial Pacific nursery areas with 82% classification success. Results indicate the approach has promise for distinguishing individuals of both species from different nurseries in the WCPO. Assessment of inter-annual variability in chemical tags is currently in progress using a second year (2009) of age-0 chemical signatures. Moreover, isolated otolith core material (~ comparable to age-0 period) of age-1 and age-2 yellowfin and bigeye tuna are underway to determine the nursery origin of these individuals.

Whitten, Athol

Athol Whitten[1]; Gary Jackson[2]

The University Melbourne, Victoria, Australia[1]; Western Australian Fisheries and Marine Research Laboratories[2]

Investigating Density-Dependent Growth in Snapper (Sparidae) in Shark Bay, Western Australia

Understanding density-dependent growth processes is critical to the predictive capabilities of fisheries models and thus management. In fish stocks that have declined and recovered, otolith growth increment measurements are likely to reveal how somatic growth rates vary with population densities and thus affect stock dynamics. Here we investigate a large collection of archived Snapper (*Pagrus auratus*) otoliths from the Eastern Gulf of Shark Bay. The otoliths were collected from a mostly recreationally fished stock that became depleted around 1995-96, leading to the closure of the fishery between 1998-2003. Egg production-based surveys and age-based stock assessment modelling indicate that spawning biomass in the Eastern Gulf declined, by ca. 1997-1998, to as low as 10% of the unexploited level. Spawning biomass was estimated to have recovered to around 60% of unexploited level by 2005. We utilised otolith growth increment analyses to examine the relationship between changing stock densities and somatic growth rates. Preliminary analysis reveals that within-cohort variation in otolith growth is low and cohorts that experienced very different population densities exhibit differences in otolith growth. Information from this study will be used to enhance existing population dynamics models and in the management of Shark Bay snapper stocks.

Wickstroem, Hakan

Hakan Wickstroem

Swedish Board of Fisheries, Institute of Freshwater Research

Individual Growth in Two Otolith-Marked Stocked Eel Populations.

As part of the Swedish eel stocking program some introduced eel populations are monitored with respect to growth, size at silvering, sex ratios and recapture rates. This is done by using outlet traps and/or by test-fishing with fyke nets. In two of these stocking experiments, fish were either otolith-marked with Alizarin Complexone or with strontium chloride (SrCl2) before being released. A considerable number of the Sr-marked eels were also PIT-tagged allowing us to study growth on an individual basis. A cove in mesotrophic Lake Malaren was stocked in 1997 with 5,000 Alizarin-marked glass eels of about 1 g each. Lake Ymsen, a more productive lake, was stocked in 1999-2002 with 17,768 eels weighing 0.9 to 20.1 g. In total 2,627 of them were tagged with PIT-tags. The introduced population in Lake Malaren was monitored annually since 1997 and analysed for fluorescence in their otoliths. From Lake Ymsen we have access to all PIT-tagged eels that were recaptured and detected as tagged by a local fisherman. Since the first recaptures were found in 2000 and 2004 in Lakes Malaren and Ymsen, respectively, we now have enough material to analyse and present some results on growth in stocked eels from two very different types of lakes. The eels in Lake Malaren have grown from 95.3 mm at stocking in 1997 to 508 mm in 2008, i.e. 37.5 mm year-1 when corrected for size at stocking. In Lake Ymsen the corresponding datum is 56 mm year-1. There is also a quite considerable temporal variation in growth rates. In Lake Malaren the first recaptures (e.g. from 2002) had grown very fast (by North European standards), viz. with 66.3 mm year-1 compared to 37.5 mm year-1 in 2008. Annual growth decreased continuously over time (by age) in Lake Malaren. In Lake Ymsen however, there is a tendency to higher growth rates in more recent recaptures. These results and differences between lakes are discussed with respect to trophic status, individual growth potentials, size at stocking and the difficulties in defining what growth in an ageing eel cohort actually is.

Wilhelm, Margit R.

Margit R. Wilhelm[1]; Jean-Paul Roux[2]; M. Deon Durholtz[3]

Marine Biology Research Centre, University of Cape Town, South Africa[1]; Ministry of Fisheries and Marine Resources, Namibia[2]; Marine and Coastal Management, Cape Town, South Africa[3]

Indirect Age Validation of the Shallow-Water Hake *Merluccius capensis* in the Northern Benguela Using Otoliths From Monthly Seal Scat- and Annual Demersal Survey Samples

Merluccius capensis Castelnau is one of the two hake species that commonly occur in the northern Benguela region making up Namibia's most valuable commercial fishery. They are managed in the form of an annual TAC (total allowable catch) and for this are assessed annually using an age-structured production model. So far no validation of hyaline bands on M. capensis otoliths has extended beyond the first two years of age. In this paper we attempt to validate the seasonal formation of hyaline bands using otoliths of young (0.25- to 1.5-year-old) hake obtained from seal scat (SS) samples collected at monthly intervals from seven seal colonies in Namibia. Cohorts identified from otolith diameter (OD) measurements from these monthly samples are easily distinguishable. They could thus be complemented by otoliths of older hake collected during annual demersal surveys from the same cohort, based on growth projections from the SS samples and progressive survey length frequency distributions. About 6000 otoliths from five strong cohorts (spawned in 1996, 1998, 2002, 2005 and 2006) were analysed measuring OD of each hyaline band. We used fitted ogives on % number of complete bands against collection date and against OD to estimate date of completion and approximate OD of each band. Fish lengths back-calculated from OD were compared to expected mean lengths (projected from SS samples) and observed mean lengths-at-age. Our results suggest that survivors of each cohort stem from different months each year, always spanning winter to spring (June-Sept). The first hyaline band is usually formed (the following) late summer to autumn (Feb-Apr) depositing at between 5 and 7 mm OD. A second band is formed late winter to spring (July-Sept) at 7-8 mm OD, representing the first true annulus. A third band is again formed in summer (Jan-Feb, 8-12 mm OD). This biannual formation of hyaline bands seems to continue until at least four years of age. The implications are that ages for this species have previously been over-estimated and growth under-estimated, potentially resulting in erroneous age-length keys used for stock assessment and management.

Williams, Jonathan

Jonathan Williams[1]; Daniel Pondella II[1]; Eric Miller[2]

Vantuna Research Group - Occidental College[1]; MBC Applied Environmental Sciences[2]

Life History of the Spotfin Croaker (*Roncador stearnsii*) in the Southern California Bight

To further our understanding of the common nearshore fishes of southern California, life history parameters were studied for spotfin croaker (*Roncador stearnsii*). Plankton tows were performed near Huntington Beach Generating Station in 2004 where 120 larval spotfin croaker samples were captured. A total of 935 juvenile and adult spotfin croakers were captured in heat treatments, beach seines and gill net surveys from 1994 to 2003. Day specific ages for the larvae and the year specific ages for the juveniles and adults were determined by analyzing saggital otoliths and growth parameters were calculated. Captured larvae were determined to be between three and 28 days old, and showed a distinct difference in growth between spring hatches and summer hatches. The von Bertalanffy growth parameters (Linf = 500.5, K = .1093, t0 = -3.688) show a smaller length at age than previously found using scales. The oldest fish was determined to be 24 years old - nine years older than the fish that was determined to be the oldest in previous studies.

Woodcock, Skye

Skye Woodcock[1]; Bronwyn Gillanders[1] ; Andrew Munro[1] ; David Crook[2]; Andrew Sanger[3]

Southern Seas Ecology Laboratories, DX 650 418, School of Earth and Environmental Sci[1]; Arthur Rylah Institute for Environmental Research[2]; New South Wales Department of Primary Industries, 3/556 Macauley St Albury NSW 2640[3]

Batch-Marking Otoliths of Australian Native Larval Fish Using Immersion Techniques with Combinations of Enriched Stable Isotopes

It is often difficult to distinguish hatchery-produced fish from those spawned in the wild, thus limiting the ability to properly assess the success of stocking programs. Recent work suggests that marks can be created in the otoliths of fish reared in water spiked with enriched stable isotopes. A variety of enriched stable isotopes exist, but only a few have been used to mark fish and none have attempted to mark the fish at the larval stage. We tested the ability to create multiple unique batch marks in the otoliths of the larvae of two native Australian fish, golden perch, *Macquaria ambigua* and Murray cod, *Maccullochella peelii peelii* using combinations of enriched stable isotopes. In the first experiment, seven distinctive marks were created in the otoliths of larval golden perch using three isotopes of barium (136Ba, 137Ba and 138Ba). In the second experiment, we created another set of unique marks using combinations of enriched 24Mg, 88Sr, 137Ba and 138Ba. Marking the otoliths of larval fish by spiking the water in which they are reared with combinations of enriched stable isotopes is a simple and cost-effective method of marking thousands of fish with multiple unique batch marks that could be used to identify stocked fish when evaluating fisheries enhancement programs.

Xie, Songguang

Kizhakke Veettil Radhakrishnan; Songguang Xie

Institute of Hydrobiology, Chinese Academy of Sciences

Otolith Retrieval From Feces and Reconstruction of Prey Fish Size in Great Cormorant (*Phalacrocorax carbo*) at Poyang and Dongting Nature Reserves of China

Diet studies of piscivorous birds at Nature Reserves assume high significance due to the valuable information they may provide for the conservation and harmonious co-existence of both the predator bird species and the prey fish species. We studied the diet of Great Cormorant (*Phalacrocorax carbo*) by analyzing 460 faecal samples collected from their roosting sites at Dongting and Poyang lakes, two important Nature Reserves of central China during winter season, between November 2008 and January 2009. A total of 423 fish otoliths could be retrieved and were identified as belonging to two Cyprinid fish species, *Carassius auratus* and *Parabramis pekinensis*, by comparing with a reference collection of otoliths of fish species, collected through several research voyages which overlapped temporally and spatially with the foraging activities of the bird from which the faecal samples were collected. *Carassius auratus* stood as the dominant food item, accounting for 72% of the otoliths. The otolith size (maximum length, Lo)-prey fish size (standard length, Ls) relationships determined for the two fish species were as Ls = -0.7402 + 1.0035Lo (r2 = 0.7321) and Ls = -1.0391 + 1.0521 Lo (r2 = 0.8744) respectively. The equations were then used to back-calculate prey fish size from the otoliths recovered from faeces. The level of erosion for the otoliths recovered from faecal samples were high and only sagittal otoliths (n=66, n=51 respectively) with intact margins and good medial relief and well defined sulcus were used for reconstructing prey fish size. We preferred using sagittal otoliths rather than lapillus otoliths to develop otolith-fish size relationships because they were larger and allowed for less measurement error. The bird was found to prefer *Carassius auratus* of 106.1mm±4.2 (ranged 99.2-116.2 mm) Ls and *Parabramis pekinensis* of 101.2mm ±4.8 mm (ranged 89.3-114.3 mm) Ls. Conservation of Great Cormorants in the respective nature reserves should ensure habitat protection and resource conservation of these two prey fishes.

Yamane, Kodai

Kodai Yamane[1]; Shirai Kotaro[2]; Sachinobu Yamane[1]; Yoshitomo Nahakura[3]; Takaomi Arai[1]

Ocean Research Institute, The University of Tokyo[1]; Department of Earth and Planetary Science, The University of Tokyo[2];National Center for Stock Enhancement, Fishery Research Agency[3]

Otolith Elemental Fingerprints of Pacific Herring *Clupea pallasii* in Northern Pacific Part of Japan

In order to understand life history and stock structure of the Pacific herring *Clupea pallasii* in northern pacific part of Japan, we examined the otolith chemistry using laser ablation inductively coupled plasma mass spectrometry. The adult fishes were collected from three spawning sites (Lake Obuchinuma, Miyako Bay and Akkeshi Bay) from March to May 2008. Eleven elements (Li, B, Na, Mg, P, K, Ca, Mn, Rb, Sr and Ba) were determined in transects of otolith cross-sections. The Mg/Ca ratio value in Lake Obuchinuma was relatively stable, however, the Mg/Ca ratios in Miyako Bay and Akkeshi Bay varied through their lives. These variabilities in otolith elemental ratios may reflect endogenous variations such as growth, age, and reproduction rather than differences in migration pathways. Na/Ca and K/Ca ratios of all specimens were constant throughout the lives of the fish. Additionally, mean ratios of these elements significantly differed among the three sampling sites. On the other hand, a number of individuals in the three sampling sites showed high Ba/Ca and Mn/Ca ratios at the cores of the otolith. These elevated Ba/Ca ratios suggested that most herrings in these sites might live in areas affected by riverine water during their larva and juvenile stages. The Sr/Ca ratios of the three sampling sites showed a high value from the core to around 200 um, decreased gradually from 200 um to 500 um, and then showed constant values to the edge of the otolith. This change from the core to around 500 um probably reflects endogenous factors rather than environmental factors because the region corresponded to the period of metamorphosis. A multivariate analysis of variance showed that the differences among sampling sites were highly significant. Thus, this study found that the ontogenic patterns of Ba/Ca and Sr/Ca ratios are useful tools for life history analysis. Further, Na/Ca and K/Ca ratios are excellent indicators for stock discrimination.

Yokouchi, Kazuki

Kazuki Yokouchi; Kei Zenimoto; Kagari Aoki; Jun Aoyama; Katsumi Tsukatomo

Ocean Research Institute, The University of Tokyo

An Analytical Method for Detecting the Timing of Continental Habitat Shifts in Individual Life Histories of the Japanese Eel (*Anguilla japonica*) Using Otolith Sr:Ca Transects

A method for the objective detection of habitat shifts of Japanese eels (*Anguilla japonica*) was developed using a simple sequential data analysis of otolith chemical chronology. This method consisted of Fast Fourier Transformation and smoothing by a moving average to omit high frequency noise from transect data in otoliths. To define a threshold value of habitat shifts in otolith transects, this methodology was first applied to Japanese eel otoliths in experimental conditions when the water chemistry was changed. This provided an accurate analysis of the timing of habitat shifts (seawater to freshwater) using otolith Sr:Ca ratios along an otolith growth axis. Experimental water changes were reflected as maximum values of mean moving average differences in Sr:Ca ratios that ranged from 0.463 to 0.704 (mmol/mol) in their otoliths, whereas constant water conditions showed lower values that ranged from 0.146 to 0.233. The accuracy of this method was 2.5 Âµm (range: 0.0 - 6.0, n = 4) when the diameter of the data points were 2.0 Âµm in their otoliths. When applying this method for interpreting the migratory history of silver-phase Japanese eels in each habitat use type (river, estuarine, and coastal type: determined by average Sr:Ca ratios of the whole continental-growth phase), a habitat shift was found in the estuarine and coastal eels. The potential application of this method to reconstruct individual chronologies gives an objective method for the detection of the timing of habitat shifts in the continental life history of eels, or even in eels that had a habitat shift that could not be recognized by subjective visual inspection of Sr:Ca transects.

Zabel, Rich

Rich Zabel; Kerri Haught; Paul Chittaro

NOAA Fisheries/Northwest Fisheries Science Center

Variability in Fish Size/Otolith Size Relationships Among Populations of Chinook Salmon

The growth rate of juvenile salmon is potentially an important indicator of habitat quality, and therefore understanding which factors determine growth rate is important part of developing recovery plans for the many threatened and endangered populations of Pacific salmon. We focused on Snake River Chinook, which are separated into two "Evolutionarily Significant Units" (ESUs) under the US Endangered Species Act: Snake River spring/summer Chinook that rear in high elevation streams and Snake River fall Chinook that rear in lower elevation rivers. Our overall goal is to reconstruct juvenile growth trajectories from otoliths to examine how juvenile growth rates vary across time and space and among populations. Our first step in the process, and the focus of this talk, was to develop fish length/otolith length relationships from otoliths sampled from juveniles representing both ESUs and representing several distinct populations within the spring/summer ESU. We addressed questions concerning how fish length/otolith length relationship varied across populations, the form of the relationships, and the importance of factors such as growth rate and temperature. We found distinct differences in relationships between the ESUs and more subtle distinctions among populations within the spring/summer ESU. Also, nonlinear models generally fit the data better than linear ones. We will present preliminary results on how growth trajectories varied within seasons in relationship to temperature and how growth varied across populations in response to factors such as food availability.

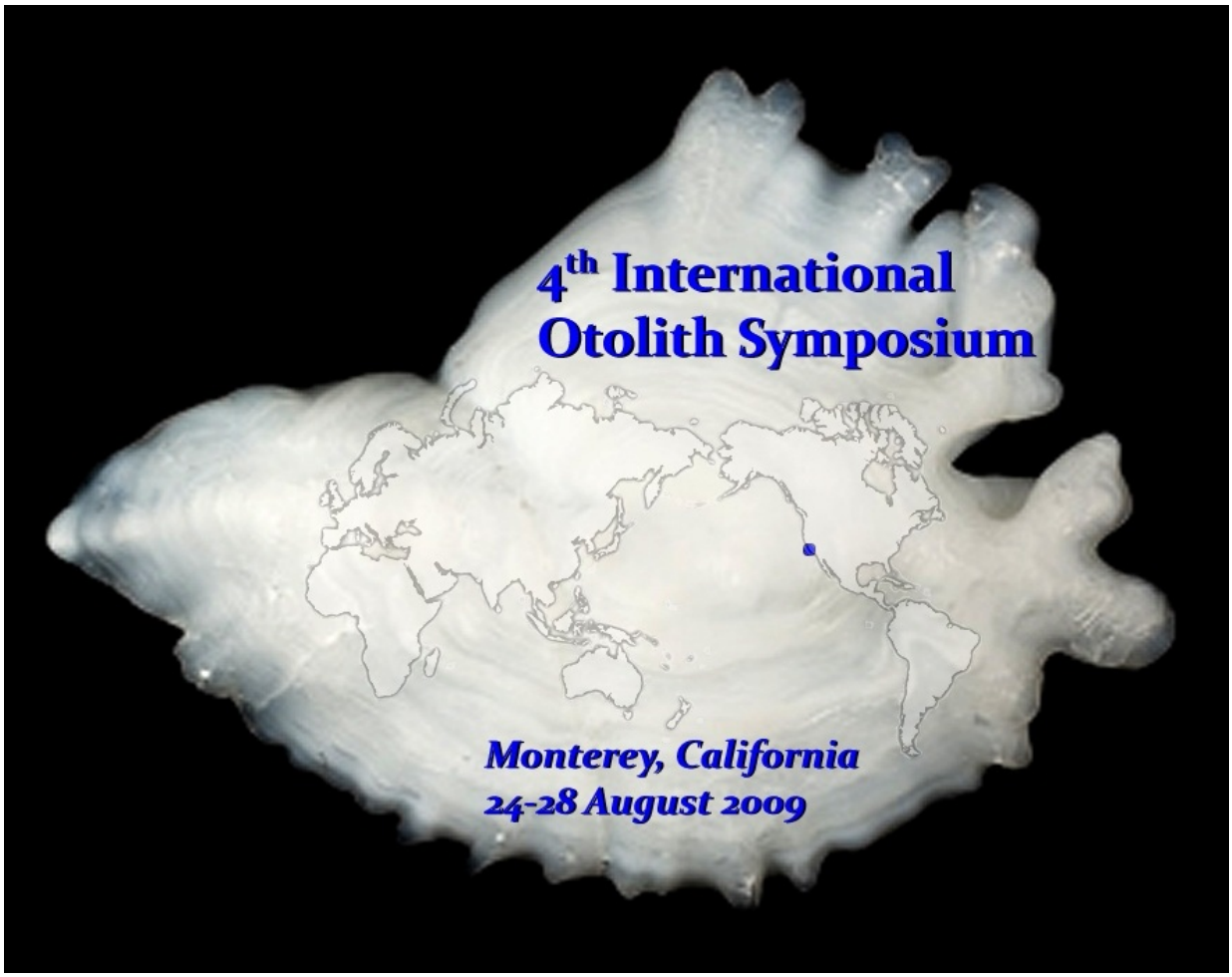
Zaki, Shama

Shama Zaki[1]; Carl Smith[2]

Ministry of Fisheries wealth, Muscat, Sultanate of Oman[1]; University of Liecester, Liecester, UK.[2]

Age and Growth of European Bitterling *Rhodeus amarus* Larvae.

European bitterling *Rhodeus amarus* fishes lay their eggs on the gills of living freshwater mussels and are valuable models in behavioural and evolutionary ecology. There have been no previous reliable attempts to examine the otoliths of larval or juvenile bitterling for the purposes of ageing. The aim of our study was to improve our understanding of the duration of spawning in bitterling and to link spawning season duration with the availability of mussels. Otolith microstructure appears to correspond to daily growth increments. The length of the spawning season in European bitterling appears to be linked to mussel availability. Based on the formation of daily growth increments, there is good evidence that larval bitterling begin exogenous feeding while still inside their host mussel. An unexpected finding of the present study was the observation that larval bitterling probably commence feeding approximately 12 days before they emerge from their host mussel.



Poster Abstracts

Angstrom, Carin — Theme: Age and Growth

Carin Angstrom; Martina Blass; Carina Jernberg; Yvette Heimbrand; Anne Odelstrom

Swedish Board of Fisheries

Comparing Two Methods for Age Determination of Herring (*Clupea harengus*) in the Baltic Sea

Herring (*Clupea harengus*) is distributed all over the Baltic Sea, which is one of the largest brackish seas in the world. The average surface salinities decline from 10-20ppt in the south to almost fresh waters in the north. Surface temperatures range from 20 °C in the summer to close to 0 °C in the winter when ice may cover up to 45% of Baltic Sea. The low water temperatures and salinities affect the herring growth in being lower in the northern compared to the southern Baltic. Low growth and smaller asymptotic length impose problems in the age determination of herring in the northern Baltic Sea, particularly in otolith samples from cold years when growth zones are conspicuously narrow and hard to evaluate. In general, age determination of Baltic herring is based on microscopic inspection of whole otoliths using reflected light. An alternate method was tested using transversal and stained sections of otoliths. Inspection was done with transmitted light. The stain depicted clear annulii at the end of each growth (summer) zone. This method required twice as much time as the whole otolith method. A test was set up in order to compare the two methods in terms of potential bias. The hypothesis was that the traditional method will underestimate number of growth zones of northern herring compared to the new method. A total of 245 herrings were selected from samples collected in autumn 2008. Five herrings were randomly selected from each observed length group in the southern, central, northern and northernmost Baltic Sea basins. From each individual one otolith was kept whole while the other was sectioned and stained with neutral red. This enabled a pairwise comparison of age determination methods. Results indicate differences between obtained ages by method in the northern areas but no differences in the southern areas. Using length as a covariate, log-transformed differences in estimated ages was significantly affected by area but not by readers. It is concluded that using whole otoliths for age determination is sufficient in samples from the southern Baltic. However, otolith samples from the northern Baltic need to be subjected to the new methodology in order to avoid an underestimation of the age distribution in these waters.

Arai, Takaomi — Theme: Life History and Management

Naoko Chino[1]; Takaomi Arai[2]

Kitasato University, Tokyo, Japan[1]; Ocean Research Institute, The University of Tokyo, Tokyo, Japan[2]

Comparison of Habitat Use Between Temperate and Tropical Freshwater Eels of the Genus Anguilla

The freshwater eels of the genus Anguilla, being catadromous, migrate between freshwater growth habitats and offshore spawning areas. However, a number of recent studies found that the temperate species have never migrated into freshwater, spending their entire life history in the ocean by otolith Sr:Ca ratio analyses. Furthermore, those studies found an intermediate type between marine and freshwater residents, which appear to frequently move between different environments during their growth phase. The discovery of marine and brackish water residents in these eels suggests that anguillid eels do not all have to be catadromous, and it calls into question the generalized classification of diadromous fishes. However, there has been little available information concerning its migration in the tropical eels. Therefore, to gather information regarding habitat use of the tropical eels, otolith microchemical analyses of Sr and Ca concentrations were carried out to determine individual migratory history. The results were compared for the temperate eels to understand the habitat use in Anguilla. In *A. marmorata*, showed three fluctuation patterns; (1) freshwater residence, (2) continuous residence in brackish water, and (3) residence in freshwater after recruitment, while returning to brackish water. Such migratory histories were found in other tropical eels, *A. bicolor bicolor* and *A. bicolor pacifica*. Based on these results and previous studies, the migratory behaviors of tropical eels appear to differ in each habitat in response to inter- and intra- specific competition. The results suggest that tropical eels have a flexible pattern of migration, with an ability to adapt to various habitats and salinities. Similar phenomena were also found in previous studies of temperate eels. Otolith analyses of these temperate eels found the occurrence of freshwater, estuarine, and marine residencies. The mean otolith Sr:Ca ratios during the growth phase after recruitment in tropical eels were less variable than those of temperate eels. Thus, temperate eels could have more flexible migratory behaviors in ambient water than the tropical eels.

Araya, Miguel

Theme: Age and Growth

Miguel Araya[1]; Jessica PeÃ±ailillo[2]; Luis A. Cubillos[3]; Claudio Casillo-JordÃ¡n[3]

Universidad de Antofagasta, Antofagasta, Chile[1]; Universidad Arturo Prat, Iquique, Chile[2]; Universidad de Concepcion, Concepcion, Chile[3]

Daily Growth Increments in the Chilean Cardinal Fish (*Epigonus crassicaudus*) and Validation of the First Annulus

The cardinal fish is an endemic species distributed on the slope of the continental shelf, in oceanic islands and sea mounts, and inhabiting depths between 100 and 550 m. For this species, a maximum age of 15 yrs has been estimated by readings of the translucent zone on the surface of whole otoliths. Instead, for *E. telescopus*, a related species distributed in New Zealand waters, longevity close to 100 years has been estimated. In this contribution, we described the daily growth increments to validate the first annulus. Specimens were collected on board trawlers, from which 26 otoliths were prepared for reading daily growth increments. The width of increments was measured in SEM, and the average was approximately 2.2 um at a distance from the center between 65 and 265 um, 3.1 um between 300 and 570 um and 3.6 um between 600 and 1300 um. The average distance from the center of the otolith to 365 increments was 1332.7 um (SD 163.2). This distance was comparable with average distance in which the first annulus appeared in whole otoliths.

Ardestam, Bjorn

Theme: Age and Growth

Bjorn Ardestam; Eva Bergstrand; Kerstin Holmgren; Anders Kinnerback; Bengt-Ake Jansson; Magnus Kokkin; Tanja Martins; Maja Reizenstein

Swedish Board of Fisheries, Drottningholm, Sweden; Swedish Board of Fisheries, Drottningholm, Sweden

Age and Growth of Freshwater Fish: Improved Access to Data From Swedish Lakes

Ageing of fish is often part of standardised sampling of fish communities in Swedish lakes. After more than 20 years of data collection, age determination data were recently included in an ACCESS database. Most aged fish were subsampled from catches with Nordic multimesh gillnets, according to a European standard protocol (EN 147 57: 2005). The new age database therefore conforms to a larger database, known as the National Register of Survey Test-fishing (NORS, www.fiskeriverket.se). The age database comprises more than 112,000 individuals of 26 fish species, sampled at 792 events in 181 lakes. Individuals are registered (fish species, identity, length, weight, sex, etc...) directly after field sampling, and further variables are added as soon as age reading and data control have been performed. Almost 89,000 fish have been aged, mostly perch (*Perca fluviatilis*, 48%), roach (*Rutilus rutilus*, 29%), Arctic char (*Salvelinus alpinus*, 7%), vendace (*Coregonus albula*, 5%), whitefish (*Coregonus* sp., 4%), brown trout (*Salmo trutta*, 3%), pikeperch (*Sander lucioperca*, 2%) and smelt (*Osmerus eperlanus*, 1%). More than 7,000 aged individuals are currently added to the database every year, and more species will be included this year. In age determination, otoliths were used for all species sampled since 1994, often in combination with operculum bones, scales or cleithra. Age determination followed specific quality procedures including intercalibration and quality assurance involving all procedures documented in a quality manual. This poster shows some of the variation found between fish species, in growth and in age and size distributions. We will also give examples of age data use in Swedish environmental monitoring projects. In the future, we hope that our fish age data can be presented and accessed from the internet, similar to how the fish community data are presently accessed from NORS.

Barnett, Beverly K. Theme: Chemistry

Beverly K. Barnett[1]; William F. Patterson III[2]

NOAA Fisheries, Panama City Laboratory, Panama City, FL, USA[1]; University of West Florida, Pensacola, FL, USA[2],

The Effect of Coring and Pulverizing on Age-0 Red Snapper, *Lutjanus campechanus*, Otolith Chemical Signatures

Experiments were conducted to test whether coring and pulverizing juvenile red snapper otoliths affected their chemical signatures, which consisted of stable isotope delta values (d13C and d18O) and element:Ca ratios (Ba:Ca, Li:Ca, Mg:Ca, Mn:Ca, Pb:Ca, and Sr:Ca). Analyses of whole right versus whole left otolith pairs revealed no significant difference in elemental (Hotelling Paired T2, $p = 0.120$) or stable isotope signatures (Hotelling Paired T2, $p > 0.991$). Pulverizing otoliths did not contaminate elemental signatures (Hotelling Paired T2, $p = 0.610$). Coring otoliths had a significant effect on elemental signatures (Hotelling Paired T2, $p = 0.049$); specifically, significant differences were detected in Ba:Ca and Mn:Ca between otolith pairs (paired t-test, $p = 0.005$ and $p < 0.001$, respectively). This difference was associated with a systematic difference of slightly higher ratios in cored versus whole otoliths. However, no significant differences existed when residuals were modeled. Coring significantly affected stable isotope signatures between pulverized whole right and cored and pulverized left otolith cores (Hotelling Paired T2, $p = 0.007$), which was driven by slightly depleted d13C values in otolith cores versus whole otoliths (paired t-test, $p = 0.007$). This difference likely resulted from ontogenetic shifts in diet not fully reflected in the core region alone. However, analysis of residuals yielded no significant difference between whole otoliths and pulverized cores. Results indicate that mechanically extracted otolith cores reflect the chemistry of whole age-0 red snapper otoliths, but residuals should be modeled to account for systematic ontogenetic shifts observed in some constituents.

Beyer, Sabrina Theme: Physiology and Morphology

Sabrina Beyer[1]; Stephen Szedlmayer[2]

Monterey Bay National Marine Sanctuary, Monterey, CA, USA[1]; Auburn University, Auburn, AL, USA[2]

Age Determination of Red Snapper (*Lutjanus campechanus*) by Otolith Shape Analysis

Otolith shape analysis was tested as a new method for age determination in juvenile red snapper, *Lutjanus campechanus*. Red snapper are currently aged by reading growth increments on sectioned otoliths, however, that method is subject to reader error especially in the identification of the first annulus. The present study examined otolith shape analysis as an alternative method for ageing young (< age 3) red snapper. Otolith shape variables including aspect ratio, rectangularity, box x/y, radius ratio, roundness and perimeter ratio were measured from digital images of whole otoliths. A series of known-age otoliths from age 0, 1 and 2 hatchery-reared red snapper were used for validation. Multidimensional scaling and non-parametric analysis of similarities showed significant otolith shape differences among the three age classes of hatchery-reared fish. Age classification success rates were evaluated by discriminant function analysis and cross-validation classification with 65.6 % correct age classification based on shape variables alone, and 86.7 % correct age classification with the addition of otolith weight to the analysis (n=90). Subsequently, age determination by otolith shape analysis was tested on a series of age 0, 1 and 2 wild caught red snapper aged by traditional methods. Otoliths from wild red snapper showed 68.9 % correct age classification based on shape variables alone and 86.7% correct age classification with inclusion of otolith weight (n=90). Lastly, otolith shape was compared between hatchery and wild red snapper within the same age classes to identify possible hatchery or environmental effects on otolith shape. Otoliths from age 1 hatchery and wild fish showed significant shape differences indicating that external environmental factors may affect otolith shape. Otolith shape analysis is a potentially new, objective method of age determination for young red snapper. This method eliminates potential reader error, reduces time and labor of traditional otolith sectioning, and may be the only method available when the first opaque growth increment is diffuse or non-existent.

Chang, Chih-Wei — Theme: Physiology and Morphology

Chih-Wei Chang

National Museum of Marine Biology and Aquarium, Taiwan, ROC

Otolith atlas of Taiwan

Morphology of otoliths, a species-specific character for identification of teleost fishes, is widely applied to studies on systematic, fishery biology, trophic ecology, paleontology and archeology. The Otolith Atlas of typical fishes in main oceans and regions around the world has been published. However, limited information was obtained in the West Pacific where regional biodiversity and endemism of fish were particularly high. The present study illustrated and described the morphological characters of sagittal otoliths of over 400 common fishes inhabiting the riverine, estuarine, coastal and deep-sea waters around Taiwan. Ultimately, an otolith collection of more than 3000 local fishes will be developed to compensate for the lack of an Otolith Atlas for the West Pacific region.

Chang, Chih-Wei — Theme: Life History and Management

Chih-Wei Chang[1]; Yung-Chun Ju[2]; Chia-Hui Wang[3]; Cheng-Feng You[4]

National Museum of Marine Biology and Aquarium, Taiwan, ROC[1]; Institute of Marine Biodiversity and Evolution, National Donghwa University, Taiwan[2]; Earth Dynamic System Research Center, National Chengkung University, Taiwan, ROC[3]; Department of Earth Sciences, National Chengkung University, Taiwan, ROC[4]

Otolith-Based Life History Examination of the Darwin's Roughy *Gephyroberyx darwinii* off Southwestern Taiwan

The Darwin's roughy *Gephyroberyx darwinii* (Trachichthyidae) is a rare, large-sized and high-priced fish captured by the deep-sea trawl fishery in Taiwan. Knowledge on life history of the fish was not well known. Between 2007 and 2008, a total of 22 individuals were collected at 280~340 m depths off the Liouchiou Island, SW Taiwan. Except for two smaller individuals of 154 and 277 mm, most fish ranged 401-575 mm (mean ±SD, 482 ±45 mm) in total length and 939-3333 g (2167 ±674 g) in body weight. By counting the annuli on the sagittal otoliths, the preliminary age determination suggested that the fish were of great longevity, ranging ca. 61~98 yrs. Otolith microchemistry analysis by laser ablation inductively coupled plasma mass spectrometry indicated that the life history scans of distinctive elements to calcium ratios might potentially serve as a proxy for ontogenetic stage and/or indicating a depth transition of the fish (e.g. Ba/Ca and Mn/Ca) as well as the anthropogenic pollution sunk in the deep-sea (e.g. Pb/Ca). Future efforts on age validation and the ecological relevance implied from otolith elemental profiles would be helpful for the comprehensive understanding of life history of the fish.

Chang, Chih-Wei — Theme: Chemistry

Chih-Wei Chang[1]; Chun-Jui Chen[2]; Chia-Hui Wang[3]; Cheng-Feng You[4]; Kwang-Tsao Shao[5]

National Museum of Marine Biology and Aquarium, Taiwan, ROC[1]; Institute of Marine Biology, National Taiwan Ocean University, Taiwan, ROC[2]; Earth Dynamic System Research Center, National Chengkung University, Taiwan, ROC[3]; Department of Earth Sciences, National Chengkung University, Taiwan, ROC[4]; Biodiversity Research Center, Academia Sinica, Taiwan, ROC[5]

Use of Otolith Microstructure and Microchemistry to Study Life History of the Slickhead *Alepocephalus bicolor* in the Northeastern Waters off Taiwan

The slickhead *Alepocephalus bicolor* (Alepocephalidae) is the dominant species in deep-sea fish fauna of Taiwan. To understand the unknown life history pattern of the fish, biological measurements as well as otolith structural and microchemistry analyses were conducted on regularly collected samples by demersal trawl in coastal waters of NE Taiwan during 2004 and 2007. Length frequency distributions indicated that the fish inhabited in 400~600 m depth and lengths of the fish, mainly of 160~220 mm, increased with the depth. Periodically formed growth increments, growth rings, checks of hatching, first feeding and metamorphosis (MC) and a structure of transparent zone (TZ) were discernable in the otoliths. The growth increments beyond MC did not deposit daily, whereas the growth rings were validated to be annuli that formed every February to March by marginal increment analysis. Back-calculated length and age of the fish when TZ formed were 84 mm and 7.7 yr, which might be related to the initial development of the gonad and habitat transition of the fish. Maximum age of the fish was 23 years and the von Bertalanffy growth parameters were 277 mm for Linf and 0.10 yr-1 for K. Differences of elemental composition in otoliths of the fish among life history stages were discriminated mainly by Mg/Ca and Sr/Ca ratios. Generally, the slickhead displayed the life history strategy of K-selection tendency.

Chiang, Chun-I — Theme: Chemistry

Chun-I Chiang[1]; Wann-Nian Tzeng[1]; Chia-Hui Wang[2]; Chen-Feng You[3]

Institute of Fisheries Science, College of Life Science, NTU, Taiwan[1]; Earth Dynamic System Research Center, NCKU, Taiwan[2]; Earth Dynamic System Research Center, NCKU, Taiwan[3]

Differences in Elemental Composition Among Three Pairs of Otoliths of Japanese Eel *Anguilla japonica*

Otolith microchemisty analysis has become an important technique for studying the migratory environmental history of fish. The mystery of homing by the eel has been the subject of much interest and it is believed that information from the earth's magnetic field may be involved. Three pairs of otoliths, sagitta, lapillus and astericus, occur in the inner ear of the fish. Few studies have examined the crystal structure and elemental composition among the three pairs of otoliths so this study determined whether differences occur among the three pairs of otoliths and their potential functions. Otoliths of the Japanese eel collected from the KaoPing River in Taiwan were analyzed by Raman spectrometer and solution-based ICPMS, respectively. The sagitta and lapillus are deposited in aragonite form, but the asteriscus is vaterite. The depositon rate, after the juvenile stage, was faster in sagitta than in the other two pairs of otoliths. A total of 11 elements (Ca, Mg, Sr, Pb, Fe, Cu, Mn, Ni, Na, Zn and Ba) in otolith were detected and the element/Ca concentration ratios differed significantly among the three pairs of otoliths. Na and Mg concentrations were higher in the asteriscus but Fe, Ni, Cu concentrations were higher in the sagitta and Mn concentration was higher in the sagitta than in the lapillus, but Sr concentration was the opposite. A Discriminant Function Analysis of the elemental compositions correctly discriminated the three pairs of otoliths. The differences in crystal structure and deposition rate among the three pairs of otoliths implied that they may have different physiological functions and adaptative purpose. Magnetic material, such as Fe that is higher in sagitta indicates that sagitta may play an important role in providing geomagnetic sensory input for migration.

De Albuquerque, Cristiano Queiroz — Theme: Life History and Management

Cristiano Queiroz De Albuquerque[1]; Norbert Miekeley[2]; Andres Jaureguizar[3]; Manuel Haimovici[1]; Jose Henrique[1] Muelbert

Oceanography Institute, Universidade Federal do Rio Grande, Brazil[1]; Chemistry Department, Pontificia Universidade Calolica do Rio De Janeiro, Brazil[2]; CIC, Comision de Investigaciones Cienficas de la Pcia de Buenos Aires, Brazil[3];

Evidence for *Micropogonias furnieri* Stock Segregation at Southwest Atlantic Ocean, as Revealed by Otolith Microchemistry

Whitemouth croaker *Micropogonias furnieri* comprises one of the most abundant fishery resources of the Southwest Atlantic Ocean (SWO). Genetic studies have indicated the existence of a continuous population distribution between 23 degrees and 40 degrees S. In this study we have examined elemental composition of *Micropogonias furnieri* otoliths from southeastern Brazil (Santos, 23 degrees S), southern Brazil (Rio Grande, 32 degrees S), Uruguay (35 degrees S) and northern Argentina (Partido de la Costa, 36 degrees S and Bahía Blanca, 38 degrees S) to test the hypotheses of stock mixture along this region. A LA-ICPMS using multielement pressed CaCO3 powder standards for quantitative external calibration was used to measure strontium, barium, magnesium and manganese concentrations related to the first year and last years of fish's life. Multidimensional scaling and Analysis of similarities were used to evaluate differences of otolith composition among regions. In order to assure that different environments can induce differences on otolith composition, we have included in this study otoliths from *M. furnieri* obtained from a freshwater isolated coastal lagoon. The results suggest significant differences in the concentration of Sr, Ba, Mg and Mn between otoliths from freshwater and coastal water fish, showing that otoliths from *M. furnieri* living in two distinct environments can present clearly distinct chemical signatures. Coastal stocks were partially overlapped during their first years of life suggesting a degree of connection between Bahía Blanca and Partido de La Costa-Uruguayan stock (Platensis stock). These stocks presented reasonable separation from Santos stock. Rio Grande stock could not be well separated from Santos and presented a strong overlap with the other stocks. For the last year of life, a degree of separation was observed between Rio Grande and Platensis, and Rio Grande and Bahía Blanca stocks. Our results constitute evidence for partial segregation of *M. furnieri* stocks from Southwest Atlantic Ocean and partially support findings from genetic studies.

De Albuquerque, Cristiano Queiroz — Theme: Chemistry

Cristiano Queiroz De Albuquerque[1]; Norbert Miekeley[2]; Jose Henrique Muelbert[1]

Oceanography Institute, Universidade Federal Do Rio Grande, Brazil[1]; Chemistry Department, Pontifica, Universidade Catolico do Rio de Janiero, Brazil[2];

Strontium Otolith Microchemistry as an Indicator of Long-Term Habitat Changes in a Long-Lived Fish Population

Strontium concentrations on otoliths of whitemouth croaker *Micropogonias furnieri* from southeastern and southern Brazilian, Uruguayan and Argentinean coastal waters were examined to determine patterns of estuarine use and cross-shelf fish migration towards coastal habitats in the South-West Atlantic continental shelf. Otoliths from *M. furnieri* living in an isolated freshwater coastal lagoon were used as strontium reference for otoliths from freshwater fish. A LA-ICPMS calibrated with CaCO3 standards was used to quantify strontium concentrations along profiles from the core to the edge of the otoliths. Habitat change was assessed interpreting the time of escape from estuarine influence (TEEI), measured as the time that strontium concentration in otoliths have reached values about 2000 microgram g -1. Long-term habitat change was interpreted by adjusting an exponential function to the strontium profiles along fish life time. Results show strontium concentration in otoliths to be about 800 microgram . g -1 for freshwater, 1800 for estuarine and generally over 2000 microgram . g -1 for coastal marine habitats. Whitemouth croaker presented consistent signals of estuarine habitats for the initial ages for the entire latitudinal range. Average TEEI varied from 4 yr for south Brazil to 7.5 yr for Uruguay. Our results suggest estuarine dependence as a species-specific attribute for *M. furnieri*. Three long-term habitat change patterns were observed: (1) Pattern A represent fish that do not stabilize the long-term habitat change curve and show a trend spending continuously more time in salt water for the entire life; (2) Pattern B comprise fish that stabilize long-term habitat change curve at high strontium concentrations and therefore high salinity waters; and, (3) Pattern C represent fish that stabilize the long term habitat change curve at low strontium values, spending most of their life close to estuarine influenced areas. The lack of latitudinal organization of these migratory patterns suggests a species-specific strategy of fish cross-shelf displacement along the South-West Atlantic continental shelf.

De Graaf, Trisha A.C. — Theme: Physiology and Morphology

Trisha A.C. De Graaf; Jessica Kohl Kanwit

Maine Department of Marine Resources, West Boothbay Harbor, Maine, USA

Establishment of a Digital Reference Collection for Gulf of Maine Atlantic Halibut (*Hippoglossus hippoglossus*)

Atlantic halibut (*Hippoglossus hippoglossus*) is a commercially-valuable groundfish that ranges widely throughout the North Atlantic Ocean. Mark-recapture programs conducted independently by the Maine Department of Marine Resources (DMR) and the Canada Department of Fisheries and Oceans (DFO) have shown Atlantic halibut is transboundary in nature, although moving in a unidirectional pattern from US to Canadian waters. In order to more accurately predict Atlantic halibut standing stock biomass in the Gulf of Maine, stock assessments need to incorporate updated age information, as recently collected otoliths are more representative of current oceanographic and climatic conditions affecting fish and otolith growth. Otoliths collected from an experimental longline fishery off the coast of Maine (2000-2004) will be used for the establishment of a digital reference collection and to update age-at-length estimates. Methodology for processing otolith samples include embedding in a 5:1 ratio of Araldite epoxy GY502 and Aradur hardener HY956 in mould trays lined with Frekote releasing agent, allowing to harden for 3 days, thin-sectioning (0.5 mm) the mold across the nucleus with a Buehler IsoMet low-speed saw, and polishing both sides of the resulting thin section. Image analysis included capturing an image of the otolith thin section submerged in ethanol using an Olympus SZ6145 microscope equipped with an Olympus DP71 digital camera and importing the image into Adobe Photoshop for enhancement and annotation. Age estimates were performed by staff at the DMR Fish Aging Lab and DFO Bedford Institute of Oceanography Fish Aging Lab. Quality control monitoring of aging errors and inconsistencies and the application of the Northeast Fisheries Science Center's standard precision template to calculate percent agreement and the total coefficient of variance between readings and age readers were employed. The establishment of this digital reference collection could provide valuable insight to the management of this transboundary spec es for both the United States and Canada.

De Pontual, Helene — Theme: Age and Growth

Kelig Mahe[1]; Vicenc Parisi[2]; Sebastien Carbini[1]; Jose Antonio Soria[2]; Alf Harbitz[3]; Helene De Pontual[1]; Unai Cotano[4]; Ronan Fablet[5]

Ifremer, France[1]; Universitat Politecnica de Catalunya, Spain[2]; Institute of Marine Research, Norway[3]; Azti, Spain[4]; Institut Telecom, CNRS UMR 3192 LabSTICC, France[5]

Automated Fish Ageing (AFISA)

Most of the European fish stocks are assessed using age-based models which require otolith age estimations, often associated with high uncertainty, and annually cost several million euros. In this context, the EU project AFISA aimed at developing and assessing methods which would reduce these costs while providing means for standardizing ageing among laboratories, ensuring the information traceability through annotated image data bases and improving growth studies. The project was built around four main objectives: 1) collect reference databases of otolith material including otolith images and their interpretation by expert readers 2) develop efficient algorithms for automated methods providing either individual fish age estimations or direct estimations of age distributions 3) implement these algorithms as modules of a dedicated software platform and 4) perform a cost-benefit analysis of the proposed automated ageing systems for the chosen case studies. The latter concern cod (North Sea and North East Arctic stocks), anchovy (Bay of Biscay stock) and plaice (Eastern Channel and Icelandic stocks). Objective 1 resulted in a data base including 6729 otoliths annotated images and additional information (otolith weights and fish measurements). The methodological developments of objective 2 produced new image processing tools and implementation of probabilistic approaches, namely the Gaussian mixture model proposed by Francis & Campana and conditional models based on kernel classifiers. These tools and methods have been implemented in the TNPC 5.0 scientific software platform and are already available. The cost benefit analyses have allowed us to compare the benefits gained from different automation processes while considering precision issues with respect to the traditional age estimation by experts. Results are promising, although they have to be optimized in the future in order to be systematically used.

Di Franco, Antonio — Theme: Chemistry

Antonio Di Franco[1]; Guiseppe De Benedetto[2]; Gianluca De Rinaldis[3]; Nuria Raventos[4]; Rita Sahyoun[3]; Paolo Guidetti[3]

Laboratory of Zoology and Marine Biology, University of Salento, Italy[1]; Laboratory of Chemical Analyses, University of Salento, Italy[2]; Laboratory of Zoology and Marine Biology, University of Salento, Italy[3]; Cebtre d'estudis Avancats de Blanes, Girona, Spain[4]

Large Scale Variability in Otolith Microchemistry and Microstructure: The case Study of White Sea Bream in the Mediterranean Sea

Connectivity is the exchange of individuals among local populations of species at any stage of the life cycle. For marine fishes characterised by reduced mobility at the adult stage, such exchange mostly occurs during the juvenile stages (from eggs to recruits). Otoliths have been demonstrated to be extremely useful to investigate connectivity among local fish populations. Trace elements in fish otoliths are commonly used as natural tags to get information on the dispersal history (i.e. from the natal origin to recruitment). Reading daily rings in otoliths of post-settler fish, in addition, provides indications on the pelagic larval duration (PLD) that, coupled with oceanographic models, may inform about the potential spatial scale of larval dispersal. In this study, we used the white sea bream (*Diplodus sargus sargus*; a species ecologically and economically relevant) as a model species, to assess the variability among multiple Mediterranean locations in: 1) PLD (used as a proxy for larval dispersal); 2) microelemental composition. Early settlers of white sea bream were collected at four locations along the Italian coast. Sagittae were extracted and read to assess the PLD and then analyzed by a laser ablation inductively coupled plasma mass spectrometer (LA-ICPMS) in three otolith regions: core, larval (comprised between hatching and settlement marks) and juvenile regions (between settlement mark and outer otolith edge), with three replicated pits from each region. Significant differences were found among locations both in terms of PLD (with very low within-location variability) and of microelemental fingerprints. PLD values were far lower compared to other studies. No chemical differences were recorded among regions of otoliths, which contrasts with the evidence from the literature of higher elemental concentrations in the core region. These analyses are preparatory to investigating differences at smaller spatial resolution and for more species, with the aim of assessing patterns of connectivity and then obtain crucial information to design effective networks of marine protected areas.

DiMaria, Ruth — Theme: Age and Growth

Ruth DiMaria[1]; Jessica Miller[1]; Thomas Hurst[2]

Oregon State University, Newport, OR, USA[1]; NOAA, Alaska Fisheries Science Center, Seattle, WA, USA[2]

Temperature and Growth Rate Effects on Otolith Elemental Chemistry of Larval Pacific cod, *Gadus macrocephalus*

Variation of some elements in otoliths can reflect variation in water chemistry. However, fish physiology and environmental conditions can also influence otolith elemental composition. Greater understanding of the mechanisms regulating otolith elemental chemistry will improve field data interpretations. We examined the effects of temperature and growth rate on the otolith elemental composition of larval Pacific cod, *Gadus macrocephalus*. The larvae were progeny of wild Pacific cod collected from spawning grounds near Kodiak Island, Alaska. Immediately after hatching, larvae were acclimated to 2C, 5C and 8C and reared for 38-51 days in three replicate tanks at each temperature. Experimental water concentrations (Mg, Ca, Zn, Sr, and Ba) were measured to determine partition coefficients (DMe). Using laser ablation inductively coupled plasma-mass spectrometry (LA ICP-MS), otolith concentrations of Li, Mg, Ca, Mn, Zn, Sr, and Ba were examined with a single spot ablation of 50um through the otolith. Li and Zn otolith concentrations were near detection limits and were excluded from subsequent analyses. Otolith growth during the experiment was located between the primordia, as identified by Mn-enrichment, and the outer edge of the otolith. Elemental concentrations of the experimental water did not differ among temperature treatments or tanks. The effects of temperature and growth rate on partition coefficients varied among elements. DSr decreased with increasing temperature, but within temperature treatments, DSr had an inverse relationship with otolith and fish growth rates at 2C and no effect at 5C and 8C. DBa showed the same trends as DSr. DMg was elevated at the highest acclimation temperature and showed no effects from otolith and fish growth rates within temperature treatments. Understanding variable relationships among otolith elemental signatures, environmental conditions, and fish physiology can improve the accuracy of reconstructions and interpretations of field data.

Donohoe, Christopher J. — Theme: Chemistry

Christopher J. Donohoe[1]; Christian E. Zimmerman[2]

University of California, Santa Cruz, CA, USA[1]; U.S. Geological Survey, Alaska Science Center, Anchorage, AK, USA[2]

A Method of Mounting Otoliths for Beam-based Microchemical Analyses

Beam-based analytical methods are widely used to measure the concentrations of elements and isotopes in otoliths. These methods usually require that each otolith be individually mounted and prepared to properly expose the desired growth region to the analytical beam. Most analytical instruments, such as LA-ICPMS and ion and electron microprobes, have carriers that will accept only one to four slides at a time. We describe a method of mounting otoliths that allows for easy transfer of many otoliths to a single slide after they have been prepared. Such an approach increases the number of otoliths that can be analyzed in a single session by reducing the need open the sample chamber to exchange slides - a particularly time consuming step on instruments that operate at low vacuums. For ion and electron microprobes, the method also greatly reduces the number of slides that must be coated with an electrical conductor prior to analysis. In this method, otoliths are first mounted in thermoplastic resin at one end of a narrow strip of cover slip attached at the opposite end to a standard microscope slide. The otolith can then be ground and flipped, if needed by heating the mounting medium. After otolith preparation is complete, the cover slip is cut with a scribe to free the otolith and up to 20 small otoliths can be arranged on a single petrographic slide.

Dougherty, Annette

Theme: Age and Growth

Annette Dougherty; Kevin Bailey; Tiffany Vance

NOAA, Alaska Fisheries Science Center, Seattle, WA, USA

Habitat Effects on Growth of Age-0 Walleye Pollock (*Theragra chalcogramma*) in the Gulf of Alaska.

Previous research shows that there are habitat-associated differences in length of age-0 walleye pollock caught in September in the Gulf of Alaska. Juveniles collected in the region around Sutwik Island and 300 km further downstream near the Shumagin Islands, are believed to result from the Shelikof Strait spawning aggregation that begins to release eggs by late March. If these juvenile fish are all from the same spawning cohort, then what is the explanation for the mean size difference of 20 mm between areas in September? To determine the cause of this size difference, we examined the otoliths of the larval and age-0 life stages of walleye pollock from these two areas in 2000 and 2001 to determine if hatch date, growth rate, or temperature may have influenced the size of the fish sampled in September. Temperature data were acquired in situ during the collection of larval and the age-0 walleye pollock and plotted across survey grids in late May and early September to determine changes in temperature. Circulation and transport models of the Alaska Coastal Current (ACC) were examined to estimate larval transport. Preliminary results suggest that in 2000 and 2001, the larger mean lengths of fish around Sutwik Island (80 mm) compared to that near the Shumagin Islands (60 mm) observed in September was due to enhanced survivorship of early-hatched larvae in the Sutwik area. No early-hatched larvae were present in the hatch date distributions calculated from Shumagin Island fish, in spite of expectation that older larvae would travel further. We suggest that the early-hatched larvae remaining in the Sutwik Island area had an advantage in survivorship over those larvae that were potentially swept downstream towards the Shumagin Islands or out over the shelf and then swept out to deeper waters where food may have been scarce. The larvae that were sampled in the Shumagin area, although still part of the same cohort, had undergone many changes in physical environment due to longer transport by the ACC, which resulted in the risk of higher mortality.

Draief, Mohamed Issam

Theme: Age and Growth

Mohamed Issam Draief[1]; Bachra Chemmam -Abdelkader[1]; Mohamed Ben Salem[2]

INSTM 28 ,RUE 2 MARS 1934 SALAMMBÃ–[1]; Laboratory of ecology (Faculty of science of Tunis) 2092 el manar tunis Tunisia[2]

Age and Growth of Barracuda *Sphyraena sphyraena* (Linnaeus , 1758) in the Tunisian Waters

Age and growth of Barracuda *Sphyraena sphyraena* (Linnaeus , 1758) from Tunisian waters were studied by otolith reading during the period from December 2006 to November 2007.This study has done to estimate parameters of growth of this species according to the Von Bertalanffy model.The age-length key has been established and linear growth curves and weight-growth relationships have been estimated seperately for males,females and sexes combined. The asymptotic length for combined sexes is 501mm, the growth coefficient K = 0.158 and the theoretical age t0 is -2.29. In the studied size range , the growth of females is relatively more rapid then that of males, but the difference is not significant.

Duarte-Neto, Paulo

Theme: Physiology and Morphology

Paulo Duarte-Neto[1]; Borko Stosic[1]; Tatijana Stosic[1]; Francisco Santana[2]; Rosangela Lessa[2]

PGBIOM, DEINFO, Universidade Federal Rural de Pernambuco[1]; Laboratorio de Dinmica de Popula Marinhas (DIMAR - UFRPE)[2]

Fractal Properties of sagital Otolith

Fractal dimension (FD) of otolith contour represents a promising, powerful shape descriptor for fish stock identification. Currently there is little research effort on this subject. Here we address the question whether the sagital otolith contour represents a simple (mono) fractal, or a multifractal geometric object, using 20 otolith images of *Mugil curema* (non-complex otolith shape) and 8 images of *Coryphaena hippurus* (complex otolith shape). We also calculate the capacity (monofractal) dimension of 249 otolith contours of *M. curema* individuals (age 0 to 14), caught in 3 estuaries and in the coastal water of Itamarac'e1 (Pernambuco, Brazil), to test how the fractal dimension of otolith contours varies as a function of length and age. In general, it is found that the otoliths display a monofractal pattern, and should be represented by a single FD. Nevertheless, for some *C. hipprurus* otoliths the capacity dimension was found to be slightly larger than the information dimension, that was in turn slightly larger then correlation dimension, indicating aspects of multifractal behavior. More complex otoliths than those of *C. hippurus* may turn out to be multifractal geometrical objects, and the current investigation represents an initial step in establishing adequate procedures for its measurement and quantification. The capacity FD of *M. curema* otoliths increases with age from 1.023 to 1.20, up to 1 year old (~15 cm), and then decreases to a point where it stabilizes at around 1.12, for 4 years old specimens (~27 cm). The observed FD peak at age 1 may be explained by the rhythm of calcium carbonate and protein aggregation during otolith formation, which leads to a rougher boundary for age 1 individuals, and to smoother and larger otoliths for adults. This trend was observed for all sampling sites, and Recife estuary showed more complex otoliths for age 1. Possibly, this may reflect differences in environmental conditions, since the estuary of Recife is far from the others, and more polluted. However, the hypothesis that environmental conditions lead to a more or less complex otolith shape, reflected in change of Fractal dimension, remains to be tested.

Fey, Dariusz

Theme: Age and Growth

Dariusz Fey[1]; Ewa SokoÅ‚owska[2]

Sea Fisheries Institute in Gdynia, Poland[1]; Institute of Oceanology of the Polish Academy of Science, Poland[2]

Age and Growth of Round Goby (*Neogobiun melatostomus*) in the Gulf of Gdansk, Baltic Sea

Round goby (*Neogobius melanostomus*) is a demersal fish species, native to the Black, Caspian, Marmara, and Azov Seas and their tributaries in Eurasia. In the Baltic Sea, *N. melanostomus* was first found in the Gulf of Gdansk (Poland) in 1990. Since then the population abundance in the Baltic Sea increased considerably. The goal of the present work was to describe the basic biological characteristics of round goby in the Gulf of Gdansk 16 years after its first occurrence in that area. The material for this research was collected by angling on 14 sampling days between June 2006 and June 2007 in the Gulf of Gdansk near Gdynia harbor (n = 249). Additional material was obtained in the Gulf of Gdansk with a single fyke net collection in September 2007 near Hel harbor (n = 103). The fish ranged in LT from 8.2 to 20.5 cm near Gdynia (dominant class: 14-15 cm) and from 11.3 to 23.5 cm near Hel (dominant class: 19-21 cm). Generally, males were more abundant in most size classes than were females, especially among fish larger than 15 cm. Goby age was estimated by otolith analysis and ranged from 2 to 6 years, with age class 4 dominant at both locations. While only three of the 352 fish analyzed were described as six years old, five year-olds were relatively numerous. Males were larger at age than females in both locations, which indicated their relatively faster growth rate. At the same time, females were heavier at a given LT than were males. No differences were found between males and females when the otolith size-fish size relationship was analyzed. The relationship between fish growth rate and otolith growth rate was very significant in each age class analyzed. That indicates the usefulness of goby otoliths in growth rate back-calculation. Marginal increment width analysis confirmed the periodicity of annual-rings formation in otoliths and showed that the most intense opaque zone formation occurs in July-August, while hyaline zone formation starts as early as in September-October.

Fischer, Andrew

Theme: Life History and Management

Andrew Fischer[1]; Edward Chesney[2]; James Cowan[1]

Louisiana State University Department of Oceanography and Coastal Studies, Baton Rouge, LA, USA [1]; Louisiana Universities Marine Consortium, Chauvin, LA, USA[2]

Validation of First Annulus Formation in Red Snapper Otoliths With an Alizarin Fluorescent Marker

The red snapper (*Lutjanus campechanus*) is among the most studied reef fish species in the Gulf of Mexico. Several studies have used counts of annuli in sectioned sagittal otoliths to age red snapper. However, interpretation of the putative first annulus has been a major source of debate among otolith readers. Our objective is to use the chemical marker alizarin complexone to validate whether the diffuse opaque mark adjacent to the core is the first annulus in red snapper otoliths. Juvenile red snapper were collected during a sampling cruise off Pascagoula, MS in October 2005. The juveniles were returned to the laboratory, then immersed in 100mg alizarin complexone per L seawater solution for two hours and subsequently held in 6000 l circular tanks with recirculating filtered seawater until July 2006. All experimental otolith sections displayed a distinct fluorescent mark ranging from 0.62 to 0.96 mm from the core when viewed with a rhodamine filter. The diffuse opaque zone was located distally to the alizarin mark in all specimens (ranging from 0.88 to 1.51 mm) indicating that the diffuse opaque zone is the first annulus in red snapper otoliths.

Folhas, Henrique

Theme: Age and Growth

Henrique Folhas[1]; Gustavo Franco[1]; Henrique Cabral[2]; Emanuel Gonçalves[1]

Eco-Ethology Research Unit, Instituto Superior de Psicologia Aplicada, Lisboa, Portugal[1]; Universidade de Lisboa, Faculdade de CiÃªncias, Centro de Oceanografia, Lisboa, Portugal[2]

Relation Between Growth Rates Inferred by Otolith Microstruture and RNA/DNA Ratios in Two Temperate Cryptobenthic Fishes

In recent years, the use of daily growth rates inferred through otolith microstructure analysis has become a powerful tool to study individual fish trajectories and relate those with several life-history parameters. One of those is the RNA/DNA ratio, used as a measure of recent growth. In this study, we investigate somatic growth, otolith growth and RNA/DNA ratios in juvenile fishes of *Apletodon dentatus* and *Trypterigion delaisi*. Individuals were collected in 2006 and 2007 at the Arrabida Marine Park (Portugal). Both species present a short pelagic larval duration (PLD) for temperate species, varying between 14 and 19 days for A. dentatus and between 17 and 21 days for *T. delaisi*. Larval length is strongly correlated with age for both species. Growth rates were 0.17 mm/day-1 for *A. dentatus* and 0.34 mm/day-1 for *T. delaisi*. The recent otolith growth index (ROGI) (based on the last five increments) was determined and correlated with the RNA/DNA ratios. No clear pattern was found between the ROGI and the RNA/DNA ratios and possible reasons for this lack of relationship are discussed, highlighting the need to further investigate the usefulness of these indexes when applied to cryptobenthic reef fishes.

Folkvord, Arild

Theme: Age and Growth

Arild Folkvord; Roland Koedijk; Vibeke Lok y

Department of Biology, University of Bergen, Norway

Use of Otolith Studies in Marine Juvenile Fish Production

Age and growth information from otolith analysis may seem superfluous in marine juvenile production where the age of the offspring is already typically known and population growth can be derived from easily accessible size-at-age data. However, the use of repeated samplings within the same population or tank readily facilitates the estimation size dependent mortality during important life history transitions like the onset of external feeding, metamorphosis or weaning onto formulated feeds. An example is provided from a study where larval cod were subject to two different feed types, live natural zooplankton and enriched rotifers, and two nominal initial larval densities. The results clearly indicate the onset of size selective mortality during the second week of weaning in both groups of larvae initially fed live zooplankton, while no such trend was apparent for those fed enriched rotifers. The results are discussed in relation to prey size structure and larval size variability.

Franco, Gustavo

Theme: Age and Growth

Gustavo Franco; Henrique Folhas; Emanuel Gonçalves

Eco-Ethology Research Unit, Instituto Superior de Psicologia Aplicada, Lisboa, Portugal

Early Life History Traits of Five Temperate Cryptobenthic Species Determined by Otolith Microstructure Analysis.

The otoliths of five temperate juvenile cryptobenthic reef fishes were examined to obtain information on: growth rate before and after settlement, pelagic larval duration (PLD), type of settlement-marks and size at age. Detailed descriptions of these traits are made for the gobiesocid *Apletodon dentatus*, the tripterygiid *Trypterigion delaisi*, the gobiids *Gobius xanthocephalus* and *Pomatochistus pictus*, and the blenniid *Parablennius pilicornis*. Samples were collected at the Arrabida Marine Park (Portugal) in 2006. The relation between early life history traits was analyzed for each species and between species. We used the Ontogenetic Index proposed by Fuiman to allow comparisons between species. *T. delaisi* and *A. dentatus* exhibit the shortest PLD, while the blenny *P. pilicornis* presented the largest PLD. For all the studied species, otolith size reflects fish length. Growth rates throughout the development period were compared within and between species and their relation with the PLD were analysed. The obtained trends are compared with the information available for other cryptobenthic species, both in temperate and tropical systems and the derived patterns discussed in the context of the particular life-history traits common to these overlooked reef species.

Fredell, Andrew

Theme: Chemistry

Andrew Fredell; Danielle Zacherl

California State University, Fullerton, CA, USA

Out of the Sand and Into the Surf: Determining Philopatry and Population Connectivity in the California Grunion, *Leuresthes tenuis* (Atherinopsidae).

The free swimming larval stage produced by many marine organisms has the potential to disperse long distances via ocean currents before recruiting to adult populations. However, recent research showed that a substantial portion of some marine larvae recruit back to their birth location. Whether this level of self recruitment occurs in populations of other species is an intriguing question that has implications for the management of marine populations, including culturally and economically important fishery species. This information is especially important for the California grunion, *Leuresthes tenuis*, a culturally significant recreational fishery in southern California, which relies upon sandy beaches as critical spawning habitat. My research attempts to understand the connectivity of spatially separated populations of California grunion using environmentally induced otolith natal tags. I first tested whether embryonic grunion otoliths from sites and/or regions within southern California varied spatially and temporally in their elemental composition. Grunion embryos were collected at 14 beaches from Santa Barbara to San Diego, CA in summer 2008, and from three beaches during two separate spawning events that were one month apart. Thirty otoliths from each beach/spawning run were analyzed by laser-ablation inductively-coupled mass spectrometry. Grunion natal tags varied significantly among multiple regions in southern California (MANOVA, $p<0.0001$) and discriminant function analysis accurately assigned 87% of otoliths to region. Analyses of natal tags from grunion embryos collected at three beaches among different spawning events showed significant temporal variability (MANOVA, $p<0.001$ for each beach). The spatial variation of natal tags will allow me to collect young-of-year grunion in 2009 from a subset of beaches and track those individuals to their natal regions and thus estimate the level of philopatry, or spawning region fidelity, and grunion population connectivity. Knowledge about the sources of grunion recruits would allow management decisions, such as sand nourishment and marine reserves, to be made with predictions of their potential outcomes possible.

Fuenmayor, Francisco

Theme: Chemistry

Francisco Fuenmayor[1]; Estrella Garcia[2]; Trika Gerard[3]; Barbara Muhling[3]; Lourdes Vasquez-Yeomans[4]; Eloy Sosa-Cordero[5]; John Lamkin[3]

NOAA Corps[1]; University of Miami (RSMAS-CIMAS)[2]; NOAA NMFS[3]; ECOSUR/CINVESTAV[4]; ECOSUR[5]

Determination of Chemical Signatures for Habitats of Juvenile *Lutjanus griseus* in the Mexican Caribbean

Otolith microchemistry is a proven method for producing valuable information about environmental temperature and salinity, migratory patterns and habitat use. *Lutjanus griseus* (gray snapper), an economically important species to the Mexican Caribbean; utilize a myriad of habitats throughout their juvenile life history which are crucial for their survival into adult populations. Spawning aggregations of these snappers are well documented in multiple locations off the eastern coast Yucatan Peninsula. In this study we are investigating isotopic differences in the otoliths of juvenile gray snapper from various habitats along the eastern coast of Quintana Roo, Mexico. Adults occurring on coral reefs in the Mesoamerican barrier reef system are believed to spend their juvenile life history in nursery habitats such as seagrass, mangroves and the patchy reef lagoons that occur along the coastline. Analyzing trends in stable isotope ratios in the otoliths may identify different habitats in which these fish spend their juvenile phase. Measurements of d13 C and d18 O in sagittal otolith carbonate were obtained from 50 fish (58 -153 mm Standard Length) collected in 2004-2005. There was a significant difference between habitats ($p<0.05$) values in both, carbon and oxygen. Oxygen was observed as the dominant driving force for the separation. Data from this study may lead to establishing connectivity between nursery habitats and adults occurring in the Mesoamerican barrier reef system. Future developments will allow for an assessment of ontogenetic and environmental transitions of gray snapper in this region. Ultimately we will provide baseline habitat environmental information useful for an ecosystem approach to fisheries management.

Garcia-Rodriguez, Francisco J.

Theme: Life History and Management

Francisco J. Garcia-Rodriguez; Jose De la Cruz-Aguero

Centro Interdisciplinario de Ciencias Marinas-IPN, La Paz, Mexico

A Comparison of Indexes for Prey Importance Inferred From Otoliths and Cephalopod Beaks Recovered From Pinniped Scats

Hard structures like sagitta otoliths and cephalopod beaks have traditionally been used in pinniped diet analyses. They are important since their shape and inner features can be species or genus specific and help in the identification of prey. Scats are currently the most used sample type in pinniped diet analyses because they can be easily collected, are abundant, noninvasive, and provide enough otoliths and cephalopod beaks. Traditionally, food habit studies of the California sea lion Zalophus californianus based on scats have considered the Percent Number and Percent Occurrence as measures to determine prey importance. Two other less popular indexes, Split-Sample Frequency of Ocurrence and Index of Importance (here it described) have also been used for quantifying the California sea lion prey. In this study a similar data set was used to compare results produced by using these four indexes. A total of 251 hard structures (fish otoliths and cephalopod beaks) recovered from California sea lion scats collected at Isla San Pedro Martir in the Gulf of California, Mexico, were examined. Prey taxa were identified using voucher specimen material. Results obtained from four measurements (PN, PO, SSFO and IIMP) were consistent in ranking the three main prey taxa but different in relative importance. A high correlation was found among indexes, but the standardized residuals indicated that linear regression was not an adequate model to describe the relationship between PN and any other indexes. Based on our results, the IIMP index produced better standardized information than other measurements. Representing the diet using a single measurement such as IIMP can facilitate the interpretation of results, allow comparisons, and promote consistency in pinniped diet studies based on scats.

Garcia-Rodriguez, Francisco J.

Theme: Physiology and Morphology

Francisco J. Garcia-Rodriguez; Victor A. Tapia-Rendon; Jareny Ramos-Lozano; Jose De La Cruz-Aguero; Victor M. Cota-Gomez

Centro Interdisciplinario de Ciencias Marinas-IPN, La Paz, Mexico

Geometric Morphometric Analysis of Sagitta Otoliths in the Pacific Sardines *Sardinops sagax* (Jenyns, 1842): an Approach to Discriminate Stocks in Mexico

Sagitta otoliths have been extensively used in fisheries science. Since they contain information related to growth patterns, microstructural zonation, elemental constituents, and morphological variation, sagitta otoliths can provide a phenotypic basis for stock discrimination, a priority for fisheries management. Otoliths can have an advantage over soft and external parts when they are used in morphometric analysis because the shape of internal and hard structures can be less affected during their manipulation or preservation. However, the discrimination power of otoliths in comparison to total body shape has not been well documented. In this study the variation in the otolith shape of the Pacific sardine was examined by applying geometric morphometric analyses coupled with multivariate statistical analyses. In spite of the lack of population genetic structure found in some studies, several reports support the existence of different stocks along the California Current. Many approaches have been used to infer stock structure in Pacific sardine but none using geometric morphometric analyses of otoliths. Samples from commercial fishing unloaded in San Carlos, Baja California Sur, Mexico were obtained during 2007-08. A total of 277 right otoliths (64 from September, 125 from December, 30 from April, and 58 from July) were photographed. Landmarks and semilandmarks were digitized using the TpsDig program and superimposition was based on the Procrustes method. Results of morphometric variation patterns found in the sagitta otoliths of the Pacific sardine are shown and discussed.

Geja, Yonela

Theme: Age and Growth

Yonela Geja[1]; Marius Deon Durholtz[1]; Coleen L. Moloney[2]

Marine and Coastal Management, South Africa[1]; Zoology Department, University of Capetown, Cape Town, South Africa[2]

Age and Growth of Redeye Roundherring (*Etrumeus whiteheadi*) Off the South African Coast

Ages of redeye roundherring (*Etrumeus whiteheadi*), were estimated from sagittal otoliths and used to infer life history information such as age composition, age-at-maturity and mortality. Samples were collected in November 2005 during a research survey aimed at estimating the biomass of spawning pelagic fish. Replicate age estimates obtained from sagittal otoliths were collected with no bias and relatively high precision (APE = 8.71%, CV = 11.31%). von Bertalanffy models were fitted to the size-at-age data for females and males separately. Kimura's likelihood ratio test revealed no statistically significant differences between growth parameters of males and females. Maturity ogives showed that males matured at a younger age and smaller size than females. 50% of the males attained maturity at a caudal length of 13.1 cm (corresponding to an age of about 0.8 years) while 50% of the females matured at a caudal length of 14.5 cm (corresponding to an age of 1.5 years). A linear model fitted to log transformed abundance at age data suggested an instantaneous mortality rate (Z) of 1.31 yr -1.

Gillespie, Darlene

Theme: Age and Growth

Willy Dunne[1]; Darlene Gillespie[2]; Omar Rodriguez[3]; Josie Thompson[4]; Robert Tobin[5]

Alaska Department of Fish and Game, Juneau, AK, USA[1]; DFO, Pacific Biological Station, Nanaimo, BC[2]; Northwest Fisheries Science Center, Newport, OR, USA[3]; Oregon Department of Fish and Wildlife, Oregon, USA[4]; International Pacific Halibut commission, Seattle, WA, USA[5]

CARE: A Model for Interagency Calibration and Standardization

Since its inception in 1983, the Committee of Age Reading Experts (CARE) has endeavoured to document and standardize the age determination methodologies for groundfish species and stocks jointly managed along the Northeast Pacific. As an affiliate of the Technical Subcommittee on the Canada/U.S. Groundfish Committee, membership encompasses agencies from California, Oregon, Washington, Alaska and Canada. The group meets biennially to share and discuss age criteria, new age and growth research initiatives and validation of existing methodologies. A considerable amount of time is also spent "hands-on", using teaching scopes to calibrate and resolve age interpretation issues between readers and labs. It provides a supportive learning environment for the novice as well as experienced age readers. Over the course of 26 years, the group has met 15 times, produced an ageing manual, participated in numerous age structure exchanges for interagency calibration and has discussed a broad range of issues including: age structure preparation methods, age reading methodology, equipment, imaging, ergonomics and new and developing technologies. Recent additions include a website and forum for sharing information between agencies. The CARE model may be of interest to other countries and agencies collaborating to standardize age determination methods for shared stock management. Come check us out at http://care.psmfc.org.

Gillespie, Darlene

Theme: Sclerochronology

Darlene Gillespie; Shayne MacLellan

DFO, Pacific Biological Station, Nanaimo, BC

Sclerochronology CSI: A Forensic Tool to Extend and Reconstruct Historical Geoduck Recruitment From Dead Shells

Pacific geoducks (*Panopea abrupta*) exhibit a synchronous growth pattern between individuals within a population that can be used to generate accurate age and recruitment histories. Cross-dating, a dendrochronology technique, identifies wide and narrow growth years (signature years) that assign a known calendar date to each growth increment. In this study, a master chronology developed from live shells collected near Bartlett Island on WCVI, B.C. was used to cross-date dead shells found buried in sediment nearby. We "floated" the known-date growth chronology over the dead shell pattern to determine the year of natural death, the age at death and their birth year. This information was used to extend and reconstruct historical geoduck recruitment and better estimate longevity. Geoduck growth has also been shown to be closely related to sea surface temperature. Therefore we endeavour to utilize the dead shell growth history as a proxy for temperature and other climate indices, pre-dating existing records. Many of the dead shell geoducks died during the early 1990's, leading to speculation as to the cause for a significant die-off.

Griffiths, Naomi

Theme: Chemistry

Naomi Griffiths[1]; Wolfgang Muller[1]; Orangel Aguilera[2]; Kenneth Johnson[3]

Royal Holloway, University of London, Egham, Surrey, UK[1]; Universidad Nacional Experimental Francisco de Miranda, Venezuela[2]; Natural History Museum, London., UK[3]

Depth vs. Lateral Compositional Profiling of Otoliths - Evaluating the Maximum Achievable Resolution of LA-ICPMS Analysis

The daily growth of otoliths preserves a continuous geochemical record of the life history of teleost fish from the earliest natal stage to the mature adult. For the many species of myctophid fish (e.g. *Diaphus*) that undertake diel vertical migrations from bathypelagic/mesopelagic (4000 m - 1000 m) to epipelagic (200 m - 0 m)depths, variable otolith chemistry may be expected based on considerable depth variation of trace element concentrations in seawater such as P and Zn. Over the last fifteen years, spatially-resolved in-situ determination of trace element concentrations in otoliths using ion-microprobe or laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS)have been widely used to resolve provenance and life histories of important groups of fish. However, at best spatial resolutions of around 10 um are achieved with the above techniques, which are insufficient to resolve daily growth increments that range between 2 - 10 um (e.g. *Diaphus dumerilii* (Bleeker)). Thus the challenge is to determine if it is possible to detect changes in geochemical signals at the spatial resolution of daily growth increments. In this study, we present trace element analyses obtained by high-resolution depth-profiling through the sagittae of *Diaphus* spp using a custom-built ArF excimer LA-ICPMS system fitted with a two-volume laser ablation cell. In principle, the combination of slow drilling at a rate of ~0.15 um per laser pulse with a LA cell characterized by fast signal washout allows sub-um spatial resolution to be achieved. We will present comparisons between depth and longitudinal profiles through *Diaphus* spp otoliths as well as synthetic layered standards with contrasting elemental concentrations to assess the maximum achievable resolution of our technique.

Hayden, Todd

Theme: Chemistry

Todd Hayden[1]; Karin Limburg[1]; William, III Pine[2]; Thomas Frazer[2]

Environmental Science and Forestry, State University of New York, Syracuse, NY, USA [1]; Department of Fisheries and Aquatic Sciences, University of Florida, Gainesville, FL, USA[2]

Humpback chub: Resolving Site-Specific Otolith Markers in the Grand Canyon

The construction of Glen Canyon dam and the resulting regulation of water flows in the Grand Canyon reach of the Colorado River have resulted in dramatic abiotic and biotic shifts, including much colder summer water temperatures regimes, decreases in seasonal flow variations, and the establishment of a suite of non-native fish and invertebrate species. Concurrent with the regulation of water flows, many of the native fish species in the Grand Canyon have undergone population declines leading to extirpation or designation as federally endangered or threatened. One such species, the endangered humpback chub (*Gila cypha*), is a long-lived fish uniquely adapted for the turbulent water flows of the Colorado River system. Understanding the ecology of this species is critical for the formulation of sound population recovery and management plans. To this end, adult population dynamics of the humpback chub have been extensively monitored using mark-recapture techniques, however, little is known about spawning, rearing, or foraging habitats of adult fish. Furthermore, the key factors that influence juvenile fish recruitment such as timing of emigration from tributary nursery habitats to the mainstem Colorado River habitats, or growth of early life stage individuals are not known. Given the endangered status of the humpback chub, we present preliminary site-specific elemental and isotope otolith chemistry markers (i.e., Sr, Ba, Ca, Mg, Mn, 87Sr/86Sr) from mainstem Colorado River and tributary populations of a non-endangered species with similar distributions and habitat requirements as the humpback chub. Characterizing the site-specific otolith chemistry markers of biologically critical regions in the Grand Canyon system may be useful for identifying natal origins and other factors that drive recruitment success of humpback chub.

Herzka, Sharon Z.

Theme: Chemistry

Joel Fodrie[1]; Sharon Z. Herzka[2]

University of South Alabama & Dauphin Island Sea Lab, Alabama, USA[1]; Departamento de Oceanografia Biologica, CICESE, Ensenada, Mexico[2]

Can Post-Settlement Immigration Expand a Bottleneck in the Life History of an Estuarine-Dependent Finfish?

Estuaries and coastal embayments are valuable nurseries for many economically and ecologically important fishes and crustaceans. For many of these species, spawning and larval development occurs offshore, and ingress to these preferred nurseries requires locating and passing through narrow coastal inlets. Estuarine immigration may therefore function as an important bottleneck for species defined by this general life history, particularly if individuals must recruit to estuaries before completion of the larval stage. We investigated the mode (pre- versus post-settlement) and timing (size-at-entry) of ingress for YOY California halibut in to the Punta Banda Estuary (PBE) in Baja California, Mexico, using trace element analyses of otoliths. We collected juvenile halibut (40-120 mm SL) within PBE and from adjacent coastal waters following their metamorphosis from the larval stage at 8-10 mm (SL). Chemical analyses were performed along transects from the otolith core to post-rostral margin using LA ICP MS to determine the environmental conditions (estuarine versus coastal) experienced by individuals at every 10 mm (SL) of somatic growth. Multi-element tags (Mn, Sr and Ba) in otoliths revealed that all fish we collected exhibited a "coastal" signature (high Sr, low Mn and Ba) during the larval stage and up until fish were 30-40 mm (SL). While all halibut collected from the exposed coast retained that signature throughout their lives, fish collected from PBE showed elevated concentrations of Mn and Ba, and lower concentrations of Sr, in the otolith growth bands deposited once halibut were > 40 mm SL, which was reflective of estuarine residency. We also observed an inverse relationship between: (a) the distance from the inlet mouth to where fish were collected in PBE, and (b) the back-calculated, size-at-entry of individuals inferred via otolith chemistry. This suggests that earlier immigrants selected habitat in the upper reaches of the estuary, while later immigrants occupied the lower estuary (i.e., PBE fills from the 'back-end-first'). Although many species recruit to estuaries during the larval stage, post-settlement immigration may allow YOY halibut additional time to locate estuarine nursery habitat.

Huang, Shih-Shan

Theme: Life History and Management

Shih-Shan Huang[1]; Chih-Wei Chang[2]; Yue-Gau Chen[3]; Jen-Chieh Shiao[4]

Institute of Oceanography, College of Science, National Taiwan University, Taiwan[1]; National Museum of Marine Biology and Aquarium, Pingtung, Taiwan[2]; Department of Geosciences, College of Science, National Taiwan University, Taiwan[3]; Institute of Oceanography, College of Science, National Taiwan University, Taiwan[4]

Migratory Life History of Grey Mullet (*Mugil cephalus*) Inferred from Otolith Stable Isotope

Powders of sagittal otoliths were obtained sequentially from edge to core along the growth rings and used for stable isotopic carbon and oxygen analyses in order to study the migratory life history of grey mullets. Field mullets were collected from the sea off Hsinchu and the approximately 3-year-old cultivated mullets from aquaculture pools in which mean annual temperature is between 18~33 degrees C and salinity is around 6.6psu. The decrease of d13C and d18O near the core of cultivated mullets otoliths imply that the fish were caught from the sea and then released to pools which have lower salinity. After that, d18O has periodic fluctuation which may be caused by seasonal temperature changes, whereas d13C remains stable, implying that d13C of otoliths can indicate the change of environmental salinity without affecting by water temperature. The d13C and d18O patterns of wild mullet otoliths have different types of changes. Some specimens have no decrease of d13C and d18O near the core and always remained at relatively high values, which imply that the fish remains in the sea and do not enter estuaries or freshwater. Some individuals stay in estuaries or freshwater for different periods inferred from their depleted d13C and d18O values. In the present study, we find d13C values of otoliths is influenced by salinity but not water temperature and that there are different kinds of migratory life history of grey mullets by using stable isotopic carbon and oxygen analyses of otoliths.

Ibañez, Ana

Theme: Life History and Management

Ana Ibañez[1]; Chih-Chieh Hsu[2]; Chih-Wei Chang[3]; C.H Wang[3]; Yoshiyuki Iizuka[4]; Wann-Nian Tzeng[5]

Universidad Autonoma Metropolitana Iztapalapa, Mexico[1];Department of Biology, College of Science, National Taiwan Normal University, Taipei[2]; Institute of Fisheries Science, College of Life Science, National Taiwan University, Taiwan[3]; Institute of Earth Sciences, Academia Sinica, Nankang, Taipei, Taiwan[4]; Institute of Fisheries Science, College of Life Science, National Taiwan University, Taiwan[5]

The Diversity of Migratory Environmental History of Striped Mullet *Mugil cephalus* and White Mullet *M. curema* in the Mexican Waters as Indicated by Otolith Sr:Ca Ratios.

The analysis of Sr:Ca ratios in otoliths, in combination with age data, makes likely the reconstruction of the migratory environmental history of the fish and the explanation of its habitat use. This study aims to compare the Sr:Ca ratios in otoliths of the mullets *Mugil cephalus* and *M. curema* among three geographic zones in the Gulf of Mexico. Specimens were collected respectively from Tamiahua Lagoon, the river-estuaries of Cazones,and Tecolutla in November 2006 and March 2007. This experimental design was to improve the understanding of the species-specific habitat use and migratory behavior of the mullet. Ten specimens were randomly selected for the otolith Sr:Ca ratios analyses in each of the samples except Tecolutla River where only one *M. cephalus* was collected due to the geographic distribution of this species. A total of 31 *M. cephalus* and 40 *M. curema* were analyzed. The Sr/Ca concentration ratios in sagittal otoliths of the mullet were measured from primodium to the otolith edge along the posterior maximum growth axis by Electron Probe Micro Analyser. Strontianite (SrCO3) and calcite (CaCO3) were used as standards for the calibration of Sr and Ca concentrations in the otolith. The temporal change of the Sr:Ca ratios in the otolith was obviously different between species and among geographic areas. *M. curema* seems to prefer brackish waters while *M. cephalus* showed more preference for seawater. *M. curema* tended to inhabit freshwater for Tecolutla River specimens while they stayed in brackish waters for Cazones River and Tamiahua Lagoon specimens. This study demonstrated the evolution of species-specific and the adaptative radiation in habitat use of the mullet.

Kokkin, Magnus

Theme: Age and Growth

Magnus Kokkin; Beier Ulrika

Institute of Freshwater Research, Swedish Board of Fisheries, Sweden

Age and Growth of Pikeperch (*Sander lucioperca* L.) : a Crucial Tool for Stock Assessment and Management

Pikeperch is among the six most economically valuable fish species in Sweden, caught mostly in relatively small-scale lake fisheries in the large lakes Malaren and Hjalmaren, but also along the Baltic coast. Pikeperch is a piscivorous species, and in Lake Malaren individuals often reach sizes above 55 cm (the current minimum allowed size limit for fishing is 40 cm), although individual growth is highly variable. Year classes often show a bimodal size distribution, as individuals becoming piscivorous already in their first year grow faster. Individual growth patterns show that initial fast growth often continues during the coming years and vice versa, resulting in different life history patterns in the population. Year class size also shows strong response to temperature during the season, in that warm years usually gives strong year classes. Fishery implies that fast-growing individuals will have a disadvantage, as they will risk being caught as soon as reaching the minimum size limit. For sustainable management of the economically valuable pikeperch population in Lake Malaren, a survey in connection to the fishery was set up in 2008. The study presented here focuses on a) growth patterns of 3-year old individuals (born 2005), i.e. early growth of individuals before the onset of increased mortality due to fishery, and b) growth patterns of remaining 9-year old individuals from the very large year class of 1999, which was still common in the fishery in 2008. Results exemplify the crucial estimation of correct age, especially in the first few years, as highly variable growth can result in large size overlap between adjacent year classes.

Kuroki, Mari

Theme: Chemistry

Mari Kuroki; Raymond M. Buckley; Larry L. LeClair; Lorenz Hauser

University of Washington, Washington Department of Fish and Wildlife, Seattle, WA, USA

Validation of Transgenerational Mass Marking of Viviparous Fish Otoliths

Otolith mass marking of fish larvae has been used as a useful tool for understanding the dispersal and retention patterns and mechanisms in the early life history of fishes. Two viviparous fish species, the brown rockfish *Sebastes auriculatus* and the kelp perch *Brachyistius frenatus* from Heyer Reef in Puget Sound, Washington, were used to validate that transgenerational mass marking of larvae in vivo occurs with the transfer of elemental strontium to otoliths of developing larvae via matrotrophic viviparity. Gestating females were injected with 30,000 ppm strontium chloride and were reared for about 72 hours in each tank. Breeding patterns and otolith sizes of these two viviparous fish species were greatly different, but all otoliths of larvae produced from strontium injected females showed enriched strontium signatures near the otolith edges. The mean strontium to calcium ratios in larval otoliths were 20.80 Â± 5.25 (range: 12.94-27.04) in rockfish and 17.94 Â± 7.25 (11.89-33.78) in surfperch, while those of control larvae were 4.42 Â± 0.33 (3.92-5.12) in rockfish and 4.90 Â± 0.42 (4.16-5.55) in surfperch, which were significantly different from those of the injected individuals of each species ($p < 0.01$). These results indicate that transgenerational mass marking is a highly efficient technique for marking viviparous fish otoliths.

Laidig, Thomas

Theme: Life History and Management

Thomas Laidig

NMFS FED, Santa Cruz, CA, USA

Differences in Settlement for Juvenile Blue Rockfish (*Sebastes mystinus*) Between Northern and Central California

Settled young-of-the-year blue rockfish (*Sebastes mystinus*) were collected from two kelp beds 335 km apart off the coast of California; one near Albion in northern California and other from Monterey in central California. Total age, settlement date, timing of juvenile transformation, and birthdates were determined from otoliths. A total of 112 rockfish were collected from both sites over 5 years (1993, 1994, 2001, 2002, and 2003). Fish from Monterey settled in May while fish from Mendocino settled mostly in June, with an average difference in settlement of 24 days. The timing of settlement followed the same pattern for both areas over the five years, with settlement occurring later in 2002 and 2003. The number of juveniles recruiting to the kelpbed was low in 1993 and 1994, while 2001, 2002, and 2003 were years with above average recruitment. The timing of settlement was compared to recruitment success and oceanographic variables to ascertain a possible cause for variability in settlement date between locations and years.

Lessa, Rosangela

Theme: Age and Growth

Rosangela Lessa[1]; Francisco Santana[2]; Paulo Duarte-Neto[1]

DIMAR, Universidade Federal Rural de Pernambuco, Brazil[1]; Laboratorio de Populo (DIMAR-UFRPE), Brazil[2];

Ageing Tropical Species from Brazil

During the REVIZEE (Renewable Resources of the Exclusive Economic Zone) Program, from 1995 to 2004, age and growth studies were carried out using specimens collected between 2 degrees and 55 minutes south latitude to 13 degrees south latitude / 35 degrees west longitude to 42 degrees west longitude, aiming at stock assessments. Bony fish (10 species) were studied, counting 1) periodic annuli in sectioned sagitta (*Pseudupeneus maculatus* and *Haemulon aurolineatum*); 2) increments on sagitta microstructure (*Coryphaena hippurus*, *Opisthonema oglinum*, *Hemiramphus brasiliensis*), 3) increments on lapilli (*Hirundichthys affinis*; *Hyporhamphus unifasciatus*; *Hemiramphus brasiliensis*), 4) increments on whole otoliths (*Scomberomorus brasiliensis*, *S. cavalla*), and 5) counting annuli in sections of dorsal spines of *Thunnus albacares*. Validation was conducted through marginal increment analysis for species of groups 1, 4 and 5 listed above; through fluorescent OTC dyes for group 2 (except C. hippurus) and through captive rearing from hatch (group 3). In the current work we comment on two main sources of errors: a) mean marginal increment indicated the deposition of annuli throughout the year, generally depicting very high standard deviations which was attributed to enlarged reproductive periods; b) the identification of the first periodic increment was a complex issue requiring countings of daily increments in microstructure of juveniles. Besides, age underestimations frequently attributed to sagitta microstructure in dolphinfish could not be verified. Further, contrasting with the literature, a low longevity was estimated for the thread herring *Opistonema oglinum*. Overall, the estimated von Bertalanffy growth parameters were consistent with biological references known for each species, demonstrating that otoliths of tropical species are suitable structures for fish ageing, providing coherent input data for age-based stock assessments.

Lewis, Anna

Theme: Chemistry

Anna Lewis[1]; Ewan Hunter[2]; Clive Trueman[3]

University of Southampton/CEFAS, UK[1]; Centre for the Environment, Fisheries and Aquaculture Science (CEFAS), UK[2]; University of Southampton, UK[3]

Investigation to Identify a Spawning Signal in the Chemistry of Plaice (*Pleuronectes platessa* L.) Otoliths

Physiology and ontogeny are known to affect otolith composition, however the underlying mechanisms are poorly understood. Growth rate, gonad development (1, 2) and migratory behaviour (3) have all been suggested to control otolith Sr/Ca fluctuations in marine fish, but discrimination between these factors requires further study. We present preliminary results from a current aquarium study that aims to investigate the blood trace metal composition of non-migrating plaice over a full reproductive cycle, and to examine how changes in blood chemistry are expressed in the growing otolith. Since May 2009, length, weight, GSI and blood plasma trace metal composition have been monitored in immature and mature plaice kept in a large (9 cubic meter) seawater tank, where they will remain for 1 year under controlled and/or closely monitored conditions (water chemistry, temperature, salinity and diet). After one year, otoliths will be retrospectively sampled by laser ablation ICP-MS. Trends in blood and otolith microchemistry will be identified and examined alongside possible physiological mechanisms. The experiment builds on previous studies (1-3) by monitoring blood and otolith chemistry within individual fish kept under known conditions, and by measuring trace metal concentrations that were below detection limits of earlier machines. The identification of a chemical signal uniquely attributable to reproduction could potentially be used to improve estimates of spawning stock biomass, an important parameter in stock assessment models. However, the work is presented at a relatively early stage and we welcome comments that may help to improve on the methodologies employed.

Limburg, Karin — Theme: Chemistry

Karin Limburg[1]; Mikael Elfman[2]

SUNY College of Environmental Science and Forestry, Syracuse, NY, USA[1]; Department of Nuclear Physics, Lund University, Sweden[2]

Oscillatory Patterns of Zn in Otoliths Support a Recent Phylogenetic Typology of Salmoniformes and Their Sister Groups

We present data showing oscillations in Zn:Ca in otoliths from members of the Salmoniformes. Although patterns differ, annual oscillations are always visible. These are also detectable in esocids, but not in osmerids, nor in more distantly related taxonomic groups. We suggest this may be a trait under phylogenetic control, and that recent suggestions of a revision in the systematics of Salmoniformes and their sister groups may be supported by otolith Zn chemistry.

Limburg, Karin — Theme: Chemistry

Karin Limburg; Bongghi Hong

SUNY College of Environmental Science & Forestry, Syracuse, NY, USA

OtoGIS: a New Way to Analyze Otolith Multivariate Chemistry (and Other) Data

Otoliths are spatially heterogeneous, yet relatively few analyses apply spatial methods of analysis. We show how otolith elemental maps can be quantitatively analyzed with geographical information (GIS) software, by converting the data into raster-based maps and applying GIS analyses. A strength of this approach is that any number of elemental maps can be analyzed simultaneously, and subsequently compared to optical imagery. We demonstrate the use of transects and area masking to extract line transects (including curvilinear transects that follow axes of growth) and regions of interest in the maps.

Limburg, Karin — Theme: Chemistry

Karin Limburg[1]; Aude Lochet[1]; Darren Dale[2]; Deborah Driscoll[1]

SUNY College of Environmental Science & Forestry, Syracuse, NY, USA[1]; Cornell High Energy Synchrotron Source, Cornell University, Ithaca, NY, USA[2]

Where Does the Selenium Come From? A Geographic Survey of Central New York to Determine the Source of Selenium Discovered in Otoliths.

Selenium, rarely reported as a component of otolith chemistry, has been discovered in otoliths of multiple species of fish from different families in Onondaga Lake near Syracuse, NY. We undertook a set of synoptic geographic surveys in 2006, 2007, and 2008 to determine the source of selenium. Water analysis by ICP mass spectrometry indicated that tributaries of Onondaga Lake contain highest concentrations of Se within the Central New York region. Also, Onondaga Lake is contaminated with mercury, and we discuss the potential interactions of Se with Hg in terms of uptake by fish.

Lombardi, Linda

Theme: Chemistry

Linda Lombardi[1]; Allen Andrews[2]

NOAA Fisheries Service, Panama City, FL, USA[1]; NOAA Fisheries Service, Aiea, Hawaii, USA[2]

Validation of Growth Zone Deposition in the Golden Tilefish *Lopholatilus chamaeleonticeps* Using Lead (210Pb) and Radium (226Ra) Dating

There is a growing concern over the lack of life history information for many deepwater fisheries, including golden tilefish, *Lopholatitus chamaeleonticeps*. Not knowing fundamental characteristics, like age and growth, precludes accurate stock assessments. A previous effort to validate age estimates using bomb radiocarbon dating for this species was inconclusive and led to an application of lead-radium dating, a method that uses radioactive 210Pb:226Ra disequilibria in otoliths as an independent estimate of age. Golden tilefish were intercepted from commercial bottom longline vessels in 2007 on the east coast of Florida. Both sagittal otoliths and gonad tissue were collected. One otolith from each pair sampled was thin sectioned and the other was cored to the first few increments of growth by grinding the whole otolith. Core samples were pooled based on estimated age and sex (male, female, unknown) into groups that could be analyzed using lead-radium dating. Age was estimated using counts of growth increments in thin otolith sections and aged independently with lead-radium dating. Radiometric ages closely agreed with age estimates from counts of growth zones for females and unknown sex fish, which confirmed an annual increment formation. However, radiometric ages did not agree with age estimates from counts of growth zones for males. This difference may be attributed to differing growth rates by sex. Radiometric results indicated the golden tilefish can live at least 25 years.

Megalofonou, Persefoni

Theme: Physiology and Morphology

Nicolaou Costas[1]; Niki Milatou[1]; John M. Dean[2]; Persefoni Megalofonou[1]

Department of Biology, University of Athens, Greece[1]; Baruch Institute for Marine and Coastal Sciences, University of South Carolina, USA[2]

Comparison of Bluefin Tuna Age Estimations Based on External and Internal Features in Otoliths

Age estimates from bluefin tuna otolith sections have been validated and thus confirmed that Atlantic bluefin tuna otoliths are a valid indicator of the age of fish. However, the preparation and reading of thin otolith sections is time-consuming and an expensive procedure. In the present study, we tested whether the external growth features that can be observed on bluefin tuna otoliths can be used in ageing and yield as reliable an estimate as the internal growth zones with less effort. The null hypothesis is that there is no difference in age estimates obtained from analyzing the whole otoliths or transverse sections of otoliths. Otoliths were extracted from specimens sampled from the Mediterranean Sea and were aged using two methods. The first was to infer age from external examination of otoliths. All intact otoliths (N=177) were observed in reflected light and a black background under a binocular stereoscope equipped with an image analysis system. Growth increments were counted beginning from the primordium and along the axis of the rostrum to the boundary. These increments were assumed to be annual in formation, but this assumption has not been validated for bluefin. The second method was to estimate age from examination of transverse thin otolith sections under transmitted light. Ages were estimated by counting growth bands on the long arm of otolith sections. For each otolith and method, two independent counts were performed. The precision or the reproducibility of repeated measurements was estimated using the coefficient of variation. The results from the whole otoliths and the sectioned otoliths gave clearly different age frequency distributions. The percent agreement between the two methods was high in fish up to 8 yrs of age but lower in older fish. Specifically, in fish older than 8 yrs old age was underestimated in the whole otolith method compared to the sectioned otolith method. However, the whole otolith method is fast. It is now possible to do direct determination to estimate year class composition of large numbers of fish of less than 8 yrs, which is prohibitively expensive with sections and is confounded using length and weight estimates.

Mercier, Leny — Theme: Chemistry

Leny Mercier[1]; David Mouillot[1]; Audrey M. Darnaude[2]

University Montpellier 2 (UMR 5119 ECOLAG), France[1]; CNRS (UMR 5119 ECOLAG), France[2]

Otolith Microchemistry Elucidates Lagoon Habitat Use in the Mediterranean Gilthead Sea Bream (*Sparus aurata* L. 1758)

The gilthead sea bream (*Sparus aurata* L. 1758) is an emblematic species of Mediterranean fish markets. Its juveniles are found in many lagoons along the French Mediterranean coast, where they grow from early spring to late autumn, before returning to the sea in winter. Although this behavior has been extensively described, juvenile spatio-temporal distribution within each lagoon still remains unclear. Yet, this can have major consequences for stock recruitment in S. aurata, especially now that lagoons are under increasing local climatic and anthropic pressures that amplify the spatial variability in their environmental quality. In this study, we tried to match spatio-temporal differences in lagoon water chemistry with concomitant LA-ICPMS microchemical analyses of sea bream otoliths, to infer the movements of the juveniles of the species in one of its main nursery areas in the Languedoc-Roussillon region (Etang de l'Or, South of France). To this aim, the lagoon was divided into 3 zones with distinct water characteristics: the western zone, near the entrance of the lagoon and under strong marine influence, the eastern zone under strong freshwater influence due to rivers unload, and the middle zone showing intermediate conditions. Water was sampled monthly in the 3 zones (7 sampling locations) and its chemical composition was assessed using SB-ICPMS. LA-ICPMS analyses were made on the otoliths of 12 juveniles from the 3 zones (4 per zone) captured in September, i.e. after 6 months of lagoon life. Detailed assessment of otolith growth during lagoon life (10 fish per month) allowed accurate matching of elemental ratios from otolith LA-ICPMS transects (N = 12) with corresponding water chemical signatures (N = 42). Among the 12 chemical elements measured in both water and otoliths, Sr, Rb and Mn seemed to be the best candidates to follow fish movements between the 3 zones since, on average, the evolution of their monthly otolith concentrations closely followed those of lagoon water. Our results suggest that S. aurata juveniles do not remain in the same zone during their lagoon life and all exploit the whole nursery habitat.

Miller, Michael J. — Theme: Physiology and Morphology

Michael J. Miller[1]; Akira Shinoda[1]; Mari Kuroki[1]; Nobuto Fukuda[1]; James D. McCleave[2]; Katsumi Tsukamoto1

Ocean Research Institute, University of Tokyo, Nakano, Japan[1];School of Marine Sciences, University of Maine, Orono, Maine[2]

Missing Time in Anguillid Glass Eel Otoliths: Evidence of a Predator Swamping Strategy?

Otolith microstructure studies on temperate species of anguillid glass eels have generally found many total age values that do not back-calculate to hatching dates consistent with the known spawning seasons based on collections of small leptocephali. Although validation studies have documented that daily deposition of otolith increments occurs in the early stage leptocephali and in glass eels that recruited to coastal waters, two studies on glass eels or elvers of *Anguilla japonica* showed that increment formation can be disrupted by low temperatures. Therefore, available evidence suggests there is a period during the glass eel stage before upstream migration in rivers when otolith increments are not deposited or otolith deposition is too slow to form separate increments. It is hypothesized that this period of little or no deposition occurs when glass eels arrive in coastal or estuarine areas near river mouths and they stop migrating and hide in bottom substrates. For temperate species, this period occurs during the winter months when water temperatures are low, and because they are not feeding or swimming, otolith rings may not be deposited. There is also the possibility that a similar period of dormancy could occur in tropical glass eels that wait for other glass eels to accumulate, which, due to a lack of feeding and activity could result in minimal otolith deposition even though the water temperatures are warm. The "freshwater check" present in many glass eel otoliths may actually mark this period of lack of deposition, and so it may represent an accurate age at recruitment to coastal regions and indicate a period of temporary cessation of migration. A minimum temperature is thought to be important in triggering upstream migration of glass eels in temperate species, but density of recruits could be an alternative factor in tropical species. Both temperate and tropical glass eels may have evolved behavioral mechanisms to prevent solitary upstream migration behavior and facilitate predator swamping by migrating when large numbers of glass eels arrive in a particular area and when environmental conditions are appropriate.

Miner, Jeffrey — Theme: Life History and Management

Jeffrey Miner[1]; John Farver[1]; Christopher Boehler[1]; Mia Hall[1]; Todd Hayden[1]; Brian Fryer[2]

Bowling Green State University, Ohio, USA[1]; GLIER, University of Windsor, Canada[2]

Using Otolith Chemistry to Identify and Track Hatchery Stocks of Steelhead (*Onchorynchus mykiss*) in Lake Erie

In Lake Erie, the steelhead fishery is supported primarily via annual stockings of approximately two million fish from the four states (NY, PA, OH, and MI) with some fish coming from Ontario sources and natural reproduction. Although the numbers of steelhead stocked into tributaries from each state are well documented, little is known about the migration and mixing of these different stocks, the degree of release-site fidelity (philopatry), the composition of the returning population during fall and spring fishing periods, and the extent of natural reproduction in some streams. Instead of using wire-coded tagging to identify and track fish, which is currently done in the upper Great Lakes, we are trying to use natural chemical signatures from steelhead otoliths to identify each stock. MI, OH, and NY each have one state hatchery used for stocking steelhead into Lake Erie, while PA has three state hatcheries (and three private hatchery systems stocking about 150K steelhead annually). We have obtained fish from all of these hatcheries. Using elemental ratios from laser-ablated traverses (LA-ICPMS) on the otolith, we determine the extent to which unique hatchery-specific signatures are detectable. This is the first step in generating a better understanding of steelhead stock dynamics in Lake Erie, including mixed stock analysis, distribution throughout the year, and the degree to which fish return to release tributaries (i.e., quasi-philopatry).

Morales-Nin, Beatriz — Theme: Age and Growth

Josep Alos; Beatriz Morales-Nin; Miquel Palmer

Instituto Mediterraneo de Estudios Avanzados, IMEDEA (CSIC-UIB)

Novel Individual Growth Pattern for the Painted Comber, *Serranus scriba* (Linnaeus, 1758), a Bayesian Approach

Back-calculated lengths-at-age data from sagittal otoliths of the painted comber, *Serranus scriba* were used to describe the individual growth of this Serranid and its intra-population variability by means of a Bayesian approach. Conventional three-parameter based von Bertalanffy model (i.e., which assumes that the growth rate parameter is constant along fish life) systematically biases predicted size at early ages and underestimating the asymptotic size at infinite age (Linf). Here we propose an extension of the von Bertalanffy model that accommodates for one change of growth rate at some moment of the life span. This alternative five-parameter model (Linf, k0, k1, t0 and t1, i.e., size at infinite age, initial and final growth rate, age at size zero and age at the change of growth rate). Results showed how the change in growth rate could probably be caused by the different allocation of the energy to the somatic growth or reproduction prior- and post-sexual maturity. Regarding the relationships between the Bayesian means of the individual growth parameters, results showed different tendencies and contributed to understand the individual growth of this species. Intra-population variability was noticeable and depicts a remarkable plasticity of growth that usually remains unreported. This novel individual growth model and its intra-population variability suggested some interesting relationships with environmental cues that should guide future research.

Munk, Kristen

Theme: Age and Growth

Kristen Munk; Jodi Neil

Alaska Department of Fish and Game, Juneau, AK, USA

Refining the Bomb Radiocarbon Profile in the North Pacific Ocean Using Fish Otoliths

We suspect notable differences among the bomb radiocarbon profiles ranging from Southeast Alaska to the Aleutian Islands. For example, the post-peak radiocarbon trend for the North Pacific Ocean Pacific Halibut chronology differs markedly from the Southeast Alaska Yelloweye Rockfish chronology. Differences may compromise the application of a radiocarbon reference curve from one area, to the validation of a species collected from another area. We are in the process of refining the bomb radiocarbon record from Southeast Alaska to the Aleutians on three fronts. Otolith cores for one Pacific rockfish species collected from 4 locales have been submitted for radiocarbon analysis. Black rockfish (*Sebastes melanops*) was selected because it is considered easy to age and where we assume variability will be due to radiocarbon variability and not age reading inaccuracy. We will compare the year markers of "initial rise" and "initial decline" and the mean radiocarbon values of "prebomb" and "peakbomb" to assess regional differences. Second, we are defining the postbomb radiocarbon profile from 1977 to 2007 using otoliths from fish of known-age or nearly known age. Surface marine radiocarbon reached prebomb levels in Southeast Alaska in 2005; however radiocarbon values again spiked in 2006 and 2007. We speculate that this spike may be due to the proximity of nearshore sample locations to radiocarbon reservoirs; possibly from the seasonal and increased melting from nearby glaciers. And third, we will extend the existing Southeast Alaska Yelloweye Rockfish chronology (1940 to 1990) from 1991 to 1998, and the Southeast Alaska Quillback rockfish radiocarbon profile (1950 to 1985) from 1986 to 1995, using otoliths of estimated age. All radiocarbon profile refinements (locale-specific, and extensions using known-age and young but unknown-age fish) will increase understanding of radiocarbon variability and be used to address age estimation questions.

Nichols, Ryan

Theme: Age and Growth

Ryan Nichols; Ed DeMartini

NOAA NMFS PIFSC, Honolulu, HI, USA

Preliminary Estimates of Age and Growth for the Endemic Hawaiian Grouper (Hapu'upu'u, *Epinephelus quernus*, F. Serranidae)

In this preliminary study, we describe the general size and growth characteristics of the endemic Hawaiian grouper or hapu'upu'u, *Epinephelus quernus*, using sagittal otoliths. The hapu'upu'u is endemic to the Hawaiian Islands and Johnston Atoll and is a particularly stressed bottomfish stock in the Main Hawaiian Islands (MHI). We evaluated otolith-to-fish size and body size-at-age relationships utilizing a randomly selected subset of 158 of 548 specimens (24.1-110.3 cm total length) collected in all months spanning a three-yr period. Otolith-to-fish body size relationships were proportional, and body size was predictably related to fish age in years. Otolith length was lineraly related (r-square=0.81) to fish length, and otolith weight was curvilinearly related (r-square=0.70, p-value less than 0.001) to fish weight. Otoliths were sectioned using conventional techniques, and these sections were aged (years) based on presumed annuli. A standard, 3-parameter von Bertalanffy Growth Function (VBGF) fit well (r-square=0.98) to mean back calculated total length-at-age (k=0.157 per yr, L-infinity=82.3cm; t-sub-zero =-1.45). Back calculated total lengths ranged from 27.5 cm at age 1 to 87.0 cm at an observed maximum of 34 years. Marginal increment analysis partially validated a yearly periodicity of annulus formation but additional validation is still required. Our preliinary results nonetheless indicate that the potential exists for using otolith-based age estimates to conduct an age-structured stock assessment of Hawaiian grouper. This might be possible after annuli have been fully validated and after additional specimens have been analyzed to provide more precise parameter estimates. In the very least we increase the information available on the size and growth patterns of the hapu'upu'u and strongly suggest that the alternation of translucent and opaque bands present on sagittal otoliths of this species are formed once a year and can be used to estimate age and growth.

Panfili, Jacques

Theme: Chemistry

Laurent Vigliola[1]; Maylis Labonne[2]; Aurelia Martino[2]; Jean-Dominique Durand[3]; Olivier Bruguier[4]; Jacques Panfili[3]

IRD, UR 028 CoReUs[1]; IRD, UMR LEMAR[2]; IRD, UMR 5119 ECOLAG[3]; University Montpellier 2, UMR 5243 Geosciences Montpellier[4]

Can Otolith Microchemistry be Used to Reconstruct Movement Patterns and Environmental History of Mullets in Hyperhaline Estuaries?

Otolith microchemistry is increasingly used to reconstruct environmental history of fishes. This assumes that elemental signatures of the environment translate into specific signatures in fish otoliths. We tested this hypothesis in contrasted estuarine environments. Six mullet species (626 individuals) and 204 water samples were collected at 12 sites regularly located along two close West-African estuaries, the hyperhaline Saloum (Senegal) and the Gambia. Collections were made during both the dry (June) and the rainy (October) seasons in 2007. Salinities ranged from 0 in October in the upstream Gambia estuary to 84 in June in the upstream Saloum. Solution-based ICPMS revealed strong and significant correlations between water chemistry, salinity and temperature, with highest R2 (>0.97) observed between Sr, Li, Rb and salinity. In contrast, laser ablation ICPMS analyses of otolith edges indicated poor (R2<0.28) but still significant correlations between otolith chemistry, temperature and salinity. Multivariate analyses showed that elemental composition of water allowed excellent discrimination of sites, seasons and estuaries (80-100% of correct classification). Despite poor correlation between water and otoliths microchemistry, elemental signatures in otoliths remained sufficiently specific to discriminate sites, seasons and estuaries with a good precision (69-100% of correct classification). Greatest contributors to discriminating function were Sr, Ba, Mn, Ca and Mo for water, and Sr, Ba, Mg, Zn and Fe for otoliths. These results suggest that otolith microchemistry may be used to reconstruct movement patterns between different saline areas but not precise environmental conditions experienced by these mullet species.

Payne, Nicholas

Theme: Chemistry

Nicholas Payne; Bronwyn Gillanders

University of Adelaide, Australia

An Enriched Isotope Mass-Marking Technique for the Early Life-History Stages of Cephalopods

The natal origins of juveniles recruiting into adult populations in marine systems are invariably unknown. Stable isotopes offer the potential to provide unique, unequivocal chemical signatures for calcified structures of fish and invertebrates at a variety of life-history stages. Giant Australian cuttlefish (*Sepia apama*) eggs were immersed in water enriched in 137Ba for a range of immersion times (2, 5 and 8 days) and concentrations (0.3, 1.0 and 10 Âµg L-1). To test for the effect of developmental stage, eggs were also immersed in 137Ba for 2 days at a range of stages prior to hatching. Statolith isotope ratios were measured using laser ablation inductively coupled plasma-mass spectrometry. Ratios of 138Ba/137Ba were significantly different to controls for all 137Ba concentrations and immersion times, suggesting that this technique could provide a valuable tool for mass-marking the early life-history stage of cephalopods. The optimal timing for marking statoliths of *S. apama* eggs is currently being investigated, and will provide information on whether the incorporation of 137Ba will vary with developmental stage. Our results reinforce the value of stable isotopes as a tool for tracing movement and natal homing of fish and invertebrates.

Pflugeisen, Bethann

Theme: Life History

Bethann Pflugeisen; Catherine Calder; Jennell Bigrigg

The Ohio State University, Columbus, OH, USA

A Bayesian Mixed-Model Analysis of the Rate of Return of Lake Erie Walleye to Natal Spawning Grounds Using Otolith Microchemistry Data

Fisheries biologists believe that sexually mature Lake Erie Walleye return to their natal spawning grounds to spawn, even though discrete spawning groups mix in the pelagic lake waters during non-spawning seasons. We will describe a hierarchical Bayesian mixture model that can be used to characterize the rate of return of sexually mature Walleye to their natal spawning grounds. Using microchemistry data from otolith cores in tandem with water chemistry data from the spawning grounds, we illustrate the method for the simplest case of two distinct, tributary spawning grounds that feed the Lake Erie Walleye population. We will discuss implications for fisheries management and the application of this technique to other spawning communities in Lake Erie. Because the computations can be performed in R or Winbugs, the method is generally accessible.

Pruell, Richard

Theme: Chemistry

Richard Pruell[1]; Bryan K. Taplin[1]; Jonathan D. Karr[2]

U.S. Environmental Protection Agency[1]; Duke University, Department of Biology, NC, USA[2]

Spatial and Temporal Trends in Stable Carbon and Oxygen Isotope Ratios of Juvenile Winter Flounder Otoliths From Selected Nursery Areas

Winter flounder (*Pseudopleuronectes americanus*) populations have supported large commercial and recreational fisheries along the coast of New England. In recent years the population of this important species has declined precipitously in some areas. Winter flounder spawn in late winter in nearshore areas and juvenile fish reside in shallow-water habitats along the coastline during their first summer. Once young-of-the-year flounder undergo metamorphosis and settle they remain in close proximity to that site until fall. Adult fish move offshore during the late winter and spring then return to their natal estuaries during the fall and winter to spawn. This study was designed to determine if stable carbon (DELTA13C) and oxygen (DELTA18O) isotope ratios in otoliths could be used to differentiate the locations and habitat types that serve as important nursery areas for winter flounder along the Rhode Island coastline. Locations included the upper, mid and lower bay portions of Narragansett Bay, three coastal salt ponds and Narrow River, an estuarine river system. Juvenile winter flounder (45 - 65 mm) were collected yearly over a three-year period from 18 nursery locations along the coast. Sampling locations were selected to include a wide range of physical characteristics and important habitat types. Sagittal otoliths from the flounder were analyzed for DELTA13C and DELTA18O using continuous flow isotope ratio mass spectrometry. Results from these analyses show significant differences in DELTA13C and DELTA18O among location types. Mean DELTA18O values in the juvenile flounder otoliths ranged from -4.8 ± 0.4 to -0.8 ± 0.1, and mean DELTA13C ranged from -3.9 ± 0.7 to -0.4 ± 0.3 among nursery areas. Isotope ratio trends were observed along salinity gradients in Narragansett Bay and Narrow River and significant positive correlations (2002: r = 0.93; 2003: r = 0.80; 2004: r = 0.97) were found between DELTA18O and salinity. Results from the first two years were strongly correlated but the third year data were somewhat different. This indicates that it is important to obtain results for each yearly cohort in order to investigate recruitment to the offshore fishery from various nursery areas.

Quinones, Rebecca

Theme: Life History and Management

Rebecca Quinones; James Hobbs; Michael Johnson; Peter Moyle

University of California at Davis, CA, USA

Successful Life Histories of Klamath River Salmonids (*Oncorhynchus* spp.)

Pacific salmon and trout (salmonids; *Oncorhynchus* spp.) have evolved flexible life histories that allow them to exploit habitats in changing environments. In rivers, life histories determine the timing and periodicity of adult upstream migration and spawning as well as time to hatch, rearing and outmigration of juveniles. We are using otolith strontium isotope ratios (87Sr: 86Sr), determined through laser ablation multi-collector ICPMS, to establish the life histories of adult Chinook salmon, coho salmon and steelhead trout from the Klamath River basin. Ratios from otoliths will be compared to those of water samples collected throughout the basin (n = 42), including locations in all major salmonid-producing tributaries. To date, we have determined ratios for approximately 400 individual salmonids. We are in the process of reconstructing the time and locations of incubation, rearing, outmigration, estuarine entry and spawning of each individual. Future studies will compare the life histories of these adults to those of juveniles leaving the system. In this way, we may determine where and when juvenile salmonids are encountering increased mortality rates. Our information will be used to identify watersheds that are or are not successfully reproducing salmonids, allowing for the prioritization and adaptation of restoration and management activities.

Reis-Santos, Patrick

Theme: Life History and Management

Patrick Reis-Santos[1]; Rita Vasconcelos[1]; Bronwyn Gillander[2]; Henrique Cabral[1]

Instituto de Oceanografia - Faculdade de Ciencias da Universidade de Lisboa, Portugal[1]; School of Earth and Environmental Sciences, University of Adelaide, Australia[2]

Can Otolith Elemental Fingerprints of a Species be Used as a Proxy to Classify Individuals of Other

The ability to use otolith elemental fingerprints of a species as a proxy to classify individuals of other species could be an appealing feature in connectivity and environmental history studies. Currently, little is known on the causes of species related differences in otolith composition. We explored species related patterns in otolith chemical composition among juveniles of five fish species caught within the same estuarine nurseries and tested the use of elemental fingerprints as a proxy to classify other species. Otolith chemical compositions differed between juveniles of *Solea solea*, *Solea senegalensis*, *Platichthys flesus*, *Diplodus vulgaris* and *Dicentrarchus labrax* from nursery areas of six estuaries along the Portuguese coast. Elemental fingerprints varied between juveniles of fish species collected in the same estuarine nursery areas. Using the data from all species simultaneously, the discrimination of estuaries had a lower resolution in comparison to the discrimination of species. Moreover, species specific patterns were observable across sites for some elements, with intra estuarine species discrimination averages ranging from 86.2 to 100.0%. Similarity in otolith elemental fingerprints between species with close phylogeny and ecology was also discernible, particularly among flatfish and perciform species. In addition to the differences in species physiological regulation, specific microhabitat use in a common environment may explain the variation of otolith chemistry among species within the same locations. Overall, the variation in otolith composition suggests the use of different species as proxies to classify other species to their system of origin is limited.

Ruessmann, Hans-Werner

Theme: Age and Growth

Hans-Werner Ruessmann; development team WebGR

Federal Agency for Agriculture and Food, Germany

Web Services for Support of Growth and Reproduction Studies

WebGR is an open source project for supporting calibration workshops. The software includes a set of web services to support the organization and data analysis of calibration workshops, both for age and maturity information of fish. The most common exercises carried out during these workshops are counting otolith growth rings or classifying gonads, with subsequent analysis of the results in order to build age-length keys or maturity ogives. This should be possible to do online using WebGR services. WebGR includes procedures for training purposes, like browsing images, reading expert's annotations or simulating a calibration exercise. The services are installable as a website. All workshop participants have access to a repository of images grouped or classified by workshop (species, date, area, etc.). Each image could be annotated by several scientists. The annotations include fields for the classification (age x or maturity stage y, etc.), observations, scientist, etc. This information is stored in a database so that the statistical analysis of the results can be automated as far as possible and made public as online reports. The software is licensed by an Open Source license to promote transparency, technology transfer and peer review; in addition this allows the scientific community to get involved in further developments, like linkage to statistical analysis engines, or any other specific features. As a second part of the presentation I want to show a small piece of the software: 1)How to make an annotation to image, 2) How to make a calibration exercise, 3) How to compare the results.

Robertson, Simon

Theme: Physiology and Morphology

Corey Green[1]; Simon Robertson[2]; George Jackson[1]

University of Tasmania, Australia[1]; Fish Ageing Services, Pty Ltd, Portarlington, Victoria, Australia[2]

Stock Discrimination of Arrow Squid, *Nototodarus gouldi*, Using Fourier Shape Analysis

Arrow squid form the primary catch of oceanic squid taken off south-eastern Australia. Completing their lifecycle in less than one year, they exhibit high variability in growth, distribution, recruitment, age composition, and catch rate; all of which are thought to be highly influenced by differences in their environment. Given their variability, such fisheries can be problematic in providing population structure for assessment and management purposes. The arrow squid fishery is currently managed under the assumption that it is a single population, though fishermen may be catching squid from several discrete stocks. For this reason, management regimes based on a single population may not be suitable to effectively promote sustainable practices while maximizing yield. Stock discrimination techniques provide fisheries managers with alternative assessment tools to determine the presence of one or multiple stocks within a population and may assist assessment processes. To determine stock structure within the arrow squid fishery, new discrimination techniques have been developed using image analysis and applied to arrow squid statoliths, analogous to otoliths. Using the Fast Fourier Transform (FFT) the shape of the statolith is converted from the time domain to the frequency domain (harmonics) and a Euclidian distance between the two groups calculated. Randomization techniques are applied to the frequency harmonics and the probability of the two groups of statoliths originating from the same stock calculated. This is the first time this technique has been applied to squid statolith shape to answer important stock separation questions and may lead to more effective decisions that will promote sustainable harvesting practices of the arrow squid fishery.

Rodriguez-Fernandez, Lorena Theme: Sclerochronology

Lorena Rodriguez-Fernandez[1]; Jose Quintanilla[2]; Alexandre Alonso-Fernandez[3]; Carmen Pieiro[1]

Instituto Espanol de Oceanografica, Centro Oceanogra¡fico de Vigo[1]; Instituto Espanol de Oceanografica, Centro Oceanografico Malaga[2]; Instituto de Investigaciones Marinas, (CSIC)[3]

Geographic Factors Effect on Otolith Shape of European Hake (*Merluccius merluccius*) Off the Northeast Atlantic

The variability in otolith shape of hake was investigated as a tool to detect differences between geographic areas. A total of 3000 otoliths (sagittae) from individuals between 6 and 92 cm total length collected in three important areas of their Northeast Atlantic distribution (Gulf of Cadiz, Galician and Porcupine waters) were digitised and analyzed for shape variation. The images were analyzed using Leica image analysis software for the export of morphometric characteristics meanwhile fast Fourier transform (FFT) and Wavelet transform (WT) were obtained using the Age&Shape software. In this study we investigated (1) how otolith shape varies in response to somatic growth rate and (2) the differences in otolith shape parameters between distant locations. The effects of somatic and otolith growth, sex and geographical area on the shape were investigated. The feasibility of otolith shape analysis for stock identification was evaluated. There were no consistent differences between left and right otoliths and between sexes within the same length classes. Significant differences in morphometric variables between areas and years were found for lengths between 18 and 41 cm (ANCOVA,F(2,876)=8.5544, p=0.00021).

Rodriguez-Fernandez, Lorena Theme: Sclerochronology

Lorena Rodriguez-Fernandez[1]; Carmen Pieiro1; Francisco Velasco[2]

Instituto Espanol de Oceanografica, Centro Oceanografico de Vigo[1]; Instituto Espanol de Oceanografica, Centro Oceanografico de Santander[2]

Otolith Microstructure Analyses of European Hake (*Merluccius merluccius*) From Atlantic Waters

Daily growth of juvenile hake from three important areas in their Northeast Atlantic distribution (Gulf of Cadiz, Galician and Porcupine waters) were studied along two consecutive years (2004 and 2005) in order to analyze and compare the growth rates in relationship with geographical and environmental factors. A total of 162 otoliths (sagittae) from individuals between 10 and 18 cm total length were collected during autumn bottom trawl surveys were used in this study. Averaged individual growth rates were estimated for the three areas ranging from 0.70(±0.009) to 0.78(±0.005) mm/day, which showed a higher inteanual variability than geographical variability. A growth model was calculated to know the length that juvenile hake could attain at one year in each geographical areas. Despite the mean values being higher than most of the previously reported estimates, they are in line with the fast-growth hypothesis recently reported for this species. Furthermore, variation of increment widths were analyzed, which showed different increment-width patterns related to geographical and seasonal growth variations.

Rohtla, Mehis — Theme: Age and Growth

Mehis Rohtla; Kristiina Jürgens; Markus Vetemaa
Estonian Marine Institute, University of Tartu, Estonia

Differences in Somatic Growth and Otolith Weight Between Two Flounder *Platichthys flesus* (L.) Populations in the North-Eastern Baltic Sea.

Present study examined the differences in the somatic growth and otolith weight between two flounder, *Platichthys flesus* (L.), populations in the Northern and Western Estonia, Baltic Sea. One location, Kasmu Bay (Gulf of Finland), is situated at the eastern frontier of flounder's distribution in the Baltic Sea. It can be characterized by critically low salinities (4-5 ppt) for flounder. Therefore the population inhabiting Kasmu Bay can be considered as living at least under moderate environmental stress. The second location, near Vilsandi Island (Baltic Proper), in contrary, could be described as very suitable area for this species, as the salinities around Vilsandi Island fluctuate between 7-9 ppt. It is generally expected that the growth rate of flounder in the Baltic Sea is positively correlated with increasing salinities and temperature. This means that the growth rates decrease from south to north and from west to east. Our earlier data, however, identified a faster growth of Kasmu Bay flounders compared to Vilsandi Island flounders. In an effort to analyze this phenomenon further we investigated the relationship between fish age, total length and weight, and otolith (left and right sagittae) weight in these two populations. To exclude the yearly variations due to the climatic conditions, the data from two locations were compared between the same year classes. Our starting hypothesis is that in both study areas the otolith's weight has a higher correlation with fish age than with fish length or weight. The results will be discussed.

Rosel, Rodolph Charles — Theme: Life History and Management

Rodolph Charles Rosel[1]; Chih-Chieh Hsu[1]; Yoshi Iizuka[2]; Wann-Nian Tzeng[3]

Institute of Fisheries Science, National Taiwan University, Taipei, Taiwan[1]; Institute of Earth Sciences, Academia Sinica, Nankang, Taipei, Taiwan[2]; Department of Life Science and Institute of Fisheries Science, National Taiwan University, Taiwan[3]

Otolith Microchemistry and Life History Strategies of a Resident Population of Grey Mullet *Mugil cephalus* from the Kao Ping River, Taiwan

The life history strategies of a resident flathead mullet population in the Kao Ping River estuary of southwestern Taiwan were analyzed from samples collected monthly from the estuary between November 2007 and February 2009. The mean fork length of 581 mullet was 420.64 ± 2.43 mm and the modal length was 450 mm (n = 199). Fish age was determined through the observation of annuli in the whole otolith. The modal length, based on ageing data, corresponded to an age of 2 to 3 years old. The mean length and the estimated age at first sexual maturity were 447.64 ± 5.58 mm and 2 years old (n=23).The age at first maturity was smaller than for the offshore population. The migratory environmental history of the fish was reconstructed by the temporal change in otolith Sr/Ca ratios measured from the core to otolith edge by Electron Probe Micro Analyzer. The mean (±SD) Sr:Ca concentration ratio in the otolith was 4.38 ± 0.80 x 10-3 (n = 13), and decreased significantly between the core (5.16 ± 1.61 x 10-3) and otolith edge (3.41 ± 1.59 x 10-3) ($p < 0.01$). This suggests that the grey mullet may spawn in estuary waters and migrate to lower salinity estuary waters. Spawning frequency was examined by gonadosomatic indices (GSI) and gonad histology. The mean (± SE) GSI of the female increased to a maximum of 9.59 ± 1.74 during November 2007 then decreased to 0.71 ± 0.16 in February 2008. For the 2008 spawning season, the female GSI started to increase in October 2008 (3.13 ± 0.34) and peaked in December (7.84 ± 1.18). The male GSI increased to 6.25 ± 1.70 in January of 2008 and decreased to 4.69 ± 0.91 in February of 2008. These changes indicate that the resident mullet population may spawn earlier than the offshore migratory population, and also imply that early recruiting juveniles on the western coast of Taiwan might originate from the resident population. The life history traits of the resident population differ from those of the offshore population. However, further studies are necessary to clarify any differences in population genetic structure and the degree of mixing between resident and offshore populations.

Santana, Francisco — Theme: Sclerochronology

Francisco Santana[1]; Eric Morize[2]; Mayliss Labonne[2]; Rosangela Lessa[1]

Laboratorio de Dinmica de populaes Marinhas (DIMAR-UFRPE)[1];Laborotoire de Schlerochronologie des Animaux Aquatiques (LASAA-IRD)[2]

Recruitment and Connectivity Between the Marine Coast and Estuary for White Mullet (*Mugil curema*)

The white mullet (*Mugil curema*) occurs in the Atlantic Ocean from the United States to Argentina and is the most abundant mugilid species in northeastern Brazil, accounting for 96% of the catch of all mullets in the region, whereas the juvenile white mullets are captured in estuaries and shallow coastal areas, while adults are found at sea. Overall, the exploitation of the white mullet relies strongly on the catch of juveniles within estuaries, which may account for 68.7% of the total catch of the species in certain areas along the northeastern coast. Off Pernambuco (Brazil) females spawn throughout the year, with highest frequency from November to February (dry season) and lowest frequency in June (rainy season). The spawning takes place at sea, with eggs and larvae carried to the estuary, where they become mature (3 year-old). Juveniles are abundant in the estuary zone; therefore studies on connectivity between sea and estuary for this species are important for recruitment. Thus, we analyzed daily ages based on alizarine validated microstructures of individuals kept in captivity, and Sr:Ca ratio related to salinity in white mullet young-of-year (YOY). Specimens ranged from 1.3 to 16.9 cm fork length with ages from 42 to 281 days. All YOY were caught in estuarine zones as indicated by two patterns of Sr:Ca ratio found in the estuary, attributed to two spawning periods. We assume that birth takes place during the rainy season (low salinity) and in the dry season (high salinity). The number of YOY shows two spawning periods with peaks between April and September as a result of the spawnings in the dry and rainy seasons.

Scutt Phillips, Joe — Theme: Life History and Management

Joe Scutt Phillips; Joanne Walton; Wendy Dawson; Sally Songer; Graham Pilling

Cefas, Pakefield Road, Lowestoft, UK

What Has Computer Imaging Ever Done for Otolith Science? The Need for a Standard Digital Otolith Data Format.

Digital imaging of otoliths is a rapidly expanding area of otolith science, providing a useful tool across many areas of study. As these image-based methods develop, and digital data exchange becomes increasingly important and commonplace, the need for a standard image format to facilitate consistent future work is of increasing importance. However, few attempts to develop such an approach are found in the literature. We review the increasing use of digitally imaged otoliths. Areas to be considered within a standardised specification are developed based on this work, information from stakeholder surveys, and the recognition of likely future areas of development. The review examines the use of otolith images in different studies, noting that they vary dependent upon how data is captured and used, and how the data capture and outputs obtained from images differ. The process required to implement the standardised specification in a digital otolith data format is explored. The benefits of using a standard approach are identified, within theoretical and practical otolith science areas including automated age determination, human otolith reading, population discrimination and the inference of other biological parameters from images. Based upon this work, a set of properties that are required for otolith image research is produced, and the specification of a standard data format is suggested. A variety of file formats are investigated to provide this specification, as well as determining how they may be manipulated to provide the best solution for otolith research. The possibilities of storing associated data within the image file are explored, in addition to image specific data such as otolith feature coordinates, vector information, and layered information. These findings are presented within the poster, and it is anticipated that further information and research requirements will be solicited from symposium attendees, with the aim of developing a best practise digital solution for capturing and storing otolith images for a variety of research areas.

Shen, Kang-Ning — Theme: Life History and Management

Kang-Ning Shen[1]; Chih-Chieh Hsu[1]; Chai-Hui Wang[2]; Chen-Feng You[3]; Wann-Nian Tzeng[4]

Institute of Fisheries Science, National Taiwan University, Taiwan[1]; Earth Dynamic System Research Center, National Cheng Kung University, Taiwan[2]; Department of Earth Sciences, National Cheng Kung University, Taiwan[3]; Institute of Fisheries Science, National Taiwan University, Taiwan[4]

Population Genetic Structure and Migratory Life History of the Flathead Mullet *Mugil cephalus* in the Coastal Waters of Taiwan as Indicated by Microsatellites and Otolith Elemental Signature

To identify the population units of flathead mullet *Mugil cephalus* in the coastal waters of Taiwan and to reconstruct their migratory environmental history, a total of 428 adults were collected from its well-known spawning ground in the SW and NE Taiwan (n = 296) and from the Kaoping estuary of SW Taiwan (n = 132) in the winter of 2005 to 2008, for both genetic and otolith analyses. Three populations were identified by microsatellite analysis, namely P1, 2 and 3. Assignment test indicated that the mullet collected from the spawning ground was mostly P1, comprising 94 % of the specimens examined. Those collected from Kaoping estuary was mostly P2 (62 %), and P3 (30 %) and few P1 (8 %). The life history scan of Sr/Ca and Ba/Ca ratios in the otolith (n = 41) analyzed with a laser-ablation ICPMS indicated that larval stage of P1, P2 and part of P3 individuals (44%) were spent in seawater while the natal stages of other P3 mullets (56%) were spent in brackish water. These imply that P1, P2 and some P3 mullets might spawn offshore, and the others might spawn near the estuary. The growth rates of the mullet as back-calculated from the annulus of the otolith were not significantly different among populations, indicating that the feeding environment may be similar among populations. This study indicated that using both DNA and otolith microchemistry makers can answer more questions than a single marker for the life history events of *M. cephalus*.

Shih-Huan , Lin — Theme: Life History and Management

Lin Shih-Huan[1] ; Thibault Isabel[2] ; Dodson Julian J.[2] ; Caron Francois[3] ; Iizuka Yoshiyuki [4]; Tzeng Wann-Nian[5]

Institute of Fisheries Science, National Taiwan University, Taiwan, ROC[1]; Department of Biology, Quebec-Ocean, University Laval, Quebec, Canada[2]; Ministry of Resources Nature, Boulevard Harvey, JonquiÃ¨re, Quebec, Canada[3]; Institute of Earth Science, Academia Sinica, Taipei, Taiwan, ROC[4]; Institute of Fisheries Science, College of Life Science, National TaiwanUniversity, Taiwan[5]

Migratory Behavior of Yellow-Stage American Eel *Anguill rostrata* in the St Jean River Watershed of Canada as Indicated by Microtagging and Otolith Sr/Ca Ratio

St Jean River is a long river of 115 km that discharges in a bar-built brackish estuary that experiences a great variation of salinity because of the tidal regime and freshwater inflow. The movement of the eel in the lower 10 km of river was studied according to the releasing and recapture sites of the eel marked with code wire tags (CWT). Four categories (or groups) of movement were observed, however, the salinity preference of the yellow-stage American eel in the river was still not clear. Thus the Sr/Ca ratios in otolith of the eel returned from the mark-recapture experiment were examined by Electron Probe MicroAnalyzer. In Group 1, eels (n=6) were released 7 km upstream the river mouth and recaptured in the estuary. The temporal changes of the Sr/Ca ratios in the otolith indicated that 4 eels stayed in the freshwater after release and then migrated to brackish water, and the other 2 migrated directly to brackish water. In Group 2, eels were released in the estuary and recaptured in the lower reach of the river (n=14), otolith Sr/Ca ratios indicated that the majority of them tended to stay for a while in the brackish water. In Group3, eels were released and recaptured in the lower reach of the river (n=19). Otolith Sr/Ca ratios indicated that more than half of them migrated to the brackish water at least once. In Group 4, eels were released and recaptured in the estuary (n=12). Otolith Sr/Ca ratios indicated that they all stayed in the brackish water. This study indicated that otolith microchemistry can provide insight into the salinity preference of the yellow-stage American eels in an area of high tidal action.

Shih-huan, Lin — Theme: Life History and Management

Lin Shih-Huan[1]; You Chen-Feng[2]; Iizuka Yoshiyuki[3] ; Tzeng Wann-Nian[4]

Institute of Fisheries Science, National Taiwan University, Taiwan, ROC[1]; Department of Earth Sciences, National Cheng Kung University, Tainan, Taiwan, ROC[2]; Institute of Earth Science, Academia Sinica, Taipei, Taiwan, ROC[3]; Institute of Fisheries Science, College of Life Science, National Taiwan University, Taiwan[4]

Migratory Behavior and Micro-Habitat Use by Japanese Eel *Anguilla japonica* in the Kao-ping River of Taiwan as Indicated by Otolith Sr/Ca Ratios and Sr Isotopes

The Japanese eel *Anguilla japonica* is facultatively catadromous, migrating between freshwater and seawater at the yellow stage, which can be identified by otolith Sr/Ca ratios. However, otolith Sr/Ca ratios cannot distinguish among eel movements in different freshwater environments. The Sr isotopes ratios in otoliths were consistent with that in the ambient water and were not affected by fish physiology. If the Sr isotopes ratio differed among freshwater habitats due to different river geologies, the otolith Sr isotopes ratio could be helpful to trace the micro-habitats utilization of the fish. We collected water samples from 10 stations in the low to middle reaches of the Kao-Ping River. The temporal change in otolith Sr/Ca ratios from eels collected from the river was analyzed by Electron Probe Micro Analyzer. The migratory environmental history of the eel could be divided into seawater (n=2, 3.3%), brackish water (n=39, 65%) and freshwater (n=19, 31.7%) groups. The Sr isotopes in otolith sections of 5 selected eels were analyzed by TIMS from powders micro-milled between the otolith edge and core region. 87Sr/86Sr of the water samples was negatively correlated to salinity, which increased from 0.709508Â±2 Ã—10-4 in the estuary (salinity: 4.3~ 20.5 psu) to 0.712537Â±2.9 Ã—10-4 in the river (salinity: 0psu). 87Sr/86Sr ratios in the otoliths showed a similar tendency, which was significantly higher for eels living in freshwater (0.711349Â±1.3 Ã—10-3) than in the estuary (0.709338Â±1.0 Ã—10-4). One of the 5 eels collected from freshwater had constant low otolith Sr/Ca ratios but with variable Sr isotope ratios (0.709637~0.711169), which implied that the eel had migrated through different freshwater microhabitats in the river. This study indicated that otolith Sr isotopes can discriminate not only eel migration between freshwater and seawater but also their freshwater microhabitat use in the river.

Sun, Chi-Lu — Theme: Age and Growth

Chi-Lu Sun[1]; Li-Hua Jhan[1]; Su-Zan Yeh[1]; Gerard DiNardo[2]

Institute of Oceanography, National Taiwan University, Taiwan[1]; NOAA Fisheries, Pacific Islands Fisheries Science Center, Honolulu, HI, USA[2]

Age and Growth of Wahoo, *Acanthocybium solandri*, in the Waters off Eastern Taiwan Based on Otoliths

Age and growth of Wahoo, *Acanthocybium solandri*, in the waters off eastern Taiwan were determined using otoliths. A total of 436 fish ranging from 47.5 to 138.7 cm FL (fork length) and from 0.6 to 21.5 kg RW (round weight) were collected in Shinkang fish market from January 2006 to December 2008 and preliminary results indicated that daily increments could be read for fish smaller than 116 cm FL, while annual counts could be read for fish larger than 116 cm FL. The smallest and largest number of daily increments estimated is 112 days and 399 days, for the fish of 47.5 cm and 116 cm FL, respectively. The oldest fish aged in this study was estimated to be 5 years old, with an associated length of 138.7 cm. Back-calculated spawning dates span the period February to October, which covers the whole spawning season, and is consistent with results from current reproductive biology studies on wahoo. The absolute growth rate decreased with increasing age, indicating faster growth in younger fish, and differential growth rates between individuals of the same daily age group was also detected.

Tanner, Susanne — Theme: Chemistry

Susanne Tanner[1]; Rita Vasconcelos[1]; Patrick Reis-Santos[1]; Henrique Cabral[1]; Simon Thorrold[2]

Centro de Oceanografia, FCUL, Campo Grande, 1749-016 Lisboa, Portugal[1]; Biology Department, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA[2]

Spatial and Ontogenetic Variability in the Chemical Composition of Juvenile Common Sole (*Solea solea*) Otoliths

A description of variations in the chemical composition of fish otoliths at different spatial scales and life history stages is a prerequisite for their use as natural tags in fish population connectivity and migration studies. Otolith geochemistry (Mg:Ca, Mn:Ca, Cu;Ca, Sr:Ca, Ba:Ca, Pb:Ca) of juvenile common sole (*Solea solea* (L.)), a marine migrant species collected in a total of nine sites within six Portuguese estuaries, was examined. Elemental ratios were analysed in right otolith zones corresponding to late larval and juvenile stages using laser ablation inductively coupled plasma mass spectrometry (ICP-MS). Stable carbon and oxygen isotopes (d13C and d18O) were determined in whole left otoliths using isotopic ratio monitoring mass spectrometry (irm-MS). Significant differences in otolith geochemical signatures were found among estuaries, among sites within estuaries and between otolith zones. Several elemental ratios (Mg:Ca, Mn:Ca, Cu:Ca and Sr:Ca) showed consistent patterns between otolith zones which were likely influenced by environmental factors and ontogenetic effects associated with physiological changes during metamorphosis. Assignment of individuals to their collection estuary based on the otolith geochemical signatures was more accurate at the site level (81%) than among estuaries (69%). Temperature at the time of collection was uncorrelated with any of the elemental or isotope ratios, but salinity was significantly correlated with Ba:Ca, d13C and d18O. Observed spatial variations among estuaries and sites within estuaries indicate that geochemical signatures in otoliths are accurate natural tags of estuarine habitat use in common sole. However, the significant variations observed between otolith zones should be taken into account in the design of such studies.

Taplin, Bryan K. — Theme: Chemistry

Bryan K. Taplin[1]; Richard K. Pruell[1]; Ross A. Kean[2]

United States Environmental Protection Agency[1]; Research and Productivity Council, New Brunswick, Canada[2]

Spatial and temporal Variability of Elemental Signatures in Juvenile Winter Flounder: Implications for Natal Connectivity

Elemental signatures in otoliths are important for identifying fish migration patterns, reconstructing environmental histories, and for delineating the nursery origins of fish populations. In this study, we investigated the spatial and temporal variability of elemental signatures in juvenile winter flounder collected from different nursery areas over a 3 year period to determine if chemical signatures could be used as natal tags. Juvenile winter flounder (45-65mm) were collected (2002-2004) from different locations and habitats (unvegetated, macroalgae, and eelgrass) within Narragansett Bay, RI (USA), surrounding coastal ponds, and from a tidal river system. Sampling stations were selected based on salinity gradients and historical abundances of juvenile winter flounder. Otolith samples were analysed for elemental concentrations of Ba, Ca, K, Li, Mg, Mn, Na, Ru, and Sr using Inductively Coupled Plasma Mass Spectrometry (ICPMS) and or Inductively Coupled Plasma Atomic Emission Spectroscopy (ICPAES). Elemental concentrations in juvenile winter flounder otoliths varied according to water body type. Trends among water bodies were consistent over the 3 year sampling period. As expected, fish collected along a salinity gradient (19-32ppt) in Narragansett Bay showed positive correlations (2002: r=0.25; 2003: r=0.52; 2004: r=0.47) between salinity and Sr. In contrast, fish collected along a salinity gradient (13-32ppt) in Narrow river had the highest Sr concentrations and showed negative correlations (2002: r=0.78; 2003: r=0.70; 2004: r=0.69) between salinity and Sr. Linear discriminate functional analysis used to classify fish to different nursery areas showed that Sr was the most important element to describe the multivariate fingerprint followed by Ba, Mg, Mn, and Li. Results of our study provide insight into the spatial and temporal scales of variation in chemical signatures of juvenile winter flounder and suggests that differences in watershed characteristics (bedrock, soils, sediments, hydrogeology, mixing of water masses, etc.) and physical properties (salinity) may play important roles in elemental incorporation in otoliths.

Titus, Robert G. Theme: Physiology and Morphology

Robert G. Titus

California Department of Fish and Game, Sacramento, CA, USA

Applications of Otolith Microstructure Analysis for Assessment of Growth Rates, Stock Origin, and Selection for Growth Potential in Juvenile Fall-Run Chinook Salmon in the Central Valley, California

The California Department of Fish and Game (CDFG) has established protocols for use of otolith microstructure analysis to assess daily growth rates, stock origin, and selection for growth potential in juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in the Sacramento-San Joaquin river system in California's Central Valley. Morphometric measurements were made of Chinook salmon otoliths sampled from 13 riverine, delta, and hatchery rearing habitats in the Central Valley during two years. Mean daily growth rates were high for the species overall, and while relatively homogeneous within rearing habitats, they varied significantly between rearing habitats, yielding the surprising result of being higher on average in riverine habitats than in delta habitats and hatcheries. These results were also well reflected in both daily growth rate estimates based on backcalculation and in daily size-at-age models, and illustrate the high aquatic productivity of the Central Valley system at the southern extent of the Chinook's range. Results of discriminant function analysis (DFA) for assignment of individuals to stock and rearing habitat (river vs. hatchery) reflected a similar pattern. Using six otolith morphometrics, DFA correctly classified 32% of samples by stock, reflecting a relatively high level of homogeneity in otolith microstructure across Central Valley fall-run Chinook stocks. In contrast, 80% of samples were correctly classified by rearing habitat, which paralleled differences observed in growth rates between juvenile Chinook of riverine and hatchery origin. Measures of otolith size at fry emergence were the best predictors for distinguishing Chinook from among both stocks and rearing habitats. Differences in otolith size at emergence may reflect differential responses in development of Chinook salmon embryos reared under different temperature regimes. Otolith size at emergence is also being used to test a growth potential hypothesis where individuals with large otoliths are expected to dominate among juvenile fall-run Chinook salmon that have a protracted in-stream rearing period, while those with small otoliths emigrate without taking up stream residence.

Torrecilla, Elena Theme: Physiology and Morphology

Elena Torrecilla[1]; Jaume Piera[1]; Antoni Lombarte[2]; Vicenc Parisi-Baradad[3]

Marine Technology Unit (UTM-CSIC), Spain[1]; Institute of Marine Sciences (ICM-CSIC),Spain [2]; Dep. of Electrical Engineering, Universitat Politecnica de Catalunya (UPC), Spain[3]

Automatic Landmark Selection of Otolith Shape Contour Using the Wavelet Transform Modulus Maxima

Otolith shape has been used in recent years as natural tags in automatic taxon identification of fish species, essentially in feeding ecology, paleontology and archeology. Two main groups of shape analysis have been used, contour analysis and homologous points (landmarks) analysis. One of the major challenges of otolith morphology research is developing objective landmark selection methods to better develop systematic studies. In this article, a multiresolution analysis, specifically the discrete Wavelet Transform Modulus Maxima (WTMM) method, is presented for the automatic extraction of otolith shape features. Wavelet-based analysis has advantages over traditional Fourier-based methods since it has the ability to quantify sharp transitions of the signal and establish its precise location. The suitability of the technique for this purpose has been tested through the use of an assorted set of otolith images belonging to the AFORO database (http://aforo.cmima.csic.es). Based on a Cartesian codification of the two-dimensional representation of its outline contour, the most discriminating points at different scales of observation have been determined in two sets of groups. First, a group which includes otoliths having very differentiated contours and second, a group based in the Family Myctophidae. The results exemplify the usefulness of the WTMM method as a new promising tool in automatic otolith landmark selection. Achieving this type of multiresolution shape descriptors points out the importance of continued development of new, more advanced otolith classification systems which could be based on a combination of different extracted descriptors (morphological, multiscale, etc.).

Tracey, Sean R. — Theme: Chemistry

Sean R. Tracey[1]; Leonid Danyushevsky[2]; Jeremy M. Lyle[1]

Mar.Res.Lab,Tasmanian Aquaculture and Fish. Inst.,Univ. Tasmania, Hobart, Australia[1]; School of Earth Sci. and Centre for Ore Deposit Res.,Univ.Tasmania,Hobart, Australia[2]

Shallow Inshore Reefs as Juvenile Habitat for the Striped Trumpeter (*Latris lineata*) as Inferred From Otolith Microchemistry

An understanding of the critical life history requirements, including habitat utilization, is important when managing fish populations. Striped trumpeter (*Latris lineata*) support small, but iconic commercial and recreational fisheries in Tasmania, characterised by exceptional recruitment variability and apparent ontogenic habitat preferences. Using otolith microchemistry analysis we have attempted to estimate the comparative contribution to the adult population of juvenile striped trumpeter from shallow inshore habitats. Juvenile striped trumpeter from a strong recruitment pulse were collected at age two from inshore reefs and as adults at age six from deeper offshore reefs around the coast of Tasmania. Natural variations were identified in the concentrations of lithium and strontium within the incremental structure of the observed otoliths. Although when the otoliths of cultured striped trumpeter were analysed an ontogenic trend in strontium and lithium levels was discovered. This finding had significant implications for the perceived geographically driven trace element variation.

Trape, Sebastien — Theme: Life History and Management

Sebastien Trape; Jean-Dominique Durand; Laurent Vigliola; Jacques Panfili

UM2

Seasonal Variability in Recruitment, Habitat Use and Growth of Young-of-the-Year Mullets in a West African Hypersaline Estuary

Climatic change in West Africa has deeply impacted estuarine ecosystems, causing at some locations an inversion of the salinity gradient and hypersaline conditions (salinity > 60). To provide a first insight on the consequences of this massive environmental change on fish recruitment, we investigated growth and spatio-temporal distribution of 0+ juveniles of three mullet species (*Mugil bananensis*, *M. curema, L. dumerili*) in the hypersaline Saloum estuary (Senegal) where salinities range from 31 downstream to 140 upstream. Juveniles were sampled monthly from April 2007 to March 2008 with a beach seine at eight sites regularly distributed along the salinity gradient. PCR-RFLP technique was used to identify species for smallest individuals and otolith transverse sections were used for estimating the age and back-calculating daily growth rates. Mullet abundance and growth were analyzed in relation to biological (state of mangrove) and physical environmental factors (salinity, temperature, turbidity). Results indicated that recruitment of *L. dumerili* occurred in early and late cold dry season at a minimal size of 12 mm, whereas both *M. bananensis* and *M. curema* recruited during the hot rainy season at a minimal size of 17 and 19 mm, respectively. Otolith analysis revealed that differences in size at recruitment among species resulted from differential growths rather than differences in oceanic stage duration. Growth patterns of *L. dumerili* differed between cohorts: the late cold season cohort grew faster than the early cold season cohort. Maximum catches of juvenile mullets occurred in the lower part of the estuary (31 < salinity < 60) and were correlated with higher growth rates for *L. dumerili*. Our results suggest that hypersaline parts of the Saloum estuary have lost their nursery function and that eurohaline (30 < salinity < 40) and mesohaline (40 < salinity < 60) habitats may be essential nursery zones for the mullet populations of hypersaline estuaries in West-Africa.

Tyagun, Marina — Theme: Life History and Management

Marina Tyagun; Bakhtiar Bogdanov; Yulia Tolmacheva; Elena Dzuba

Limnological Institute of the SB RAS, Russia

Otolith and Scale Atlas of Lake Baikal Fishes

Fishes of Lake Baikal are highly polimorphic. A wide range of subspecies morphs is typical of deepwater, pelagic and lithoral species of Lake Baikal. It is also expressed in variety of scales and otolith forms. It is necessary to identify species and, in some cases, subspecies with reliable accuracy. We are planning to present information and illustrations of scales and otoliths of Baikal ichthyofauna with keys for their species identification. The whole complex of studies consists of blocks of tasks. The following taxonomic features are among them: (1) growth and peculiarities of life cycle, including studies on seasonal periodicity of growth using intra-annual hyaline-opaque increments (in otolith) and sclerite size (in scale); (2) life cycle length with preliminary estimation of ageing validity; (3) otolith form, including search of difference in outlines and volume of otoliths; (4) architectonic and relief dimensions of the upper scale layer; (5) peculiar features of sulcus acusticus outline and scale sensor channel; (6) morphometric species/subspecies indexes of otoliths, and (7) microsculpture studies of surfaces and sections of otoliths/scales. Stages for compiling the atlas include: 1) Preparation of specimens, 2) photography of specimens with optical instruments and scanning electronic microscopy, 3) creation of photobank, 4) describing typical species-specific outline peculiarities of otoliths and description of geometric similarity of scale forms, 5) measurements of annual and seasonal increments including periodic harmonics of hard tissue growth, 6) morphometric indexes of species/subspecies, 7) drawings and graphic schemes, 8) keys of species/subspecies identification, 9) general patterns of growth and formation of scales and otoliths typical of representatives of different faunistic communities of the lake, and 10) creation of polygraphic and HTML version of the atlas. The majority of the Baikal fauna representatives are freshwater endemics. Therefore, this work may serve both as a guide and illustration of adaptations of various freshwater taxa under conditions of different zones and habitats of the lake.

Tzeng, Wann-Nian — Theme: Sclerochronology

Yu-Jia Lin[1]; Jen-Chieh Shiao[2]; Linas Lozys[3]; Maris Plikshs[4]; Atis Minde[4]; Yoshiyuki Iizuka[5]; Rashal Isaak[6]; Wann-Nian Tzeng[1]

Insitute of Fisheries Science, National Taiwan University, Taiwan[1]; Institute of Oceanography, National Taiwan University, Taiwan[2]; Institute of Ecology of Vilnius University, Lithuania[3]; Latvian Fish Resources Agency, State Agency, Ministry of Agriculture, Republic of La[4]; Institute of Earth Sciences, Academia Sinica, Taiwan[5]; Institute of Biology, University of Latvia, Republic of Latvia[6]

Does European Eel Anguilla anguilla in the Yellow Eel Stage Deposit a Transition Check in the Otolith During Their First Freshwater Entrance?

Most elvers of anguillid eels deposit a transition check in the otolith during their upstream migration from estuary to river. The European eel *Anguilla anguilla* in the Baltic countries enter freshwater from the brackish sea during the yellow eel stage. It is unclear whether they deposit a transition check in the otolith as do elvers. A total of 113 naturally-recruited yellow eels from Lithuania and Latvia that entered freshwaters at least once were used to evaluate the relationship between transition check and the formation of annuli and other growth checks by Electronic Probe Micro analyzer and optical microscope. The transition check, identified from the temporal change of Sr/Ca ratio in the otolith, occurred at the first freshwater entrance of the eel. At the check the Sr/Ca ratio in otolith sharply decreased from approximately 1.6% to less than 0.4%. The mean age of the eels at first freshwater entrance was 4.8 years old. For the majority of the eels (81.7 ~ 84.9 %), the first freshwater entrance check was coincident with an annulus. For 8.3 ~ 11.3 % of eels, the first freshwater entrance check coincided with another check which was darker in color and distinguishable from an annulus. For a few eels (3.8 ~ 10 %), the first freshwater entrance check did not correspond to any otolith check or annulus. The coupling of the transition check and annulus in the otolith of yellow-stage European eels in the Baltic Sea area implies that most of the eels move from the Baltic Sea to freshwater during the winter.

Vanderkooy, Steve

Theme: Age and Growth

Steve Vanderkooy

Gulf States Marine Fisheries Commission

A Practical Handbook for Determining the Ages of Gulf of Mexico Fishes - Second Edition

In 2003, the Gulf States Marine Fisheries Commission published the first edition of "A Practical Handbook for Determining the Ages of Gulf of Mexico Fishes", a manual of standardized protocols and techniques to facilitate consistent, quality age determination of exploited Gulf of Mexico fishes. The Second Edition of the manual includes several additional species for which data are currently being collected under the Gulf's Fisheries Information Network (FIN) Program. Those FIN species have been identified for stock assessment in NOAA's Southeast Data, Assessment, and Review (SEDAR) process in the near future. 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. 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 well beyond the Gulf region and will provide comparable information necessary for age structured stock assessments both at state and regional levels.

Vaz dos Santos, Andre

Theme: Age and Growth

Carolina Siliprandi[1]; Carmen Lúcia Rossi-Wongtschowski[1]; Andre Vaz-dos-Santos[2]

Instituto Oceanografico, USP, Brasil[1]; Universidade Sao Judas Tadeu, Brasil[2]

Age and Growth of the Beardfish *Plymixia lowei* in the Southeast-South Region of Brazil

The beardfish *Polymixia lowei* is a demersal species that inhabits the outer continental shelf and upper slope of the Western Atlantic Ocean. The species has been caught on the Brazilian coast by bottom trawlers since 2002. In order to evaluate its growth, 399 otoliths were analyzed from specimens caught (52 mm < Ls < 227 mm) in the area between 22º-29ºS, during surveys with bottom-trawl (REVIZEE Program) in 2001 and 2002. Otoliths saggitae were measured (length, height, thickness and weight), embedded in resin, sectioned transversely, polished and mounted on slides. Three readings were done about the ring number, the rings radius (R, length measured between the core and each ring) and the section radius (distance from the core to the edge). The type of the edge (translucent or opaque) was also recorded. The validation was performed through the analyses of the translucent/opaque edge zones and marginal increment analyzed bimonthly (beginning in August/September). Data of average length by age was used to fit the von Bertalanffy growth model (VBGM) (Ford-Walford method). The otoliths showed seven rings, the first being considered as prime (P), followed by six rings. The subsequent rings showed the following mean values: R1 = 1.94 mm, R2 = 2.51 mm, R3 = 3.05 mm, R4 = 3.57 mm, R5 = 4.01 mm and R6 = 4.47 mm; the constancy analyses corroborated the accuracy of readings. For validation, the marginal increment analyses showed an annual ring formation, during the winter (June to September), with the following values (average ± standard deviation): 0.073 ±0.042 (August/September), 0.082 ±0.035 (October/November), 0.083 ±0.041 (February/March), 0.081 ±0.043 (April/May) and 0.072 ±0.041 (June/July). The type of edge analyses did not provide conclusive results. The parameters of VBGM fitted were Linf = 231 mm, K = 0.30 and t0 = -0.7 year. The results are consistent with the observed lengths in the sample, describing adequately *P. lowei* growth and providing information that must be used in its stock assessment and to manage the fisheries of Southeast-South of Brazil.

Vaz dos Santos, Andre M.

Theme: Age and Growth

Maria Ines Lorenzo[1]; Andre M. Vaz dos Santos[2]; Carmen Lucia D.B. Rossi-Wongtschowski[3]

Direccion Nacional de Recursos Acuaticos, Uruguay: Dirección Nacional de Recursos Acuáticos / UTF/URU/025/UTF, "Proyecto de Gestión Pesquera en el Uruguay", FAO-DINARA, Montevideo-Uruguay[1]; Universidade Sao Judas Tadeu, Brazil[2]; Instituto Oceanografico da Universidade de Sao Paulo, Brazil[3]

Age and growth of the young of the year of the Argentine hake, *Merluccius hubbsi Marini*, 1933 (Gadiformes: Merlucciidae) in the Southwest Atlantic

The Argentine hake *Merluccius hubbsi* is the most important fish stock in Uruguay. Since 2001, it has been targetted in Brazilian waters by national trawlers. In order to verify geographic growth differences among fishes living between 22°S and 37°S, authors analyzed otoliths of hakes collected in Uruguay (area A - 34°S-37°S), south of Brazil (area B -34°S-37°S) and southeast Brazil (area C - 29°S-22°S). Fishes (28 mm < total length (LT) < 250 mm) were collected during autumn (April to June; n=522) and spring (October to December, n = 473) 1997. The length (Lo), height (Ho) and weight (Wo) of the saggitae were measured and the data analyzed in relation to fish total length according to area and time of the year using discriminant analysis (DA) and linear regression followed by ANCOVA. The mean radius of the demersal rings I and II from transversal sections of the otoliths were compared for areas and seasons (applying the Scheirer-Ray-Hare test). The otoliths edge type (translucent or opaque) was analyzed as an indicator of the time of ring formation. The DA and regression analysis showed statistical differences among otoliths of the three areas. The otoliths radius from areas A, B and C collected in autumn were 0.289 mm, 0.509mm and 0.541, respectively, and those from spring 0.277 mm, 0.494 mm and 0.544 mm, respectively. In autumn and spring the radius values of the demersal ring I in each area were 0.687 mm (A), 0.910 mm (B) and 0.823 (C); and 0.677 mm (A), 0.853 mm (B) and 0.833 mm (C), respectively. The radius values of the demersal ring II in autumn were 0.687 mm, 0.910 mm and 0.823 mm and in spring 0.677 mm, 0.853 mm and 0.833 mm for areas A, B and C, respectively. Statistical differences ($P < 0.001$) were found among these areas. Translucent edges predominated in autumn in area A (72%) and in spring in areas A (86%) and C (72%). The results showed that Merluccius hubbsi growth at age zero differs according to the area. Growth of the ring takes place during spawning in areas A and B during autumn/winter and in area C during spring/summer. Oceanographic processes contribute to the presence of growth differences in the juveniles of *Merluccius hubbsi*.

Vaz-Dos-Santos, Andre M.

Theme: Physiology and Morphology

Andre M. Vaz-Dos-Santos[1]; Nayra N. Santos-Cruz[2]; Carmen Lucia D.B. Rossi-Wongtschowski[3]

Universidade Sao Judas Tadeu, Brazil[1]; FAPESP fellowship, Brazil[2]; Instituto Oceanografico da Universidade de Sao Paulo, Brazil[3]

Otolith Morphology of the Argentine Hake, *Merluccius hubbsi* as a Tool to Stock Identification in Brazilian Waters

Among the demersal fish stocks of the South and the Southeast Brazil (22°S-34°S), *Merluccius hubbsi*, the argentine hake, is one of the better studied. Growth and reproduction studies revealed two stocks north and south of 29°S. In order to describe the hake otoliths and gather further evidence of the existence of these stocks, 14 characteristics of 551 saggitae otoliths (fishes length ranging from 42 and 546mm) were analyzed: otoliths total length and total height, thickness, dorsal and ventral height, sulcus acusticus length, length and height of the cauda, of the colum, of the ostium and the length of its anterior and posterior parts. Samples were analyzed according to latitude (22º S, 23º S, 24º S, 25º S, 26º S e 32º S). Analysis has shown that the otolith growth length is always bigger than its height and that the otolith presents an elongated shape. Its profile is plane, thin and uniform; the sulcus acusticus is homosulcoid, located in central face of the otolith and divided by the colum in cauda and ostium; the cauda and the ostium are oval shaped and over a same plane; colum is wall like tipe. Other characteristics varied greatly. Otoliths length ranged from 2.67 to 24.79 mm (mean value 13.72 mm) and its height from 1.17 to 10.33 mm (mean value 5.87 mm). Regression analysis has shown clear differences among otoliths of all the areas in what concerns otolith length versus colum length. In some cases other latitudinal differences were observed, most of them in relation to latitude 32°S, but not following a clear pattern. The results suggest that the morphology of the hake saggitae of *M. hubbsi* contains elements that could reveal different Brazilian stocks. Nevertheless, a definitive assessment is only to be reached if new studies are carried out, looking at a larger sample and including elements of geometric morphometrics.

Vitale, Sergio

Theme: Age and Growth

Sergio Vitale[1]; Charles Hutchinson[2]; Craig Kastelle[2]; Pietro Rizzo[1]; Salvino Gancitano[1]; Marco Arculeo[3]; Leonardo Cannizzaro[1]

National Research Council, Institute for Coastal Marine Environment, Italy[1]; National Marine Fisheries Service, Seattle, WA, USA[2]; Department of Animal Biology, University of Palermo, Italy[3]

Age Estimation of Silver Roughy, *Hoplostethus mediterraneus*

The accurate age determination of fish is one of the most important elements in the study of their population dynamics. Age determination from growth zone patterns in otoliths has a level of variability which is species dependent. Therefore, accuracy and precision are important considerations in ageing fish. In this study we focused on a deep sea species, silver roughy *Hoplostethus mediterraneus* with two goals: (1) to increase the scarce biological information, (2) to consider a new older maximum longevity. A sample of 82 otoliths, from the Mediterranean Sea, was used for growth zone interpretation from whole otoliths and thin sections. We compared the independent age estimations from the whole otoliths and thin sections. To compare methods we used the following measurements of precision: Average Percent Age Error index (APE), coefficient of variation (CV), and percent agreement. The results showed low percent agreement and low precision between the two methods. The ages estimated using the thin sections were older (mean age = 17.42 years) than the ages estimated from the whole otoliths (mean age = 9.8 years). Although readability of otoliths was very good, the results clearly reveal a rather poor precision level between methods. The differences between the ages estimated from whole otoliths and thin sections highlight the need to develop a reliable ageing method based on validated otolith growth zone interpretations, and emphasize the importance of accurate age estimation for all studies on stock assessment.

Wang, Chia-Hui

Theme: Life History and Management

Chia-Hui Wang[1]; Chih-Chieh Hsu[2]; Chen-Feng You[3]; Wann-Nian Tzeng[2]

Earth Dynamic System Research Center, NCKU, Taiwan[1]; Institute of Fisheries Science, National Taiwan University, Taiwan[2]; Earth Dynamic System Research Center, National Cheng Kung University, Taiwan[3]

Otolith Elemental Composition as Natural Tag in Studying Migratory Environmental History of Flathead Mullet *Mugil cephalus* L. in the Coastal Waters of Taiwan

Flathead mullet *Mugil cephalus* is one of the most important fisheries in Taiwan because its valuable roe product; however, the knowledge on the migration of the fish is still limited. To understand the migratory environmental history of the mullet in the coastal waters of Taiwan, 74 mullets were collected from offshore waters, estuary, freshwater and the otolith elemental compositions were analyzed with a LA-ICP-MS. The mullets collected from freshwater habitat were immature, aged 1+-2+ year-old and fork lengths were small. The otolith Mg/Ca and Mn/Ca ratios were not significantly different among habitats of the mullet. The otolith Sr/Ca ratios were 2.8 ±1.1x10-3, 4.2 ±1.5x10-3, and 6.7 ±2.0x10-3 respectively, which was positively correlated to their habitats salinity. On the contrary, the Ba/Ca ratio in the otolith of the mullet was significantly higher in the freshwater habitat (14.5 ±5.5x10-5) than offshore (5.9 ±2.9x10-5) and estuary (5.2 ±2.2x10-5). The Ba/Ca ratios were not different between estuaries and offshore. Ba is a terrigenous element but not negatively linearly correlated to salinity. According to the temporal changes of Sr/Ca ratio and Ba/Ca ratio, the natal origin of the mullets in the coastal waters of Taiwan can be classified into 3 major types. Type I (n=29), the Sr/Ca ratio was greater than 5.96x10-3 in the otolith core region, indicating that the mullet reside in the offshore water after hatching. Type II (n=40), the Sr/Ca ratio ranged from 3.24x10-3 to 5.96x10-3 in the otolith core regions, indicating that the mullet reside in the offshore or brackish water after hatching. Type III (n=4), the Sr/Ca ratio in the core region of the otolith was less than 3.24x10-3, indicating that the mullet may reside in freshwater after hatching. These findings supported the result of population genetic study that there are different populations in the coastal waters of Taiwan. It was also determined that *M. cephalus* were found in a diverse environment migrating among seawater, brackish and freshwater in different degrees throughout their life history.

Wang, Chia-Hui

Theme: Chemistry

Chia-Hui Wang[1]; Hung-Yu Hsu[2]; Chih-Wei Chang[3]

Earth Dynamic System Research Center, NCKU, Taiwan[1]; Graduate Institute of Marine Biodiversity andEvolutionary Biology, NDHU, Taiwan[2]; National Museum of Marine Biology and Aquarium, Taiwan[3]

Studies on the Relationship Between Fish Otolith Metal Accumulation and Water Chemistry

This study aims to understand the metal accumulation in fish otoliths in the polluted environment, and furthermore to study the relations between otolith elemental composition and water chemistry. A controlled rearing experiment that modified water chemistry in polluted Erren River in Taiwan were carried out. Rearing water were spiked with different level of metals, including Pb, Cu, Zn, Mn, Sr and Ba, in order to understand how water metal concentrations affect otolith metal accumulation. We chose flathead mullet Mugil cephalus, a widely distributed and highly tolerant euryhaline fish as the target species. Three experimental groups (low-, medium-, and high metal concentration) and one control group were designated, and fish were randomly selected to each group. Water chemistry and otolith metal concentration were analysed with an inductively coupled plasma mass spectrometry (ICP-MS). The results provide information on levels of accumulation on different metals, and furthermore, could be applied to wild fish populations in order to back-calculate past migratory history of fishes in polluted environments.

Wann-Nian , Tzeng

Theme: Life History and Management

Tzeng Wann-Nian[1] ; Lin Shih-Huan[2] ; Iizuka Yoshiyuki[3] ; You Chen-Feng[4] ; Weyl Olaf[5]

Institute of Fisheries Science, National Taiwan University, Taiwan, ROC[1]; Institute of Fisheries Science, College of Life Science, National Taiwan University, Taiwan, ROC[2]; Institute of Earth Science, Academia Sinica, Taipei, Taiwan, ROC[3]; Department of Earth Sciences, National Cheng Kung University, Tainan, Taiwan, ROC[4]; Department of Ichthyology and Fisheries Science, Rhodes University, Grahamstown, South Africa[5]

Unprecedented High Sr/Ca Ratios in Otoliths of Wild *Anguilla mossambica* in Madagascar: a Signal of Volcanism

To understand the migratory environmental history of the eel *Anguilla mossambica* in the Mangory River, approximately 400 km northeast of Antananarivo, Madagascar, the Sr/Ca ratios in otoliths of the eels (n=30) were examined by Electron Probe Micro Analyzer. The mean (Â±SD) age, length and weight of the eels were 7.8Â±1.4 yrs, 46.7Â±4.6cm and 241.9Â±86g. We found that the migratory life history of the eel can be classified into two types. Type 1, the Sr/Ca ratios in otoliths of the eel after the elver check (approximately 100 Âµm from the primordium of the otolith) decreased from 12 at metamorphosis from leptocephalus to glass eel to less than 4 at the otolith edge. This indicates that the eel was resident in freshwater from recruitment until collection and was consistent with 33% of the eel otoliths examined. In Type 2, the temporal change of the Sr/Ca ratios in the otolith was similar to that of Type 1 before the elver check, but the ratios in the otolith beyond 500 Âµm from the primordium (at an age of approximately two years old) fluctuated between 5 and 20. The frequency of this fluctuation was approx. 3 to 4 times per year. This is the first record of such high Sr/Ca ratios in eel otoliths. The relationship between otolith Sr/Ca ratios and water Sr/Ca ratios indicates that the high otolith Sr/Ca ratios in the wild *A. mossambica* are a result of elevated Sr levels in the freshwater environment rather than from a seaward migration because the eels were collected in freshwater and the high Sr/Ca ratios in their otoliths was greater than that in the marine leptocephulus stage. Similarly high Sr/Ca ratios have only been reported in hot-spring fish, and the high environmental Sr levels in the Madagascar eel samples may be a result of similar volcanic activity, the igneous geology and the very deep weathering profiles typical to tropical environments. Sr isotopes will be applied to trace possible Sr sources in these otoliths.

Wetzel, Lisa A

Theme: Life History and Management

Lisa A. Wetze[1]; Kimberly A. Larsen[1]; Michael J. Parsley[2]; Bjorn K. van der Leeuw[2]; Christian E. Zimmerman[3]

USGS, Western Fisheries Research Center[1]; USGS, Columbia River Research Laboratory[2]; USGS, Alaska Science Center[3]

Investigating the Life History of a Non-native Species, the American Shad (*Alosa sapidissima*), in the Columbia River, using Otoliths and Scales

American Shad (*Alosa sapidissima*) were introduced to the West coast of the United States in 1871 (Sacramento River). Since then, they have expanded their range from southern California to southeast Alaska. Initially, the Columbia River population remained at low levels, but increased after dam construction improved spawning and rearing conditions. The number of adult shad passing Bonneville Dam peaked at over 5.2 million fish in 2004, but has since declined, with over 2.1 million fish passing the dam in 2008. Since American shad are well-established and numerous in the Columbia River, it is important to understand their potential impacts and interactions with threatened fish species such as salmon. There have been a few investigations of Columbia River shad, but much of our knowledge of shad biology and ecology is from East coast populations. We are using otoliths and scales to add to our knowledge of Columbia River shad life history. We report on the size, age, and spawning history of adult shad captured at Bonneville Dam in 2008. Additionally, evidence is presented for the presence of an alternate juvenile life history type based on size and age at capture during downstream migration. Otolith microstructure and microchemistry analyses are used to further describe this life history type.

Wilson, Matt

Theme: Life History and Management

Matt Wilson; Kathy Mier; Annette Dougherty

NOAA Fisheries, Alaska Fisheries Science Center, Anchorage, AK, USA

The First Annulus of Otoliths: a Useful Tool for Studying Recruitment Processes of Walleye Pollock (*Theragra chalcogramma*)

Processes affecting the movement and survival of juvenile fish determine the geographic distribution and abundance of adult populations. Much information about juvenile fish movement, growth, and survival has been obtained using otolith microstructure (e.g., daily and annual growth increments). The first annulus formed in the otoliths of age-1 (yearling) walleye pollock from the western Gulf of Alaska (GOA) during a several month period centered around 16 March 2001 (N = 420). Otolith growth following the first-annulus formation was used to construct a fish body length-at-date trajectory for yearling fish as they progressed through their seasonal growth cycle (February to September 2001). Yearling growth may be susceptible to external forcing so, in anticipation of future work, model parameters were estimated to characterize the growth rate cycle. Growth rate peaked at 0.58 mm standard length d-1 on 2 July 2001. Growth rates of at least 50% of the peak rate (i.e., >0.29 mm SL d-1) occurred during four months. The springtime increase in growth rate was associated with increasing water temperature and day length. The autumnal decrease in growth rate was associated with decreasing day length. Otolith length at the first annulus was also compared between regional groups of yearling and adult (N = 174) walleye pollock. Yearlings from the Kodiak nursery had relatively large lengths-at-first annulus. Not all Kodiak yearlings may have recruited to the Shelikof Strait spawning aggregation. This could result in geographic structure in length-at-first annulus among GOA adults, which warrants further investigation due to the relevance of stock structure to management of the GOA walleye pollock fishery.

Yaragina, Nathalia A.

Theme: Sclerochronology

Nathalia A. Yaragina[1]; Hans Hoeie[2]; Valentina P. Koloskova1[1]; Hildegunn Mjanger[2]; Kjell H. Nedreaas[2]; Harald Senneset[2]; Natalya V. Zuykova[2]; Per Aagotnes[2]

Institute of Marine Fisheries and Oceanography (PINRO)[1]; Institute of Marine Research (IMR)[2];

Precision of the Northeast Arctic Cod Age Determination Under Variable Environmental and Information Conditions

During 15 years (1992- 2006) of comparative cod age-reading studies carried out by the two national laboratories PINRO, Murmansk, Russia, and IMR, Bergen, Norway, 6386 pairs of Northeast arctic cod otoliths were read and compared to assess precision of age estimation between the two laboratories. Cod otoliths providing basic information for cod assessments were re-analyzed to reveal if there are any discrepancies in age determination given fish length data was not always available to different age readers. Two types of exchange of otoliths sampled during two years (1992 and 1994) were analyzed in parallel: 285 otoliths with known length data and 661 otoliths without length data available. Knowing the length of the cod appeared to increase the discrepancies between the two labs. We also tested to see if there was any connection between ownership of otoliths (i.e., collected and owned by PINRO or IMR) and the subsequent re-reading results (in terms of precision) by both laboratories. We found that the agers at the laboratory which owned the otoliths usually read them less carefully than the otoliths from the other laboratory. Comparisons of otoliths sampled in the years with different temperature conditions, food supply and growth pattern show environmental effects on the growth zone formation in cod otoliths. This may affect precision of the age-readings.

Yu-Ting, Lin

Theme: Chemistry

Lin Yu-Ting[1]; Wang Chia-Hui[2] ; You Chen-Feng[3]; Tzeng Wann-Nian[1]

Institute of Fisheries Science, National Taiwan University, Taipei, Taiwan[1]; Earth Dynamic System Research Center, National Cheng-Kung University, Tainan, Taiwan[2]; Department of Earth Sciences, National Cheng-Kung University, Tainan, Taiwan[3]

Elemental Composition in Otoliths of Southern Bluefin Tuna (*Thunnus maccoyii*) in the Indian Ocean: Habitat-Specific Differences and Upwelling Signal

The southern bluefin tuna (SBT *Thunnus maccoyii*) is a large and highly migratory marine fish, distributed between 30 degrees S - 50 degrees S. Its only spawning ground is located between Java Island of Indonesia and northwestern Australia. The age and elemental composition in otoliths of SBT were examined for specimens collected from 3 different habitats (east South Africa, central Indian Ocean and spawning ground). Six elements, Na, Sr, Mg, Mn, Ba and Ca were measured from the primordium to the otolith edge by laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS). Discriminate Function Analysis indicated that the elemental composition in the otolith edge of SBT differed among habitats, indicating that the otolith elemental composition can be used as a natural signature to discriminate the origin of the fish from different habitats. The otolith Ba/Ca ratio was significantly elevated during the summer time for SBT of one to five years old that congregate in the eastern Great Australian Bight (GAB). The GAB is the largest area of cool-water carbonate sedimentation in the world and has been characterized as the most productive coastal upwelling zone in Australia. Barium is poor in the open ocean but rich in the upwelling area. Accordingly, the high Ba/Ca ratios in SBT otoliths seems to be a signal deposited when SBT migrate to the highly productive upwelling zone. This study indicated that the elemental composition in otolith of the tuna can be used as a biological tracer for ontogenetic shift timing and reconstructing past migratory environment history.

Zapp, Michelle

Theme: Chemistry

Michelle Zapp1; Beverly Barnett2; James Cowan, Jr.1; William Patterson, III3

Louisiana State University, Baton Rouge, LA, USA[1]; National Marine Fisheries Service, Panama City Lab, FL, USA[2]; Louisiana State University; University of West Florida, Pensacola Fl USA[3]

Variability in Age-0 Red Snapper Otolith Microchemistry Among Gulf of Mexico Regions

Age-0 red snapper (*Lutjanus campechanus*) were sampled from five regions across the Gulf of Mexico (GOM) during fall 2005 and 2006 to develop nursery signatures from otolith element:Ca ratios (Ba:Ca, Mg:Ca, Mn:Ca, Sr:Ca, Li:Ca) and stable isotope delta values (d13C and d18O). Element:Ca ratios were analyzed with solution-based high resolution-inductively coupled plasma-mass spectrometry on dissolved left sagittae, while isotope ratio-mass spectrometry was employed to analyze pulverized right otoliths for d13C and d18O. Otolith chemical signatures were significantly different among regions (MANOVA, $p<0.0001$) per year. Mean jackknifed classification accuracies from quadratic discriminant function were 76% and 69% among regions in 2005 and 2006, respectively. Additional age-0 samples collected during the fall of 2007 are currently being analyzed to contribute a third year of nursery chemical signatures. Signatures will be applied to estimate the source of recruits to offshore regions in the northern GOM, as well as to examine interpopulational mixing among regions.

Zuykova, Natalya V.

Theme: Life History and Management

Natalya V. Zuykova[1]; Natalia A. Yaragina[1]; Hans Hoie[2]; Kjell H. Nedreaas[2]

Institute of Marine Fisheries and Oceanography (PINRO)[1]; Institute of Marine Research (IMR)[2]

Number of Spawning Seasons and Individual Fecundity of Northeast Arctic Cod

Brood stock structure is an important characteristic reflecting stock reproductive potential in terms of life history traits and long-term viability in fluctuating environmental conditions. Spawning stock structure of many species has significantly changed over the last fifty years, resulting in complete closure of some fisheries of collapsed stocks. Hence, monitoring these changes regularly is a big challenge. The Northeast Arctic (NEA) cod spawning stock structure in 2003-2008 (based on 38,051 sampled fish) was analyzed applying otolith studies to separate mature and immature specimens and to determine number of spawning seasons for each individual. Spawning zones in otoliths were identified based on change in translucency and width of translucent annuli. The NEA cod spawning population structure of the Barents Sea appeared to be predominated by first time spawners, which accounted for up to 73% of mature stock abundance. Based on NEA cod data for the period 1999-2006 (151 sp.) relationships between the biological parameters length, weight and absolute individual fecundity (AIF) of the first time spawners (recruits) and repeat spawners were evaluated. No significant relationship between AIF of cod and the number of spawning seasons at a given age was found. The cod AIF strongly depended on fish total weight, liver weight, length and age rather than spawning experience over the period investigated and age groups tested. Environmental factors in the period between two spawning events are likely to play an important role in the AIF cod formation.

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