Proceedings of the 73rd Annual Tuna Conference

The Diet Renaissance
Shedding Light on Ecosystem Function

LAKE ARROWHEAD, CALIFORNIA
MAY 22-25, 2023

PROCEEDINGS OF THE 73RD ANNUAL TUNA CONFERENCE

Lake Arrowhead, California
May 22-25, 2023

Heidi Dewar and Matt Craig – Chairs
Stephanie Flores – Coordinator

This meeting is for frank discussion of ideas, some of which may not be fully developed by the presenter(s). These proceedings are produced as an aid to the meeting and as an informal memory guide; they should not be cited. If readers wish to cite information or an idea from these pages, they should contact the author(s) so that a more proper citation can be used.

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PREFACE

Welcome to the 73rd Annual Tuna Conference. The goal of the Tuna Conference is to provide an open and informal forum for scientists, engineers, managers, fishermen, non-governmental organizations, and other interested parties from around the world to exchange information and ideas including recent research findings on tunas and "tuna-like" species. The free and open exchange of ideas is key to the Conference's success.

This year's theme is "The Diet Renaissance: Shedding Light on Ecosystem Function." The need "to eat" is a primary driver that has shaped the ecology and evolution of all animals, including tunas and other pelagic predators. Consequently, characterizing diets is key to understanding many basic biological traits including migrations, fine-scale behaviors, and aspects of physiology such as condition and growth. At an ecosystem level, diets are the foundation of food webs. There is a long history of diet studies across habitats and taxa with references dating back to Aristotle. Some of the first approaches, still used today, employed observation and stomach content analyses. Over the past few decades, the tools to study diets have expanded to include chemical analyses of tissues (e.g., stable isotopes and fatty acid analyses), genetic barcoding, and even the use of electronic tags to identify foraging events. In the past decade or so, as both our questions and analytical abilities have become more complex, new light has been shed on the value of understanding diets. Diet data are now used more broadly in species distribution models of predators, analyses assessing vulnerability to climate change, and ecosystem models like Atlantis. For highly migratory species that move large distances between nursery, foraging, and spawning grounds, diets are key to understanding shifts in abundance and distribution over short and long temporal and spatial scales. At this year's Tuna Conference, we are calling on scientists to showcase and share presentations on the trophic ecology of large pelagic predators and their application to sustainable fisheries, climate readiness, and ecosystem function.

Many of the oral and poster presentations at this year's conference directly relate to the theme and, as always, there is a diverse and interesting series of presentations on the agenda. Over the course of the next three days, there will be 45 oral presentations across 6 sessions. We also have an additional eight presentations in the poster session. Special thanks to this year's session moderators: Walter Golet, Shane Griffiths, Leanne Duffy, Cat Nickels, Suzy Kohin, Kim Holland, Jon Lopez, and Melanie Hutchinson. We sincerely appreciate their efforts to keep sessions running smoothly.

The abstracts for the oral and poster presentations contained in the Proceedings are listed by the agenda order. Bold lettering denotes the author giving the presentation. All abstracts are considered reports of preliminary work. If readers are interested in the information presented in the abstracts, they should contact the author(s) directly. No abstract should be cited without prior consent from the author(s).

This year, there were many excellent applications for student scholarships and ranking the candidates was a very difficult task. Many thanks to Dan Fuller, Leanne Duffy, Marlon Ramon, Brad Erisman, John Hyde, Matt Craig, Melanie Hutchinson, Owyn Snodgrass, and Heidi Dewar for helping to review the student application packages. Thanks to the generosity of our donors, we are very pleased to announce that funds were available to support five student scholarships this year. The Tuna Conference Scholarship was awarded to Kaylyn Zipp for her talk titled "Understanding the effect of stock of origin assignment assumptions and methodology on mixing rates of Atlantic bluefin tuna, *Thunnus thynnus*." The Manuel Caboz Scholarship was awarded to Yamilla Samara Chacon for her talk, "Stable Isotopes Analysis Provides Evidence of Pelagic Feeding on Juvenile White Sharks (*Carcharodon carcharias*)." Tristan Guillemin received the Wildlife Computers Scholarship for his talk titled "Deciphering the diet of three marlin species through stomach content and stable isotope analysis in Eastern Australia." Ching Tsun Joyce Chang received the American Fishermen's Research Foundation Scholarship for her talk titled "Ontogenetic and Seasonal Shifts in Diets of Sharptail Sunfish (*Masturus Lanceolatus*) in Waters off Taiwan." Finally, Sergio A. Briones-Hernández received the Sportfishing Association of California Scholarship for his talk "Evidence of Potential Differences in Habitat Use and Movements Between Juvenile and Adult Dolphinfish off Cabo San Lucas, Mexico Through Multiple Tissue Stable Isotope Analysis." Additional travel support for the five award winners was graciously provided by the International Seafood Sustainability Foundation.

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In addition to support for student scholarships and travel, the Tuna Conference benefits from generous donations to support the various "social" functions such as the Sushi Social/Poster Session, the Tuna Barbecue, Campfire, and Tavern get-togethers. We thank Rex Ito and Prime Time Seafood Inc. for donating the sashimi-grade tuna for the poster Sushi Social/Poster Session and Wildlife Computers Inc. for providing refreshments. Thanks to Lotek Wireless for hosting our bonfire. We also greatly appreciate our donors from the Sportfishing Association of California and the American Tuna Boat Association.

Many thanks to JoyDeLee Marrow for her time, expertise, and willingness to answer countless logistics questions regarding the conference. Thanks also to Heidi Dewar for her fun and expressive artwork gracing our cover page and Chris Patnode for the Tuna Conference website and logo. Thanks to Owyn Snodgrass for delivering the tuna for our events and to our fantastic team of sashimi cutters and poke preparers: Dave Itano, Craig Heberer, Melanie Hutchinson, John Hyde, Dan Fuller, Owyn Snodgrass, Chugey Sepulveda, Kim Holland, Scott Aalbers, and Jeff Muir. Thanks also to the team of SWFSC and IATTC staff members, too numerous to be named here, for general assistance with preparation for the conference.

Last but not least, thanks to you for participating in the our 73rd Tuna Conference. After all, it is the quality of your presentations and camaraderie that make the Tuna Conference such a great event. We hope you have a productive and enjoyable time, and we look forward to seeing you back next year at the 74th Tuna Conference!

Heidi Dewar	Matt Craig	Stephanie Flores
73rd Tuna Conference Chair	73rd Tuna Conference Chair	73rd Tuna Conference Coordinator

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73rd TUNA CONFERENCE AGENDA

Monday, 22 May 2023

11:00 Registration opens in the Lakeview (continued throughout Monday and Tuesday morning)

13:00 **Welcome and Introduction**

SESSION 1: Life History (Moderator: Walter Golet)

13:20 Length-Weight Relationships for Pacific Bluefin Tuna (*Thunnus orientalis*) in the Eastern Pacific Ocean — Heidi Dewar, Kelsey James, Michelle Horezcko, Alayna Siddall, Lyall Belquist, **Owyn Snodgrass**, and Brad Erisman

13:40 Otolith Based Age Estimates and Validated Life History of North Atlantic Albacore Tuna (*Thunnus alalunga*) Using Bomb Radiocarbon Dating — **Isabelle Sée**, Walter Golet, Allen Andrews, Robert Allam, Eric Orbesen, Derke Snodgrass, Ashely Pacicco

14:00 Corroboration of Otolith Thin-Section Age Reading of Yellowfin and Bigeye Tuna (*Thunnus albacares and Thunnus obesus*) in the Western and Central Pacific Ocean Using Post-Peak Bomb Radiocarbon Dating — **Allen H Andrews**, J Paige Eveson, Caroline Welte, Kei Okamoto, Keisuke Satoh, Kyne Krusic-Golub, Francois Roupsard, Bryan Lockheed, Jed Macdonald, Jessica H Farley.

14:20 Review of Recent Cooperative Research Activities at the IATTC's Achotines Laboratory — **Vernon Scholey**, Daniel Margulies, Yole Buchalla, Susana Cusatti

14:40 **Coffee Break (30 minutes)**

15:10 Comparative Studies of Larval Yellowfin and Pacific Bluefin Tuna in Response to Potential Climate Change Variables and Prey Conditions, and Analysis of the Effects of Broodstock Diet on Yellowfin Egg Composition — **Susana Cusatti**, Daniel Margulies, Vernon Scholey, Yole Buchalla

SESSION 2: Diet Renaissance (Moderator: Shane Griffiths)

15:30 The Diet Renaissance: Shedding New Light on Ecosystem Function — **Travis Richards**, Heidi Dewar, Barb Muhling, Antonella Preti, Cat Nickels, and Owyn Snodgrass

15:50 From Forage Fish to Predators, and Vice Versa: Assessing the Predator Community's Trophic Dependence and Predation Pressure on Forage Species in the California Current, with a Focus on Tuna and Billfish — **Nerea Lezama-Ochoa**, Isaac Kaplan, Chryston Best-Otubu, Joe Bizzarro, Laura Koehn, Catherine Nickels, Antonella Pretti, Heidi Dewar, Barbara Muhling, Desiree Tommasi, Brian Wells, and Pierre-Yves Hernvann

16:10 Using Longnose Lancetfish (*Alepisaurus ferox*) as a Biological Sampler to Monitor Midwater Ecosystems in the North Pacific — **Emily Contreras**, Justin Suca, Elan Portner, Phoebe Woodworth-Jefcoats, and Anela Choy

16:30 How Has Decades of Trophic Ecology Research Across the Pacific Ocean Influenced the Management of Tuna Fisheries? — **Shane Griffiths**

18:30 **Dinner followed by 'Welcome Gathering' in the Tavern**

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Tuesday, 23 May 2023

8:00 Breakfast

SESSION 3: The Diet Renaissance continued (Moderator: Leanne Duffy)

9:00 Operational, Environmental, and Ecosystem Drivers in the Hawai'i-Based Deep-Set Longline Fishery — **Johanna Wren**, Phoebe Woodworth-Jefcoats, Nan Himmelsbach, Jonathan Whitney, Donald Kobayashi, and Eric Kingman

9:20 Juvenile Albacore Tuna (*Thunnus alalunga*) Diet Variability and Resilience in the Northern California Current Large Marine Ecosystem —**Catherine F. Nickels**, Elan J. Portner, Owyn Snodgrass, Barbara Muhling, and Heidi Dewar

9:40 Trait-Based Resource use by Albacore Tuna in the California Current — **Miram R. Gleiber**, Natasha A. Hardy, Caitlin J. Morganson, Catherine F. Nickels, Barbara A. Muhling, Elan J. Portner, Brian K. Wells, Richard D. Brodeur, Toby D. Auth, Jarrod A. Santora, Sarah M. Glaser, Daniel J. Madigan, Elliott L. Hazen, Larry B. Crowder, and Stephanie J. Green

10:00 Feeding Ecology of Broadbill Swordfish (*Xiphias Gladius*) in the California Current — **Antonella Preti**, Stephen M. Stohs, Barbara A. Muhling, Gerard T. DiNardo, Camilo Saavedra, Ken MacKenzie, Leslie R. Noble, Catherine S. Jones, and Graham J. Pierce

10:20 Coffee Break (20 minutes)

10:40 Gelatinous Cephalopods as an Important Prey for a Deep-Sea Predator. — **Rachel S. Chen**, Elan Portner, C. and Anela Choy

11:00 Foraging and Trophic Ecology of Bigeye (*Thunnus Obesus*) and Yellowfin (*Thunnus Albacares*) Tuna in the Northwest Atlantic Ocean — **Riley Austin**, Walter Golet, John Logan, and Gayle Zydlewski

11:20 Evidence of Potential Differences in Habitat Use and Movements Between Juvenile and Adult Dolphinfish off Cabo San Lucas, Mexico Through Multiple Tissue Stable Isotope Analysis — **Sergio A. Briones-Hernández (Sportfishing Association of California Scholarship)**, Ulianov Jakes-Cota, John M. Logan, John O'Sullivan, Jeffrey C. Mengel, and Sofía Ortega-García

11:40 Stable Isotopes Analysis Provides Evidence of Pelagic Feeding on Juvenile White Sharks (*Carcharodon carcharias*) — **Yamilla N. Samara (Manual Caboz Scholarship)**, and Chris Lowe

12:00 Lunch

Renaissance continued Diet Moderator: Cat Nickels

13:30 Ontogenetic and Seasonal Shifts in Diets of Sharptail Sunfish (*Masturus lanceolatus*) in Waters off Taiwan — **Ching-Tsun Chang (AFRF Scholarship)**, Jeffrey C. Drazen, Wei-Chuan Chiang, Daniel J. Madigan, Aaron B. Carlisle, Hung-Hung Hsu, Yuan-Hsing Ho, and Brian N. Popp

13:50 Deciphering the Diet of Three Marlin Species Through Stomach Content and Stable Isotope Analysis in Eastern Australia. — **Tristan A. Guillemin (Wildlife Computers Scholarship)**, Julian G. Pepperell, Troy F. Gaston, and Jane E. Williamson

14:10 Evaluating the Foraging Ecology and Energetics of Atlantic Bluefin Tuna (*Thunnus thynnus*) in the Gulf of Maine — **Samantha Nadeau**, Walter J. Golet, John Logan, and Gayle Zydleweski

14:30 Are Tuna Always Hungry? A Deep Dive into Stomach Fullness Measures in the Western and Central Pacific Ocean — **Pauline Machful**, Annie Portal, Jed MacDonald, Valerie Allain, Joe Scutt Phillips, Joanne Potts, and Simon Nicol

14:50 Coffee Break (30 minutes)

15:20 Group-Hunting in Striped Marlin (Audax) at Multiple Scales — **Matthew Hansen**, and J. Krause.

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15:40 DNA Barcoding Stomach Contents of the Epipelagic Predator, Mahi-Mahi (*Coryphaena Spp.*) — **Nan Himmelsbach**, Molly Timmers, Raymond Boland, Justin Suca, and Jonathan Whitney

16:00 Evaluating the foraging ecology of Atlantic blue marlin (*Makaira nigricans*), white marlin (*Kajikia albida*), and roundscale spearfish (*Tetrapturus georgii*) in the Middle Atlantic Bight — **Joseph Dello Russo**, Riley Austin, Zachary Whitener, Isabelle Sée, John Logan, Lisa Kerr, Joseph Quattro, Walter Golet

16:20 Electronic Tags to Measure Feeding Behavior: A Review and State of Play — **Kim Holland**, Carl Meyer, and Charlie Huveneers

16:40 What are Yellowfin tuna doing at Bootless Bay? — **Ralph R. Mana**

Poster Session and Sushi Social – Sashimi donated by Prime Time Seafood, Inc. and refreshments by Wildlife Computers

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16:30 The IGFA Great Marlin Race: A Citizen Science Approach to Billfish Satellite Tagging — Bruce Pohlot, **Samantha Andrzejaczek**, Barbara Block, Michael Castleton, Jonathan Dale, and Jason Schratwieser

The Pelagic Species Trait Database, An Open Data Resource to Promote Trait-Based Fisheries Research — **Miram R. Gleiber**, Natasha A. Hardy, Zachary Roote, Caitlin J. Morganson, Alana M. Krug-Macleod, Iris George, Cindy Matuch, Cole B. Brookson, Larry B. Crowder, and Stephanie J. Green

Shark Incidents in California 1950-2021; Frequency and Trends — John Ugoretz, **Elizabeth A. Hellmers**, and Julia H. Coates

An Overview of the Commercial Pacific Bluefin Tuna (*Thunnus Orientalis*) Hook-And-Line Fishery From 1980 to 2022 — **Harrison Huang**

Movement of Electronically Tagged Blue Sharks in the Central and Eastern North Pacific Ocean — **Nicole Nasby-Lucas**, Suzanne Kohin, Oscar Sosa-Nishizaki, James Wraith, Owyn Snodgrass, John Hyde, Russ Vetter, Jackie King, Molly Scott, Melanie Hutchinson, Barbara Block, Dave Holts, and Heidi Dewar

Otoliths, Spines Reading and Multi-Model Inference for Age and Growth Estimation of the Striped Marlin (*Kajikia Audax*) in Baja California Sur — Mariana Worbis-Badias, Ulianov Jakes-Cota, **Sofía Ortega-García**, and Rubén Rodríguez-Sánchez

A Synopsis of Oregon's Albacore Tuna Fishery — **Jessica Watson**

Structural Features of the Olfactory System in Istiophorid Billfishes — **Ralph R. Mana**

18:30 Dinner

Wednesday, 24 May 2023

Breakfast: 8:00

SESSION 4: Electronic Tagging (Moderator: Suzy Kohin)

9:00 Multiyear Observations of Atlantic Bluefin Tuna Reveal Fidelity to Foraging and Spawning Grounds — **Chloe S. Mikles**, Camille Pagniello, Andre M. Boustany, Robert Schallert, Michael Castleton, and Barbara A. Block

9:20 Tagging of Atlantic Bluefin Tuna off Ireland Reveals Use of Distinct Oceanographic Hotspots — **Camille M.L.S. Pagniello**, Niall Ó Maoiléidigh, Hugo Maxwell, Michael R. Castleton, Emilius A. Aalto, Jonathan J. Dale, Robert J. Schallert, Michael J.W. Stokesbury, Alan Drumm, Ross O'Neill and Barbara A. Block

9:40 Evidence of Bluefin Tuna (*Thunnus thynnus*) Spawning in the Slope Sea Region of the Northwest Atlantic from Electronic Tags — **Emilius Aalto**, Simon Dedman, Michael Stokesbury, Robert Schallert, Michael Castleton, and Barbara Block

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10:00 Successes of the Inter-American Tropical Tuna Commission's Regional Tuna Tagging Project Conducted During 2019 to 2022 — **Mitchell S. Lovell**, Daniel W. Fuller, Michael J. Opiekun, and Kurt M. Schaefer

10:20 Coffee Break (20 minutes)

10:40 Global, Seasonal and Diel Patterns of Habitat Use of Blue Marlin Makaira Nigricans — **Samantha Andrzejaczek**, Jonathan J. Dale, Chloe S. Mikles, Stephanie Brodie, Steven J. Bograd, Aaron Carlisle4, Michael Castleton, Elliott L. Hazen, and Barbara A. Block

11:00 Swordfish Horizontal Movements in Relation to Stock Structure in the Eastern North Pacific — **C. Sepulveda**, M. Wang and S.A. Aalbers, Jaime Alvarado-Bremer and Heidi Dewar

SESSION 5: Fisheries, Management and Modeling (Moderator: Kim Holland)

11:20 Understanding the Effect of Stock of Origin Assignment Assumptions and Methodology on Mixing Rates of Atlantic Bluefin Tuna, *Thunnus thynnus* — **Kaylyn Zipp (Tuna Conference Scholarship)**, Lisa Kerr, Matt Lauretta, and Walter Golet

11:40 Identification of Regions in the ICCAT and IOTC Convention Areas for Supporting the Implementation of the Ecosystem Approach to Fisheries Management — **Maria José Juan-Jordá**, Anne-Elise Nieblas, Alex Hanke, Sachiko Tsuji, Francis Marsac, Donna Hayes, Eider Andonegi, Diego Alvarez Berastegui, Emmanuel Chassot, Paul de Bruyn8, Fabio Fiorellato, Lauren Nelson, Lucia Pierre, Antonio Di Natale, Laurence Kell, Guillermo A. Diaz, Umair Shahid, Craig Brown, David Die, Haritz Arrizabalaga, Oli Yates, Dimas Gianuca, Fernando Niemeyer Fiedler, Brian Luckhurst, Rui Coelho, Muhammad Moazzam, Sarah Martin, Pascal Thoya, Toshihide Kitakado, Lourdes Ramos Alonso, Jordan Moss, Leire Lopetegui-Eguren, Zaherul Hoque, Arshad Sheikh, and Hilario Murua

12:00 Lunch

13:30 Revealing Benefits, Costs, and Tradeoffs of Spatial Management Arising from Coupled Economic and Ecological Dynamics in Marine Systems — **Daniel Ovando**

13:50 Improving Predictions of How Tuna Distributions Will Change in response to MHWs: A Joint Fishery-Species Distribution Model Approach — **Nima Farchadi**, Camrin D. Braun, Andrew Allyn, Barbara Muhling, Kiva Oken, Elliott Hazen, and Rebecca Lewison

14:10 Implications for the Global Tuna Fishing Industry of Climate Change-Driven Alterations in Productivity and Body Sizes — **Maite Erauskin-Extramiana**, Guillem Chust, Haritz Arrizabalaga, William W. L. Cheung, Josu Santiago, Gorka Merino, and Jose A. Fernandes-Salvador

14:30 Projecting the Future Distribution of Highly Migratory Species in the California Current System — **Nerea Lezama-Ochoa**, Stephanie Brodie, Heather Welch, Michael Jacox, Mercedes Pozo Buil, Jerome Fiechter, Megan Cimino, Barbara Muhling, Heidi Dewar, Elizabeth Becker, Karin Forney, Daniel Costa, Scott Benson, Nima Farchadi, Camrin Braun, Rebecca Lewison, Steven Bograd, and Elliott Hazen

14:50 Coffee Break (30 minutes)

15:20 Modelling the Habitat of the Pelagic Stingray Using Fishery Data — **Andrés Romero**, Jon Lopez and Marlon Roman

SESSION 6: Bycatch (Moderator: Jon Lopez)

15:40 Testing Artificial Baits to Reduce Shark Interactions in Longline Fisheries — **Scott Aalbers**, David Itano, Jeff Muir, William Goldsmith, Lyall Bellquist, Yonat Swimmer, Mike Wang, and Chugey Sepulveda

16:00 Results Obtained During the Long-Term Sampling Program for Shark Catches in Artisanal Fisheries in Central America — **Salvador Siu**

16:20 Presentation of Scholarship Awards

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18:30 Dinner — Tuna Barbeque sponsored in part by the Sportfishing Association of California and American Tunaboat Association

20:00 Bonfire at Pioneer Village — Sponsored by Lotek Wireless

Thursday, 25 May 2023

Breakfast 8:00

SESSION 6: Bycatch continued (Moderator: Melanie Hutchinson)

9:00 Testing Electronic Microprocessor-Based Bycatch Reduction Devices to Reduce Shark Catch— **Gabriella Thomas**, Diego Bernal, Richard Brill, Peter Bushnell, Pingguo He, and Gregory Skomal

9:20 The Effects of Retained Fishing Gear on Swimming and Body Condition of Small Sharks— **Emily Robins**, Jeff Kneebone, Diego Bernal, and Greg Skomal

9:40 A Comparison of Statistical Methods for Modeling the Spatio-Temporal Patterns of Silky Shark (*Carcharhinus falciformis*) Bycatch in the Tropical Atlantic — **Leire Lopetegui-Eguren**, Haritz Arrizabalaga, Hilario Murua, Nerea Lezama-Ochoa, Jon Lopez, Jon Ruiz Gondra, Philippe S. Sabarros, José Carlos Báez, María Lourdes Ramos Alonso, Shane Griffiths, Maria José Juan-Jordá

10:00 What's the Catch? Examining Optimal Longline Fishing Gear Configurations to Minimize Negative Impacts on Non-Target Species — **Molly Scott**, Edward Cardona, Kaylee Scidmore-Rossing, Mark Royer, Jennifer Stahl, and Melanie Hutchinson

10:20 A Machine Learning Species Distribution Model for the Critically Endangered East Pacific Leatherback Turtle (*Dermochelys Coriacea*) — **Jon Lopez**, Shane Griffiths, Bryan Wallace, Verónica Cáceres, Luz Helena Rodríguez, Marino Abrego, Joanna Alfaro-Shigueto, Sandra Andraka, María José Brito, Leslie Camila Bustos, Ilia Cari, José Miguel Carvajal, Ljubitza Clavijo, Luis Cocas, Nelly de Paz, Marco Herrera0, Jeffrey C. Mangel, Miguel Pérez-Huaripata, Rotney Piedra, Javier Antonio Quiñones Dávila, Liliana Rendón, Juan M. Rguez-Baron, Heriberto Santana, Jenifer Suárez, Callie Veelenturf, Rodrigo Vega, and Patricia Zárate

10:40 Business Meeting

11:00 Close Day Three – Final remarks

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ABSTRACTS

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MONDAY, 22 MAY 2023

SESSION 1: Life History (Moderator: Walter Golet)

LENGTH-WEIGHT RELATIONSHIPS FOR PACIFIC BLUEFIN TUNA (*THYNNUS ORIENTALIS*) IN THE EASTERN PACIFIC OCEAN

Heidi Dewar[1], Kelsey James[1], Michelle Horezcko[2] Alayna Siddall[3], Lyall Belquist[4], **Owyn Snodgrass[1*]**, and Brad Erisman[1]

[1] NMFS NOAA Fisheries Southwest Fisheries Science Center
[2] California Department of Fish and Wildlife Marine Region
[3] Sportfishing Association of California
[4] The Nature Conservancy

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Pacific Bluefin Tuna (*Thunnus orientalis*, PBF) in the North Pacific Ocean are assessed by the PBF Working Group of the International Scientific Committee (ISC) for Tuna and Tuna-like Species in the North Pacific Ocean (ISC). For assessments, landings data are obtained from fisheries around the North Pacific basin, including the Eastern Pacific Ocean (EPO). In the EPO, PBF are a popular target of a U.S.-based recreational fishery, and recreational landings are included in the stock assessment.

While all commercial fisheries landings are incorporated into the stock assessment as weight, recreational fishery landings for the EPO are reported and used as the number of fish landed. Although the weight of the recreational catch is not used in the stock assessment, the total weight of recreational landings is estimated by NOAA's Southwest Fisheries Science Center and reported to the ISC, Regional Fishery Management Organizations, and the Pacific Fisheries Management Council (PFMC).

The length-weight relationship (LWR) reported by Kai (2007) for the western Pacific Ocean was previously used to estimate the total weight of recreational landings in the EPO. However, LWRs can vary spatially and impact estimates of total weight. We generated a LWR for the PBF in the EPO from length and weight data collected by the Sport Fishing Association of California and the California Department of Fish and Wildlife. The LWR based on these data were then compared to other available LWR's for PBF. Over the size range measured in the EPO, the weights of fish at larger size classes were lower at a given length than estimated using the LWR calculated by Kai (2007). Additional samples are needed to increase the sample size for larger size classes to extend the LWR and include the largest fish currently landed in the EPO by the recreational fishery. The estimated weight of recreational landings in the EPO provides an important standard metric to compare or combine recreational fishery landings and commercial landings and is useful to the monitoring and management of the PBF fishery.

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OTOLITH BASED AGE ESTIMATES AND VALIDATED LIFE HISTORY OF NORTH ATLANTIC ALBACORE TUNA (*THUNNUS ALALUNGA*) USING BOMB RADIOCARBON DATING.

Isabelle Sée, Walter Golet, Allen Andrews, Robert Allam, Eric Orbesen, Derke Snodgrass, Ashely Pacicco

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Despite ecological and economic importance, the life history of North Atlantic albacore (northern albacore tuna, *Thunnus alalunga*, ALB) remains largely unknown. The lack of data contributes to a fundamental misunderstanding of ALB basic biology. Accurate estimation of age and growth is critical for effective monitoring and appropriate management. Estimates of age and growth for ALB remain uncertain because validation of otolith growth zone deposition (opaque and translucent) has not been properly evaluated. Otolith growth structure varies in clarity and definition in tropical and temperate tunas, leaving them vulnerable to misguided management. We plan to test the validity of age estimates from quantified growth rings deposited in ALB otoliths by comparing measured ^{14}C values from aged ALB otoliths (aged 3-17 years, n=50, 81-115cm CFL) to well established spatiotemporal ^{14}C references using novel gas-AMS (accelerator mass spectrometry) technology. Measured ^{14}C levels in otolith core material is expected to reflect time-specific environmental ^{14}C levels that either support or refute age estimates based on calculated birth years. Preliminary results suggest higher maximum age estimates in the North Atlantic than previously understood (scales suggest ~13 years). If validated by our radiocarbon dating methods, we will have aged samples 30% older than the current ALB longevity estimation.

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CORROBORATION OF OTOLITH THIN-SECTION AGE READING OF YELLOWFIN AND BIGEYE TUNA (*THUNNUS ALBACARES* AND *THUNNUS OBESUS*) IN THE WESTERN AND CENTRAL PACIFIC OCEAN USING POST-PEAK BOMB RADIOCARBON DATING

Allen H Andrews[1,8], J Paige Eveson[2], Caroline Welte[3,4], Kei Okamoto[5], Keisuke Satoh[5], Kyne Krusic-Golub[6], Francois Roupsard[7], Bryan Lockheed[8], Jed Macdonald[7], Jessica H Farley[2]

1. University of Hawaii at Manoa, Department of Oceanography, Hawaii, USA
2. CSIRO Environment, Hobart, Tasmania, Australia
3. Laboratory of Ion Beam Physics, ETH Zürich, Switzerland
4. Geological Institute, ETH Zürich, Switzerland
5. National Research and Development, Fisheries Resources Institute, Yokohama-shi, Japan
6. Fish Ageing Services Pty Ltd., Queenscliff, Australia
7. Pacific Community - SPC, Noumea, New Caledonia
8. Uppsala University, Department of Earth Sciences, Uppsala, Sweden

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Age reading protocols for tuna species have evolved toward greater lifespan estimates than previous age estimation methods by quantifying presumed annual growth zones in thin otolith sections. In the western North Atlantic - Gulf of Mexico, teenage lifespan estimates for yellowfin (YFT, Thunnus albacares) and bigeye (BET, T. obesus) tuna were validated with bomb 14C dating and provided strong support for the age reading protocol of YFT aged 2 to 18 years and BET aged 3 to 17 years. The current study has extended the use of this approach to YFT and BET of the western and central Pacific Ocean (WCPO). Archived young-of-the-year (yoy) otoliths from YFT, BET, and skipjack (SKJ, Katsuwonus pelamis) tuna were analysed for 14C with accelerator mass spectrometry (AMS) for a total of 163 measurements covering 30 years of otolith formation dates (1989 to 2019). This yoy tuna 14C time series exhibited a strong concordance with the existing collective coral-otolith 14C reference chronology for the tropical and subtropical Pacific Ocean. A series of 142 otoliths from older YFT aged 1 to 14 years and BET aged 1 to 13 years were sampled for the earliest growth (core extraction within the first year of growth) and analysed for 14C, resulting in successful measurements for 76 YFT and 64 BET. The post-peak 14C decline exhibited by both the reference chronology — a combination of existing coral and otolith 14C records with the yoy tuna 14C chronologies from this study — and the calculated birth years derived from otolith growth zone counts for each species were in alignment with minor to no significant age reading bias. Hence, the use of thin otolith sections to age YFT and BET in the WCPO up to teenage lifespans is supported and the protocol currently used is confirmed as quantifying annual growth zone structure.

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REVIEW OF RECENT COOPERATIVE RESEARCH ACTIVITIES AT THE IATTC'S ACHOTINES LABORATORY

Vernon Scholey, Daniel Margulies, Yole Buchalla, Susana Cusatti

Inter-American Tropical Tuna Commission

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Achotines Laboratory remains the only research facility in the world with captive broodstock tuna that have been spawning on a regular basis for more than 25 years. Yellowfin tuna eggs, larvae and juveniles resulting from those spawns are used for a variety of studies including investigations of the effects of various environmental and biological factors on growth and survival of pre-recruit life stages. Experimental results from pre-recruit studies have also been incorporated into recent modeling studies to predict effects of climate change on yellowfin tuna in the Pacific Ocean. Wild-caught late-juvenile and adult tuna are also maintained in captivity for research purposes.

In addition to research carried out by IATTC scientists, visiting scientists from other institutions and entities around the world travel to Achotines Laboratory to utilize the unique facilities. Recent research partners include AZTI Tecnalia, the International Seafood Sustainability Foundation, the University of Texas, the University of Miami and the Environmental Leadership and Training Initiative (ELTI) of Yale University.

A review of recent joint research projects and publications will be presented.

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COMPARATIVE STUDIES OF LARVAL YELLOWFIN AND PACIFIC BLUEFIN TUNA IN RESPONSE TO POTENTIAL CLIMATE CHANGE VARIABLES AND PREY CONDITIONS, AND ANALYSIS OF THE EFFECTS OF BROODSTOCK DIET ON YELLOWFIN EGG COMPOSITION

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The Inter-American Tropical Tuna Commission (IATTC) has been conducting research on the biology and early life history of yellowfin tuna (*Thunnus albacares*) at the Achotines Laboratory in the Republic of Panama since 1986. The captive yellowfin tuna broodstock population have been spawning almost daily in a land-based tank since 1996 and represents the only sustained spawning of yellowfin tuna in captivity in the world. Eggs and larvae collected from spawning events are used to conduct investigations to estimate effects of environmental and biological factors, as well as effects of climate change, on pre-recruit life stages.

Tuna populations are key components of pelagic ecosystems, but the effects of climate change on tuna biomass, distributions and recruitment are mostly unknown. It is important to investigate the potential impacts of climate change on early life stages and incorporate those results into models that can predict effects on pre-recruit survival. A comparative study was conducted to assess the thermal and prey abundance effects on growth and time to starvation in yellowfin tuna and Pacific bluefin tuna (*Thunnus orientalis*) during the yolk-sac and larval period. The study was conducted from 2012 through 2022 at the Achotines Laboratory and the Oshima Station -Aquaculture Research Institute of Kindai University in Japan. The study was designed to estimate the starvation durations until 100% mortality for larvae of both species over the range of developmental temperatures that both species normally encounter from 24 to 30 degrees C. In addition, larval growth over a gradient of prey levels was compared between species. The preliminary results show that Pacific bluefin tuna larvae, due to their larger size and greater endogenous energy reserves, are more resistant to starvation across all temperatures. At a given temperature, Pacific bluefin tuna larvae resist starvation for 0.5 to 1 day longer. This reduced vulnerability to starvation could be a major survival advantage at the first-feeding stage. Yellowfin larvae, although relatively smaller at first-feeding, consistently exhibited higher growth rates, particularly at low prey concentrations. We offer some insights into these growth potential differences.

The yellowfin tuna spawning program at Achotines Laboratory also supports research on the reproductive biology of adult tunas related to their daily diet composition. Collaborative research with the University of Texas is ongoing to investigate the relationship between daily diet of captive spawning yellowfin and the fatty acid composition of their eggs. The progress and next steps will be summarized.

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SESSION 2: Diet Renaissance (Moderator: Shane Griffiths)

FROM FORAGE FISH TO PREDATORS, AND *VICE VERSA*: ASSESSING THE PREDATOR COMMUNITY'S TROPHIC DEPENDENCE AND PREDATION PRESSURE ON FORAGE SPECIES IN THE CALIFORNIA CURRENT, WITH A FOCUS ON TUNA AND BILLFISH.

Nerea Lezama-Ochoa[1,2], Isaac Kaplan[3], Chryston Best-Otubu[4], Joe Bizzarro[2], Laura Koehn[5], Catherine Nickels[2], Antonella Pretti[1,2], Heidi Dewar[2], Barbara Muhling[1,2], Desiree Tommasi[1,2], Brian Wells[2], and Pierre-Yves Hernvann[1,3]

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Understanding the trophic role of coastal pelagic species (CPS) is crucial to assessing CPS fisheries' indirect impact on the predator community. In the California Current ecosystem, CPS like Pacific sardine, northern anchovy, Pacific herring or California market squid sustain a wide diversity of predators, including commercially important (e.g., tuna-like species) and protected species (e.g., seabirds, mammals). CPS of the California Current are known for the dramatic abundance fluctuations they display in response to environmental changes. Combining complementary sources of information, we here assess the importance of these species in the food web and characterize the impact of CPS abundance fluctuations on their function in the ecosystem from the early 2000s and the late 2010s. Two time-series of indices reflecting the ecosystem importance of CPS were computed, both for single CPS and pairs of CPS. The Supportive Role to Fishery ecosystem (SURF) was calculated using diet time series reconstructed from the recently developed California Current Trophic Database and complementary datasets. The relative contribution of each CPS to the total consumer biomass was then derived from stock assessments or other sources of information. Within a second and more discrete approach, we represented the food-web structure and functioning for two contrasting times over the study period. The collected diet and biomass data informed the construction of two Ecopath mass-balance models representing ecosystem snapshots for the 2005-2007 and 2014-2016 periods, characterized by medium *vs* low biomass levels of sardine and anchovy. The joint analysis of the indices of ecosystem importance of CPS highlights contrasting patterns in the use of these prey in the food web relative to their abundance. In particular, while the use of sardine and anchovy in the food web appeared closely linked to their abundance, this was not the case market squid. The latter, whose amplitude of biomass fluctuations is relatively low, was especially consumed in periods of low abundance of the sardine-anchovy key forage complex. Additionally, comparing ecosystem importance indices to tuna species diet shows the singularity of the use of energy-rich prey by these predators, closely related to their use of space at short or long temporal scales. The outcomes of the modeling approach confirm such results for contrasting CPS abundance periods. The food-web models also quantify the relative impact that tunas (albacore, bluefin, yellowfin), billfish and other ecosystem components have on each other through predation. Last, our results suggest that, in contrast with the importance of CPS in the foraging ecology of tuna-like species, the latter's impact on their population dynamics remains limited in the California Current compared with other predators. This food-web modeling work is the first stage of a temporally and spatially dynamic representation of the California Current ecosystem aiming to support a climate-informed ecosystem-based fisheries management.

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USING LONGNOSE LANCETFISH (*ALEPISAUROS FEROX*) AS A BIOLOGICAL SAMPLER TO MONITOR MIDWATER ECOSYSTEMS IN THE NORTH PACIFIC

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The longnose lancetfish (*Alepisaurus ferox*), a pelagic predator, is one of the most abundant bycatch species from Hawaiʻi's longline fishery. They have no commercial value but share common prey items with commercially important predators including tunas and swordfish. Lancetfish feed on a diversity of fishes, cephalopods, and crustaceans within the top 1,000 m of the water column. Lancetfish are thought to digest food in their intestines; therefore, their stomachs store well-preserved prey that facilitate high-quality morphological identification. Through partnerships with the Pacific Islands Regional Office, over 3,400 lancetfish stomachs have been collected by Federal Fisheries Observers from 2014–2020. Collections are mostly made by observers in the deep-set longline fishery, which covers ~10 million km^2 in the central North Pacific Ocean. Diet analyses performed at the Pacific Islands Fisheries Science Center (PIFSC) and Scripps Institution of Oceanography (SIO) have identified over 51,800 prey items. Seventy percent of lancetfish diet by wet weight is derived from seven prey families, five of which are fish: Sternoptychidae, Anoplogastridae, Omosudidae, Alepisauridae, Alciopidae, Phrosinidae, and Amphitretidae. Spatial patterns in prey consumption demonstrate that lancetfish feed on several distinct prey communities across our study area. These prey communities are largely made up of midwater taxa that are historically undersampled. We present an introduction to the PIFSC lancetfish diet database and provide an update on diet composition and variability across our study area. By monitoring lancetfish diets, we can quantify how the distribution and composition of these midwater communities change over time and space, which might help explain changes in the distribution and landings of other pelagic predators.

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HOW HAS DECADES OF TROPHIC ECOLOGY RESEARCH ACROSS THE PACIFIC OCEAN INFLUENCED THE MANAGEMENT OF TUNA FISHERIES?

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Marine scientists have had a fascination with the trophic ecology of large pelagic predators, such as tunas, since at least the early 1900s, primarily as academic pursuits to understand the types and amounts of prey that fuel these charismatic species. As industrial tuna fisheries developed, so did the realization that changes in the direction and magnitude of trophic flows between species in the ecosystem due to fishing and environmental variation have the potential to manifest into broader ecosystem impacts that may negatively affect the future biomass, and thus catches, of target species.

In the 1990s such realizations across a range of fisheries worldwide led to the incarnation of ecosystem approaches to fisheries management (e.g., EAF, EBFM); an ideology of holistic ecosystem management that can maintain the natural structure and function of an ecosystem while optimizing its productivity to maximize the yield of economically important species. This subsequently spawned the development of ecosystem models (e.g., Ecopath) to quantify and visualize the complex relationships in marine ecosystems and predict their future states under specified fishing and environmental regimes.

The foundation for most ecosystem models is a sound understanding of the taxonomic composition of the ecosystem and the trophic flows between them. Over the past three decades several governmental and non-governmental organizations have invested significant resources in trophic ecology research across the Pacific to support the development of ecosystem models that could be used as tactical tools to fulfill ecological objectives in the conventions and policies of domestic and international fisheries management bodies. Paradoxically, these purpose-built pelagic ecosystem models appear to have had little tangible impact on tuna fisheries management in the organizations from which they were requisitioned. Despite the increasing sophistication and reliability of modern ecosystem models, they appear to be stigmatized by the shortcomings of primitive model versions and the high cost and long duration of the trophic studies required to inform them.

This presentation focuses on pelagic ecological research and modelling undertaken since the mid-1990s in eastern Australia, in the central and western Pacific, and the eastern tropical Pacific Ocean to discuss the interplay between trophic studies and ecosystem model development for the purposes of both improving our knowledge of the trophic ecology of pelagic animals and maximizing the potential utility and acceptance of ecosystem models as tools to guide the management of tuna fisheries.

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TUESDAY, 23 MAY 2023

SESSION 3: The Diet Renaissance continued (Moderator: Leanne Duffy)

OPERATIONAL, ENVIRONMENTAL, AND ECOSYSTEM DRIVERS IN THE HAWAIʻI-BASED DEEP-SET LONGLINE FISHERY

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The Hawaiʻi longline fishery, whose landings make Honolulu the 8th largest U.S. fishing port by revenue, operates mostly outside the Hawaiʻi EEZ in the central North Pacific. The fishery is expanding northeastward towards the edge of the subtropical gyre and has been experiencing variability in catch rates and size composition. The fishery targets bigeye tuna (*Thunnus obesus*) but catches and retains other commercially important species such as other tunas and billfishes. Fish distributions are affected by ocean temperature and food availability. Understanding changes in these distributions is vital for understanding fishery performance, yet little is known about how temperature and prey distributions affect bigeye tuna distributions and catchability. Through a Cooperative Research project, we partnered with longline vessels and placed temperature-depth recorders (TDRs) on the longline gear and collected bigeye tuna, mahimahi *(Coryphaena hippurus)*, and swordfish *(Xiphias gladius)* stomachs. By combining gear depth and prey data with environmental and fisheries catch data we hope to gain insights into how the environment influences catchability of bigeye tuna in the Hawaiʻi longline fishing grounds. To date, we have data from 11 trips covering the fall and winter months and have collected stomachs from 256 bigeye tuna, 115 mahimahi, and 11 swordfish. In this talk we will give an overview of the project, along with insights from the preliminary analysis of how catch composition, fishing depth, and environmental variables relate to each other.

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JUVENILE ALBACORE TUNA (*THUNNUS ALALUNGA*) DIET VARIABILITY AND RESILIENCE IN THE NORTHERN CALIFORNIA CURRENT LARGE MARINE ECOSYSTEM

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Juvenile Albacore Tuna (*Thunnus alalunga*) are important predators in the California Current Large Marine Ecosystem, where they support both commercial and recreational fisheries. Using a time series of Albacore diets off Northern California, Oregon, and Washington from 2009 to 2021, we investigated environmental drivers of diet variability and evaluated whether dietary differences affect intake of biomass or energy. Prey importance was quantified using three different mean proportional metrics: number (%n), weight (%w), and energy content (%e). Across all years combined, fishes were the most important prey group (%n= 51 %w= 61, %e= 66), and Northern Anchovy (*Engraulis mordax*) was the most important taxa, by all three metrics (%n= 21, %w= 24, %e= 25). In contrast, the relative importance of Euphausiids (Order: Euphausiidae) shifted from second to third (%n= 15, %w= 8, %e= 7) and Pacific Saury (*Cololabis saira*) shifted from third to second (%n= 6, %w= 10, %e= 11) in importance when measured using % weight or % energetic value versus % number. We used classification and regression tree (CART) analysis of diets characterized by % weight to identify distinct dietary modes that recur over time and the environmental conditions associated with their occurrence. The total number, weight, and energy content of prey per stomach were then compared between modes to investigate whether these different diets represent differences in food quality. Our findings indicate that Albacore are opportunistic and that diets change in association with shifting environmental conditions, independent of the metric used. Further work will quantify the potential prey biomass removals in each mode and investigate the impact of diet on predator condition and foraging strategy.

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TRAIT-BASED RESOURCE USE BY ALBACORE TUNA IN THE CALIFORNIA CURRENT

Miram R. Gleiber[1], Natasha A. Hardy[1], Caitlin J. Morganson[1], Catherine F. Nickels[2,3], Barbara A. Muhling[2,3], Elan J. Portner[2,4], Brian K. Wells[5], Richard D. Brodeur[6], Toby D. Auth[7], Jarrod A. Santora[5,8], Sarah M. Glaser[9], Daniel J. Madigan[10], Elliott L. Hazen[11], Larry B. Crowder[12], Stephanie J. Green[1]

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As global climate change drives reorganization in marine ecosystems, understanding how predators respond to natural variations in food webs is critical to forecasting future populations. Prey availability is a key aspect mediating predator responses to changing environmental conditions, yet difficult to predict due to the dynamic physical processes and predator-prey relationships in marine systems. Trait-based frameworks are useful in simplifying complex foraging dynamics by identifying traits that recur across diverse taxa within a system to better understand resource use by predators. Here we use datasets from 2005 to 2019 to evaluate diets of albacore tuna (*Thunnus alalunga*), a commercially valuable pelagic predator, in the context of forage communities sampled from shipboard surveys in the California Current Large Marine Ecosystem. We compare taxonomic and trait-based indicators of juvenile albacore resource use and selection within the ambient forage assemblage. Multivariate ordination- and model-based analyses reveal that albacore and trawl surveys sample different aspects of the pelagic system, with albacore consuming an overlapping but broader taxonomic prey assemblage than sampled in trawls. Ecological traits mediating predator-prey interactions consistently distinguished albacore diets from assemblages sampled by trawls across years and regions. Prey electivity analysis reveals consistent selective consumption of coastal and mesopelagic prey that are schooling, undefended, silvered and countershaded, and have high energy density – suggesting the ecological mechanisms of albacore foraging processes may be conserved across time and space. We propose that this trait specialization results in opportunistic feeding by albacore across a taxonomically diverse forage base and can be used to represent feeding relationships in modeling of albacore resource use, diet shifts and future population dynamics. Overall, we show how traits simplify taxonomically diverse predator-prey interactions and are a valuable tool to facilitate predictions of prey resource use in changing environments.

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FEEDING ECOLOGY OF BROADBILL SWORDFISH (XIPHIAS GLADIUS) IN THE CALIFORNIA CURRENT

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Diet data can be used to quantify trophic links across time and space, and they are critical for effective ecosystem-based and climate-ready fisheries management. Diet patterns, by year, associated with the corresponding oceanographic conditions, can offer a tool for predicting future prey abundance and feeding behaviors in similar conditions. The feeding ecology of broadbill swordfish (*Xiphias gladius*) in the California Current was described during a time period of 16 years (2007-2022). Stomachs were collected by fishery observers aboard commercial drift gillnet boats and deep-set buoy gear. Prey were identified to the lowest taxonomic level possible and diet composition was analyzed using univariate and multivariate methods. Of 664 swordfish sampled (74 to 245 cm eye-to-fork length), stomachs contained remains from 77 prey taxa. Genetic analyses were conducted to identify prey that could not be identified visually. Overall diet consisted of cephalopods, epipelagic and mesopelagic teleosts. Jumbo squid (*Dosidicus gigas*) was the most important prey based on the geometric index of importance during the years 2007-2014. The range expansion of jumbo squid that occurred during the first decade of this century may explain their prominence in swordfish diet. Jumbo squid disappeared from the diet starting in 2015 while Pacific hake started to gain importance in 2011 and it has become one of the most important prey items in recent years. Northern anchovy was a rare species during 2007 and 2008 and was not present in the diet until 2016 when it started to gain importance and it has become a prominent prey in recent years. Market squid importance fluctuated in the diet by year, but proportional abundance was very high in 2017 and 2018. Swordfish diet also varied with body size and location. Jumbo squid, *Gonatus* spp. and Pacific hake (*Merluccius productus*) were more important for larger swordfish, reflecting the ability of larger specimens to catch large prey. Jumbo squid, *Gonatus* spp. and market squid (*Doryteuthis opalescens*) were more important in inshore waters, while *G. borealis* and Pacific hake predominated offshore. Diet variation by area and year may reflect differences in swordfish preference, prey availability, distribution, and abundance. Swordfish size, area, time period, and sea surface temperature influenced dietary variation. Standardizing collection, processing and analysis methods could make future studies more comparable for conservation monitoring purposes.

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GELATINOUS CEPHALOPODS AS IMPORTANT PREY FOR A DEEP-SEA FISH PREDATOR

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We quantified cephalopods consumed by longnose lancetfish (*Alepisaurus ferox*, $n = 1267$ stomachs containing cephalopod remains) from 2009 to 2018 in the central North Pacific Ocean (between 0–35° N and 135–175° W). When cephalopods identified from beak remains in the stomach contents were included in diet analyses, clear increases in the abundance of gelatinous taxa and the inferred foraging depths of lancetfish were evident. Ontogeny in cephalopod consumption was evident for lancetfish, corroborating past diet studies. Small lancetfish (fork length < 97 cm) fed on smaller, muscular cephalopods from shallow habitats (0–500 m, e.g., Ommastrephidae, Onychoteuthidae), while large lancetfish (fork length ≥ 97 cm) consumed larger, gelatinous cephalopods from deeper waters (depths greater than 500 m, e.g., Amphitretidae, Cranchiidae). Cephalopod beaks were more abundant in the diets of large lancetfish, representing 37.8% of identified cephalopods, numerically. Although beaks likely remain in stomachs longer than soft tissues, they did not simply accumulate with increasing predator size. Cephalopods identified from beaks were also significantly larger than those identified from soft tissues. Despite having low average energy densities, large gelatinous cephalopods are important prey for lancetfish in deep habitats, with energetic values that are comparable to smaller, more muscular cephalopods (95.3 ± 125.8 kJ and 120.2 ± 169.4 kJ, respectively). Holistic consideration of cephalopod beaks in diet analyses will help to elucidate predator foraging behaviors and the trophic and ecological roles of gelatinous cephalopods in deep pelagic food webs.

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FORAGING AND TROPHIC ECOLOGY OF BIGEYE (THUNNUS OBESUS) AND YELLOWFIN (T. ALBACARES) TUNA IN THE NORTHWEST ATLANTIC OCEAN

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Surveying pelagic environments can be daunting due to the spatial scales which they encompass. Bigeye (*Thunnus obesus*) and yellowfin (*Thunnus albacares*) tunas represent two highly mobile, generalist predators which occupy and forage in areas of the epi- and mesopelagic zones. Given the utility of these tunas as biological samplers of their environment, their role as top predators in this ecosystem, and historical diet studies conducted in this area, they represent ideal organisms to monitor forage population health. With the objectives of comparing forage taxa and trophic levels between tuna species and assessing spatio-temporal variability and other factors influencing forage and trophic level in the northwest Atlantic Ocean, stomach, liver, and muscle tissues were collected from 199 bigeye and 606 yellowfin tuna captured in commercial longline and recreational rod and reel fisheries from 2018-2020. Stomach contents, identified using genetic barcoding and morphology of whole body, otoliths, and beaks, revealed *Illex illecebrosus* was the most important prey species of both tunas while prey species primarily found in the mesopelagic and epipelagic constituted the remainder of diets for bigeye and yellowfin tuna, respectively. Time and location of sampling events was the most important factor in differentiating diets between tunas which highlights the variability of forage at regional levels and under different oceanographic regimes. $\delta^{15}N$ and $\delta^{13}C$ measured in muscle and liver revealed size related increases in $\delta^{15}N$ for bigeye, while shifts in both bulk isotopes were related to on and offshore capture locations as well as across the study period for yellowfin tuna. Contrary to trophic levels calculated from $\delta^{15}N$ in bulk muscle in bigeye tuna which remained stable over time (3.96 ±0.50), trophic levels in yellowfin tuna increased from early summer (3.38 ±0.69) to late fall (3.96 ±0.73). Despite small sample sizes, the $\delta^{15}N$ measured in amino acids supports that the observed increases in trophic level calculated from bulk muscle tissues is the result of increases in $\delta^{15}N$ from trophic transfer and not from the variability between food web bases.

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EVIDENCE OF POTENTIAL DIFFERENCES IN HABITAT USE AND MOVEMENTS BETWEEN JUVENILE AND ADULT DOLPHINFISH OFF CABO SAN LUCAS, MEXICO THROUGH MULTIPLE TISSUE STABLE ISOTOPE ANALYSIS

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The application of stable isotopes to study trophic ecology or movements of marine organisms strongly relies in knowledge of different aspects of the ecology, biology, and physiology of the studied organisms. Tissue turnover rate is one of the key components, as it determines the period in which each tissue is storing stable isotope data from diet and trophic habitat, metabolically active tissues, such as liver, tend to have faster turnover rates than others like muscle, lastly stomach content analysis provides taxonomic resolution of recent diet (i.e., hours) consumed by the organism. Therefore, by coupling techniques and tissues we can reconstruct past (i.e., muscle), more recent (i.e., liver), and immediate (i.e., stomach) diet of the captured organisms to observe any variation. We analyzed 365 stomach samples of juvenile and adult dolphinfish captured by the sport fishing fleet off Cabo San Lucas during July to December of 2018 to 2021. We selected 90 organisms of which we analyzed both liver and muscle tissue for $\delta^{13}C$ and $\delta^{15}N$ values. We used a tissue steady state analysis to identify recent shifts in diet of habitat through variations in $\delta^{15}N$ values. As trophic discrimination factors are usually lower in liver than in muscle, an organism without any recent shift in diet or habitat is assumed to have liver < muscle $\delta^{15}N$ values. Therefore, we used $\Delta^{15}N_{muscle\text{-}liver} = \delta^{15}N_{muscle} - \delta^{15}N_{liver}$, in which values >0 would show organisms without any recent shifts in diet/habitat (i.e., resident) whereas values <0 would inform of recent shifts or movements (i.e., migrant). A variation was recorded for $\delta^{15}N$ in both muscle and liver tissues from July to December where values where higher during September ($\delta^{15}N_{muscle} = 17.5$ ‰) and lower in November ($\delta^{15}N_{muscle} = 13.7$ ‰) during the four years of study, which could be explained as $\delta^{15}N$ baseline variation, however, further analysis is required to identify this variation. Stomach content analysis showed dolphinfish feed mainly of fish (PSIRI = 74%) and statistical differences were observed in diet between months, being September the month that differed with the other months according to ANOSIM, however, no statistical difference was observed between months when trophic position was estimated through stomach contents. The tissue steady state analysis showed statistical differences between juvenile and adult organisms, where 90 % of adult dolphinfish had $\Delta^{15}N_{muscle\text{-}liver}$ <0 classifying this group as migrant or recent diet shift, as $\delta^{15}N_{muscle}$ were usually lower than $\delta^{15}N_{liver}$ meaning they recently arrived from a region with lower $\delta^{15}N$ baseline (i.e., southern Mexican Pacific) or increased trophic position recently. Regarding juveniles 60 % of the organisms showed $\Delta^{15}N_{muscle\text{-}liver}$>0 classifying this group as resident or without diet shift. This result show that Cabo San Lucas is potentially a converging feeding ground where resident juveniles and migrant adults from different regions mix into a single area throughout the years.

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STABLE ISOTOPES ANALYSIS PROVIDES EVIDENCE OF PELAGIC FEEDING ON JUVENILE WHITE SHARKS (*CARCHARODON CARCHARIAS*)

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The white shark is a marine predator with a global distribution, ranging from pelagic to coastal waters. Adults tend to be associated with pelagic habitats and their diet has been previously described to consist of large pelagic fish and marine mammals. During their juvenile stage, white sharks are associated with nearshore-coastal habitats, and it has been documented that their diet mainly consists of benthic coastal teleost and smaller elasmobranchs. In the Southern California Bight (SBC), juvenile white sharks (JWS) form loose aggregation at coastal beaches (<500m from shoreline). Telemetry data has showed that they exhibit high residency levels at these habitats. To describe the dietary composition of JWS, muscle biopsy samples were taken from tagged sharks at coastal aggregation sites for isotopic analysis. JWS also interacted with commercial fisheries offshore (~5km from shoreline). In this case, sharks were biopsied, tagged, and cloacal swabbed for prey DNA analysis, prior release. Isotopic prey baselines for aggregation and bycatch JWS were built by collecting samples from potential prey species found at aggregation sites, and by taking isotopes values from the literature, from pelagic species, using species DNA from swabs as guidance. Permanova tests revealed differences between aggregation and bycatch sharks' isotopic values (P= 0.001) and niche overlapping calculations resulted in a low isotopic overlap of 13% between both groups. Bayesian mixing models showed that aggregation sharks fed mainly on benthic coastal prey while bycatch sharks fed more on pelagic food sources. Additionally, detection data from bycatch sharks showed low mean detections from these sharks at inshore habitats, thus, it is unlikely that this group is making high use of coastal-food sources. This suggests that there are intraspecific differences in movement and foraging behaviors in white sharks, at least during their early life history off California.

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ONTOGENETIC AND SEASONAL SHIFTS IN DIETS OF SHARPTAIL SUNFISH (MASTURUS LANCEOLATUS) IN WATERS OFF TAIWAN

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Understanding pelagic predator feeding strategies helps clarify how species modify diet and behavior across ontogeny and seasons, demonstrating key prey species and feeding habitat that may be integrated into more holistic population assessments and conservation and management initiatives. Family Molidae is often caught with Pacific bluefin tuna in the longline fishery off Taiwan. Among family Molidae, sharptail sunfish (*Masturus lanceolatus*) shares a circumglobal distribution with ocean sunfish (*Mola mola*) and are typically regarded as gelatinous plankton feeders. However, the diet of sharptail sunfish remains poorly described. We examined the foraging habits and trophic dynamics of sharptail sunfish from waters off eastern Taiwan using stomach content analysis (SCA; n = 162), bulk tissue stable isotope analysis (SIA; n = 213) and compound-specific isotope analysis of amino acids (CSIA-AA). Results demonstrated that sharptail sunfish mainly consumed tunicates, with lower dietary proportions of diverse prey from epi- and mesopelagic, coastal, and benthic habitats. The diet of sharptail sunfish changed significantly with size; small sunfish (<80 cm) had lower $\delta^{15}N$ and $\delta^{13}C$ values and fed on more pteropods and Salpidae, while large sunfish (>80 cm) fed on more *Pyrosoma* spp., cephalopods, and benthic organisms, with corresponding higher isotope values and trophic position. Diet compositions and $\delta^{13}C$ values also showed seasonal variations across body size, suggesting that sharptail sunfish might undergo seasonal migrations with changing availability of food resources. The results provide insights into the trophic dynamics of sharptail sunfish and suggest that their foraging behavior varies across life-history stages and seasons, possibly reflecting resource partitioning and different habitat utilization than ocean sunfish. The study further describes the resource use and ecological role of the poorly studied sharptail sunfish, adding to the understanding of trophic interactions of Molidae in marine ecosystems.

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DECIPHERING THE DIET OF THREE MARLIN SPECIES THROUGH STOMACH CONTENT AND STABLE ISOTOPE ANALYSIS IN EASTERN AUSTRALIA.

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Understanding the feeding behaviours or trophic interactions between oceanic fish is key to their management. However, the ecology and behaviours of large bodied pelagic fish such as marlin are notoriously difficult to study, leading to significant knowledge gaps in their trophic ecology. Traditionally, diet was primarily understood through stomach content analysis though more recently, analysis of stable isotopes has become a key tool in deciphering trophic interactions of fish. Working with game fishing clubs, we conducted stomach content and stable isotope ($\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$) analysis of three sympatric marlin species, black marlin (*Istiompax indica*), blue marlin (*Makaira nigricans*) and striped marlin (*Kajikia audax*) to understand their feeding behaviours in temperate waters off southeastern Australia. Whilst most isotope studies use only $\delta^{13}C$ and $\delta^{15}N$, $\delta^{34}S$ has potential to discriminate between coastal and pelagic feeding, yet its use has been relatively minor in pelagic species. As it is known through fishery data that blue marlin often occur further offshore than black or striped marlin, this provided an excellent opportunity to incorporate sulphur into stable isotope analysis. Analysis of stomach contents revealed that although there were differences in the prey consumed across marlin species, trends in what each species consumed were similar to conspecifics in other regions. All species had similar $\delta^{13}C$ values, but $\delta^{15}N$ differed among species, with higher variability observed in blue marlin than in the other two species, suggesting similar prey sources between species but that blue marlin feed on a wider range of trophic levels. Sulphur isotopes were key in identifying the relative contribution of coastal or benthic influences on marlin diet, with $\delta^{34}S$ suggesting that blue marlin had less coastal/benthic dietary influence than black or striped marlin. To further fill the gaps on the feeding of these species, metabarcoding work has begun on collected stomachs to further elucidate specific prey items. Overall, this research emphasises the need for species specific management to account for the differences between marlin stomach contents and isotope values, and also highlights the potential of $\delta^{34}S$ in understanding the trophic ecology of large pelagic fish.

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EVALUATING THE FORAGING ECOLOGY AND ENERGETICS OF ATLANTIC BLUEFIN TUNA (THUNNUS THYNNUS) IN THE GULF OF MAINE

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Over the past few decades, abundance, spatial distribution, and physical condition of Atlantic bluefin tuna (*Thunnus thynnus,* ABFT) have shifted, possibly as a result of trophic changes including the composition, distribution, and/or condition of available prey. Atlantic herring (*Clupea harengus*), the dominant prey item for ABFT, are experiencing severe declines in their population, which, given their contribution to historical ABFT diet and high lipid content, may impact ABFT somatic condition and distribution. Conversely, Atlantic menhaden (*Brevoortia tyrannus*), another lipid-rich clupeid, have experienced a resurgence over the past few years within the Gulf of Maine (GOM). ABFT are known to consume Atlantic menhaden regularly along the Mid-Atlantic Bight, but similar diet trends have yet to be documented in the GOM. Stomach content analysis (SCA) was performed on 375 stomach samples collected in 2018 and 2019 to evaluate potential dietary shifts, specifically from Atlantic herring to menhaden. Additionally, energetic content analysis (EC) was conducted to evaluate the energetic value of select prey items. SCA is temporally limited only providing us with a "snapshot" of ABFT diet and as a result stable isotope analysis (SIA) was used to provide a greater historical foraging record. Results suggest shortfin squid *(Illex illicebrosus*) were the dominant prey in percent presence (61.7%, 49.4%, %O) and weight (25.3%, 19.0%, %W) for both 2018 and 2019, respectively. Declines in Atlantic herring were observed in both %O (30.1%, 15.1%) and %W (15.0%, 13.2%) across both years of the study while increases in %O (6.7%, 18.1%) and %W (2.5%, 17.9%) were observed for Atlantic menhaden across the same time series. To the best of our knowledge, river herring were documented in ABFT diet for the first time. Energetic analysis suggests average ABFT somatic condition was similar between 2018 (28.67 megajoules per kilogram) and 2019 (27.42 MJ/Kg). Prey with the greatest average EC were Atlantic menhaden (26.07 MJ/.Kg), but values did fluctuate throughout sample years. Similar to SCA results, SIA mixing model results evaluating $\delta^{13}C$ and $\delta^{15}N$ of select prey also showed a high contribution of *Illex* (median 2018 = 11.0%, 2019 = 19.5%), but instead identified silver hake (*Merluccius bilinearis*) as the primary prey source overall (median 2018 = 50.2%, 2019 = 45.9%). Collectively, these results suggest that changes among ABFT forage have occurred potentially influencing the energetics and distribution of ABFT.

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ARE TUNA ALWAYS HUNGRY? A DEEP DIVE INTO STOMACH FULLNESS MEASURES IN THE WESTERN AND CENTRAL PACIFIC OCEAN

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As key oceanic predators, a fuller understanding of tuna diet and the processes that underpin it would provide valuable insights into the dynamics of pelagic ecosystems and their capacity to adapt to future environmental and human-induced stressors. Progress may lie in exploring the drivers and consequences of recent dietary history through analyses of individuals' stomach fullness. However, to maximise inference from such analyses, accurate measures of stomach fullness are needed, along with sufficient and reliable data on which to model covariate effects.

We examined a comprehensive dataset comprising stomach fullness records from 3,491 skipjack tuna (*Katsuwonus pelamis*), 3,436 yellowfin tuna (*Thunnus albacares*) and 1,302 bigeye tuna (*T. obesus*) captured by commercial fishing and research vessels in the Western and Central Pacific Ocean (WCPO) between 2001 and 2021. We described this dataset using three alternative stomach fullness metrics: a continuous measure as a function of fish length, a subjective, categorical measure based on visual inspection, and simply binary measure of empty or not empty. We used numerous statistical models to examine the influence of three explanatory variables: time of day, fishing gear, and floating-object association.

Across the three species, models for both continuous and categorical fullness metrics that included the three covariates either failed to converge, violated model assumptions, or the predictive performance was poor. When the fullness measures were simplified into binary outcomes, the model fits were greatly improved.

Though we caution on drawing strong conclusions from our models, our analysis of the binary response variable reveals that, regardless of species, fish with empty stomachs were more likely to be caught on active gear, and more likely to be caught earlier in the day. Skipjack and bigeye tuna with empty stomachs were more likely to be caught in associated schools.

Our study highlights that at individual level, tuna stomach fullness is highly variable, and that further work is needed to identify the factors that apparently drive this variability. However, these results do add to the evidence that tropical tunas may forage more effectively during the day, and that when not associated with floating objects are more actively engaged in foraging.

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GROUP-HUNTING IN STRIPED MARLIN (*KAJIKIA AUDAX*) AT MULTIPLE SCALES

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Group hunting has been a key topic in the field of behavioural ecology and has received considerable attention in the context of its functions. In contrast, because of logistical difficulties quantifying the behaviour of dynamic predatory events, much less is known about the mechanisms by which grouping predators hunt their prey. Nowadays, technology exists which can track the positions of multiple interacting animals (predators and prey) in the wild with high spatial-temporal resolution. Importantly, these interactions occur at different spatial scales. To provide new insights into functions and mechanisms of group hunting strategies, we ideally require systems where different spatial scales can be observed at high spatio-temporal resolutions and connected in a single system: from the geometry of the chase and the dynamics of direct attacks, through to individual intake rates and the morphological structures used during prey capture.

Groups of striped marlin (*Kajikia audax*) hunt schools of prey fish (sardine and mackerel) off the coast of Baja California, Mexico each year. This predator-prey system allows for the tracking of behaviour of predator and prey at multiple spatial scales throughout the predation event. In this presentation I will provide an overview of results from a multi-year project on striped marlin group-hunting behaviour, as well as describe on-going avenues of research and future aims.

Firstly, I will describe the results from a series of papers which use microCT and underwater video to compare the structural morphology of the rostrum in several different species of billfish. I will discuss the potential role of several rostrum structures, such as micro-teeth, oil glands and the previously undescribed 'lacunae rostralis', in prey capture. Secondly, using video shot from underwater and from Unmanned Aerial Vehicles (UAVs) I will describe various aspects of striped marlin attack dynamics that are relevant to the evolution of group-hunting. For example, by individually identifying predators and measuring their intake rates during a hunt, I will describe for the first time the mechanisms by which a group of selfishly motivated pelagic predators divide a shared resource (the school of prey fish) between themselves. Thirdly, predator-prey interactions in this system occur during both long-distance chases at the ocean's surface ('mobile phase') as well as when the prey school is encircled by multiple predators ('stationary phase'). I will present work that records the spatio-temporal positioning of predators and prey during these two phases, while simultaneously measuring the predators' attack and intake rates.

While explaining striped marlin hunting behaviour at these different spatial scales, I will also touch upon a variety of different topics regarding predator-prey interactions and trophic ecology that may hold wide appeal to conference attendees. These include quantifications of collective prey escape responses in the wild (the 'fountain effect'), the potential role of the eponymous 'stripes' of striped marlin (which are visibly displayed during attacks) and the potential "resource-link" role that striped marlin's hunting behaviour may provide to other top-level predators.

Overall, because it is an open ocean system composed on non-kin related predators hunting groups of small but highly evasive prey, the functions and mechanisms I will describe generally differ from those commonly addressed in the traditional terrestrial group-hunting literature. Therefore, they are a useful point of comparison for existing work in the field but are also likely apply well to tuna or other tuna-like predators that hunt within groups in the open ocean.

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DNA BARCODING STOMACH CONTENTS OF THE EPIPELAGIC PREDATOR, MAHI-MAHI (*CORYPHAENA SPP.*)

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Dolphinfishes (*Coryphaena hippurus* and *C. equiselis*), otherwise known as mahi-mahi, are epipelagic predatory fishes that inhabit tropical and subtropical waters globally. In Hawaiʻi, *Coryphaena* spp. are an important component of insular recreational and commercial fisheries. *Coryphaena* spp. feed on a variety of fishes, cephalopods, and crustaceans as previously documented through morphological identification of stomach contents. However, the only peer-reviewed study which explicitly investigated *Coryphaena* spp. diet in the Main Hawaiian Islands relied on morphological identification of prey items. Due to the degraded nature of many prey contents and difficulty identifying taxa to species level, our approach has shifted to focus on DNA barcoding to identify prey items. Stomachs from *Coryphaena* spp. were collected from recreational and small-scale commercial caught fishes in Oʻahu waters from 2019-2021. Stomachs were comprehensively dissected and all individual prey items were measured, weighed, and sequenced at the COI, 12S, or 18S barcode region to obtain high-resolution identifications of ingested taxa. In conjunction with the species identifications from DNA barcoding, the prey size measurements recorded during dissections shed light on the life stage of prey items. Preliminary results show that *Coryphaena* spp. consume a large diversity of prey types, including the larval and juvenile stages of numerous reef-associated species. Overall, pelagic juvenile stages of reef-associated fishes represent over half of the identified prey items by number and one-third by biomass, indicating that most of their biomass is sourced from pelagic fishes and other non-reef-associated prey. This study provides evidence that insular populations of *Coryphaena* spp. consume a wide variety of prey taxa that span multiple habitats and taxonomic guilds. This suggests mahi-mahi may play a predatory role for a diversity of taxa in the pelagic realm, including larval and juvenile reef fishes.

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EVALUATING THE FORAGING ECOLOGY OF ATLANTIC BLUE MARLIN (MAKAIRA NIGRICANS), WHITE MARLIN (KAJIKIA ALBIDA), AND ROUNDSCALE SPEARFISH (TETRAPTURUS GEORGII) IN THE MIDDLE ATLANTIC BIGHT

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The Middle Atlantic Bight (MAB) represents an important foraging ground for Atlantic billfish species, most relevantly Atlantic blue marlin (Makaira nigricans), white marlin (Kajikia albida), and roundscale spearfish (Tetrapturus georgii). These Istiophoridae species support a robust recreational fishery in the MAB and their consistent presence has resulted in a series of annually held prestigious offshore fishing tournaments. Through this network of tournaments and recreational anglers, we collected stomachs of 32 Atlantic blue marlin, 34 white marlin, and 45 roundscale spearfish in the spring and summer of 2018 to 2020 to determine diet composition of these highly migratory species. Stomach contents were identified to the lowest taxonomic group possible using morphological characteristics; highly digested tissue was genetically barcoded. Twenty-nine families stretching over three phyla were identified. Stomach contents were dominated by Scombridae (36.57 %Mean Weight (%MW) and 60.22 % Frequency of Occurrence (%FO)) followed by Ommastephidae (21.32 %MW and 44.09 %FO) highlighted by bullet tunas (Auxis rochei) and shortfin squids (Illex sp.) respectively. These feeding patterns are consistent with observed vertical movements by marlin species in the Atlantic. Stomachs also contained notable amounts of Carangidae (4.85 %MW and 11.83 $FO) and Hemiramphidae (2.73 %MW and 15.05 %FO). Quantifying the short-term predator-prey dynamics of these three marlin species can help define prey reliance within this limited geographical area and ensure their representation within the scope of ecosystem-based management.

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ELECTRONIC TAGS TO MEASURE FEEDING BEHAVIOR: A REVIEW AND STATE OF PLAY

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Much is still to be learned about the timing and frequency and location (especially depth) of feeding in marine predators such as tunas and sharks. A large amount of what is known about feeding in these species is derived from stomach contents obtained from specimens caught in fisheries – commercial and scientific. Electronic tags have the potential to provide objective empirical data regarding feeding behavior. This may be accomplished through the analysis of accelerometry or gut temperature data or by measuring the conditions (e.g., acidity, conductivity) existing inside the stomach of the focal animal.
The latter approach has been tested using experiments with captive sharks and tuna and the results have demonstrated the potential utility of this approach for elucidating feeding behavior. More recently, experiments have been conducted with wild sharks to further evaluate the use of electronic tags that measure conditions inside the stomach. Here we give a brief review of the concept and present preliminary data acquired from free ranging wild sharks and suggest possible next steps.

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WHAT ARE YELLOWFIN TUNA DOING AT BOOTLESS BAY?

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Yellowfin tuna (YFT) *Thunnus albacares* and other tuna species (bigeye, skipjacks and albacore) bring in hard cash to PNG economy through National Fisheries Authority licensing fees at US$200 million per annum. Five canneries in PNG employed 1000s of people. Local fishers also benefit from tunas as food source and for exchange for cash. The need to harvest the species on a sustainable level is becoming more important as ever. Compounded with climate change we need to understand the behaviour of these fish as a matter of emergency if we want to continue benefit from tunas.

Big tunas are pelagic fish and therefore are usually found far from the shoreline at deep-waters. This is not the case here at Bootless Bay – local Taurama people have legends for the YFT as part of their socio-cultural fabric of their existence. For a fish biologist it is a 'gold mine' for research. In 2013 I began to look at the YFT behaviour by observing their reproductive activity, feeding and aging in a hope to introduce a more sustainable fishery for the villagers.

Stomach contents of over 50 fish were observed. About 50% of the YFT ate smaller fish such as sardines, anchovies and small jacks. Other materials found were squid teeth, fish bones, vegetation such as sea weeds/sea grass and plastics. Nine fish had empty stomachs. Gonado-somatic index calculation indicated that female ovaries were carrying 1-2million oocytes per fish. Oogenesis cycle displayed by fish caught at August to October indicated immature gonads, early maturing gonads, later maturing gonads and ripe ovary. Spawned ovaries could not be confirmed at this time. Spermatogenesis in males indicated immature gonads, enlarged gonads, maturing and ripe testes with milt (seminal fluid) flows freely in some fish. Microscopic observation of gonads will confirm each stage in reproductive cycle. Otoliths were collected but lack of precise instruments, it prevented the aging study to progress. Fish ranged from 70-107m FL were caught of which 40% of fish ranged from 90-95cm bracket. Three fish were over 100cm FL and smallest fish was a 69cm male and weighed 4.7kg.

Future work will focus on observing tunas that come to the bay at May-July. A critical observation of tuna larva at the bay will assist in determining exactly why YFT come to Bootless Bay from May to November every year since humans first settled at Taurama.

Keywords: Yellowfin tuna, behaviour, Bootless Bay-Papua New Guinea

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POSTER SESSION

THE IGFA GREAT MARLIN RACE: A CITIZEN SCIENCE APPROACH TO BILLFISH SATELLITE TAGGING

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Over the last two decades, the advent and continued refinement of pop-up satellite archival tags (PSATs) has proven the devices to be valuable research tools for large pelagic fishes such as billfish. However, the high cost of PSATs relative to conventional tags can be prohibitive to deploying them in large quantities. One solution to this problem is engaging recreational anglers to help fund tagging initiatives; a concept that has been utilized by several research programs focusing on large pelagic fishes. Since 2011, the International Game Fish Association and Stanford University have been deploying PSATs on billfish around the world as part of the IGFA Great Marlin Race (IGMR). Working with billfish tournaments, recreational anglers sponsor individual tags and deploy them on billfish that are caught and released during and around tournaments. The IGMR has deployed over 500 PSATs in 22 different countries on seven species of billfish including the first ever PSATs deployed on Mediterranean and shortbill spearfish. Data collected through the IGMR is made freely available to the scientific and management community through an interactive website. Here we describe the model and concept of the program as well as important results published using the database of tracking data collected.

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THE PELAGIC SPECIES TRAIT DATABASE, AN OPEN DATA RESOURCE TO PROMOTE TRAIT-BASED FISHERIES RESEARCH

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Trait-based frameworks are increasingly useful for predicting how ecological communities respond to ongoing global change. As species range shifts result in encounters between new predator and prey pairs, identifying prey 'guilds', based on a suite of shared traits, can simplify complex species interactions and assist with predicting food web dynamics. To promote advances in trait-based research in open-ocean systems, we present the Pelagic Species Trait Database, a comprehensive resource synthesizing functional traits of many pelagic fish and invertebrate species in a single, open-source repository. We used literature sources, online resources, and species images to collate traits for 521 pelagic species describing 1) habitat use and behavior, 2) morphology and morphometrics, 3) nutritional quality, and 4) population status information. Species in the database are primarily from the California Current system and broader NE Pacific Ocean, but also includes globally important pelagic species known to be consumed by top ocean predators from other ocean basins. The aim of this database is to promote the use of trait-based approaches in marine ecosystems and for predator populations worldwide.

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SHARK INCIDENTS IN CALIFORNIA 1950-2021; FREQUENCY AND TRENDS

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Many reports have categorized the frequency, circumstances, and causes for interactions between sharks and humans, often using the behaviorally inaccurate term "attack." The California Department of Fish and Wildlife (Department) instead uses the term "incident," defined as interactions where a shark touches a person, their board, or kayak, without provocation and with or without causing injury. We created a comprehensive database of California shark incidents by reviewing, verifying, and updating past records, and examined the frequency of confirmed incidents, updated reports with new information, and examined similarities and differences in incident circumstances. Two hundred and one incidents were verified in California waters between 1950 and 2021, with 107 causing injury and 15 resulting in fatalities. The vast majority (178) involved White Sharks (Carcharodon carcharias). Contrary to past reports of White Shark incidents being concentrated in a portion of northern California, incidents have occurred statewide, with some of the highest numbers in Southern California. While total reported incidents are increasing, the annual number of incidents resulting in injuries or fatalities remains low. Frequency of incidents was not found to be greater around the full moon, dawn, or dusk but was greater during summer and fall months, as expected.

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AN OVERVIEW OF THE COMMERCIAL PACIFIC BLUEFIN TUNA (*THUNNUS ORIENTALIS*) HOOK-AND-LINE FISHERY FROM 1980 TO 2022

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In the United States, the vast majority of commercial Pacific bluefin tuna (PBF) landings are made by purse seine vessels. However, landings of PBF by the commercial hook-and-line fishery increased significantly in 2015. Participation in the California commercial PBF hook-and-line fishery increased from 17 distinct vessels in 2014 to 190 vessels in 2022. Between 2014 and 2022, the average unit price of PBF landed with hook and line increased by approximately 88 percent and Ex-Vessel revenue of the commercial hook-and-line PBF fishery increased from $9,755 in 2014 to approximately $1,781,500 in 2022. An analysis of landings data shows the significant increase in landings made by the commercial hook-and-line PBF fishery, and participation largely occurred in U.S. waters, particularly in southern and central California. The observed increase in PBF landings and vessel participation in the commercial hook-and-line fishery is likely due to the increased availability of PBF in California waters. Monitoring changes and shifts in vessel participation is important for effective management of the PBF fishery.

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MOVEMENT OF ELECTRONICALLY TAGGED BLUE SHARKS IN THE CENTRAL AND EASTERN NORTH PACIFIC OCEAN

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Between 2002 and 2019, 143 blue sharks (*Prionace glauca*), ranging from 134 to 260 cm fork length, were successfully tagged with SPOT and/or PSAT satellite tags. Sharks were tagged either within the California Current between Baja California, Mexico and Victoria Island, British Columbia, Canada or offshore and to the west of the California Current, towards the Hawaiian Islands, in the central and eastern North Pacific Ocean. Data were analyzed from 86 SPOT tags with deployment durations of 2 to 740 days (mean 122 ± 117 days) and 91 PSAT tags with durations of 15 to 360 days (mean 80 ± 78 days), including data from 58 double tagged sharks. Shark movements were compared by size and age, with juveniles less than 4 years of age, maturing sharks 4 years of age, and mature sharks 5 years of age and greater. The range of horizontal movements of tagged sharks spanned from 51˚N to 4˚N along the coast of North America from the coast of British Columbia, Canada to just south of Puerto Vallarta, Mexico and out to the Hawaiian Islands. The farthest movements to the west (as far as 176˚E) were made by 4-year-old, maturing females tagged off the coast of Canada and occurred between 35 - 45˚N in the region of the North Pacific Transition Zone. Among the key findings was the discovery of a high degree of variability in horizontal movement by age and sex. There was also variability by tagging location, with sharks tagged in the Central Pacific for periods of up to 360 days not visiting the California Current Region, while sharks tagged in the California Current did travel offshore towards the Hawaiian Islands. Tagged adult males tracked for greater than 1 year returned to the California Current Region in subsequent years. These observations will be reported in greater detail.

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OTOLITHS, SPINES READING AND MULTI-MODEL INFERENCE FOR AGE AND GROWTH ESTIMATION OF THE STRIPED MARLIN (*KAJIKIA AUDAX*) IN BAJA CALIFORNIA SUR

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The striped marlin (*Kajikia audax*) is the main target species of the sport fishery that operates off Cabo San Lucas, Baja California Sur (CSL), Mexico, which contributes 80% of the marlin species catch. Previous studies on the striped marlin age have been based on counting the annual growth marks on the dorsal spine fin. This research uses the combination of spines and otoliths of fish under one year of age in a first step; counting the daily growth marks on their otoliths are counted, associating the average diameter of the first annual mark on their dorsal spines. In a second step, with this average diameter, the count of growth marks in the spines of older fish was corrected, since errors could occur in the assigned ages due to the vascularization of the center of the spines. Monthly biological sampling of the sport-fishing fleet landings was conducted in CSL from 2015 to 2022. A total of 739 organisms (358 females, 381 males) were sampled. The lower jaw fork length (LJFL), total weight, and sex were recorded for each fish. The fourth dorsal-fin spine (357) and sagittal otoliths (198) were extracted. The LJFL range for females was 132-242 cm with an average length of 187.3 cm, and 133-228 cm with an average length of 183.7 cm for males. The average size by sex showed significant differences ($p = 0.0027$), contrary to the length-weight relationship where no significant differences were found ($p = 0.5084$). The Student's *t*-test indicated that *b*-value for combined sexes was not significantly different ($p > 0.05$) from the theoretical value of isometric growth. The results showed two to nine growth marks in transverse sections of the dorsal-fin spine and up to 247 daily micro-increments in polished otolith sections of younger organisms (≤ 170 cm LJFL). The individual growth parameters of the von Bertalanffy model of young organisms estimated with the LJFL data and daily mark counts on otoliths were: $L\infty = 164.16$, k = 2.1, and t0 = - 1.87. An average LJFL of 164 cm and an average diameter of the cross sections from spines of 0.88 cm were estimated at the first annual growth mark. This estimation determined that the sport-fishing fleet caught in six age groups (0-5 years). According to the Akaike information criterion, von Bertalanffy´s model ($L_\infty = 226.92$ cm, k = 0.49, $t_0 = -1.66$) best represents the individual growth of striped marlin, which indicates accelerated growth in the early years of life of striped marlin, reaching up to 82 % of its asymptotic length in the second year.

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A SYNOPSIS OF OREGON'S ALBACORE TUNA FISHERY

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Commercial harvest of hook-and-line caught, or "troll-caught" albacore tuna has occurred off Oregon since 1929 when the fishery expanded north from the traditional Southern California grounds. The Oregon fleet consists primarily of vessels ranging from 20 to 60 feet in length, with multiple permits to harvest crab, salmon, or groundfish at other times of the year. Commercial albacore landings in Oregon have been highly variable long-term. This poster summarizes information about Oregon's commercial management of the albacore fishery including permit process and Oregon sampling data for the 2022 commercial and recreational albacore fishery.

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STRUCTURAL FEATURES OF THE OLFACTORY SYSTEM IN ISTIOPHORID BILLFISHES

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Previous studies have provided evidence that olfactory systems play a vital role in fish behavior. The present work on the morphology of the olfactory system of striped marlin (*Tetrapturus audax*), pacific shortbill (*T. angustirostris*), blue marlin (*Makaira mazara*) and sailfish (*Istiophorus platypterus*) was aimed at expanding our understanding of olfaction and behavior in fast-swimming pelagic fish. In the 4 species examined, the olfactory chamber that housed the olfactory organ was lodged at the bounds of premaxilla and nasal bones and covered by a thick epidermal tissue laterally. Extension of the chamber lateroventrally gave rise to an olfactory nasal sac. The round olfactory organ was visible through the anterior and posterior nasal openings that was separated by an upstanding nasal labial flap. Ultrastructural examination revealed 3 cell types; olfactory receptor neurons (ORNs), sustentacular and mucus cells. In striped marlin, the mean density. mm^2 was ~41 000 and the ORNs population was estimated to be ~10 million per nose. Ciliated non-sensory cells were absent. Epidermal cells forming microridge patterns comprised the nonsensory epithelium. Taken together, the data suggest that the billfishes studied thus far possess a functional olfactory system that has evolved as an adaptation to the pelagic way of life.

Keywords: Billfish, olfaction, behavior

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WEDNESDAY, 24 MAY 2023

SESSION 4: Electronic Tagging (Moderator: Suzy Kohin)

MULTIYEAR OBSERVATIONS OF ATLANTIC BLUEFIN TUNA REVEAL FIDELITY TO FORAGING AND SPAWNING GROUNDS

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The life history and spatial distributions of Atlantic bluefin tuna (ABT; *Thunnus thynnus*) have been studied extensively through electronic tagging, resulting in valuable information about their movement patterns and behaviors. Over the past three decades, we have deployed 750 internal archival tags in ABT with a mean (± SD) length of 191.2 ± 30 cm, primarily off the coast of North Carolina. Over 22% of the tags have been recovered, with some yielding multiple years of high-resolution data. We investigated the site fidelity and ontogenetic niche shifts of twelve multi-year (i.e., 514 to 1936 days), archival-tagged ABT. Nine of the twelve fish were released as adolescents, enabling us to follow their migrations to spawning grounds in the Gulf of Mexico, Mediterranean Sea (Med) and Slope Sea as mature adults. In several instances, we observed repeat visitation of ABT to their respective spawning grounds in consecutive years. We also found substantial variation in habitat preferences between individuals, and high seasonal and annual spatial site fidelity within individuals (i.e., Bhattacharyya's coefficient (BC) calculated from kernel density estimations were greater than 0.75 in the majority of pairwise comparisons). Interestingly, individuals that spawned in the Med underwent a phase shift in spatial habitat preferences. Namely, 60% of daily locations occurred in the western Atlantic prior to first entry of the spawning grounds. Following their entry to the Med, 100% of daily locations occur in the eastern Atlantic. We highlight one tagged ABT that collected a full, high resolution archival temperature and depth time series for nearly six years. This fish made repeat visits to the Gulf of St. Lawrence (n = 4 years) and Newfoundland Basin (n = 5 years) foraging hotspots. Pairwise comparisons of vertical behavior showed that the fish occupied similar depth profiles in all years (i.e., BC greater than 0.95), demonstrating high site fidelity in both the horizontal and vertical dimensions. The movement patterns observed from these multi-annual datasets have strong implications for international management efforts, also allowing for better contextualization of the migratory behaviors across different life stages observed in shorter-duration tag deployments.

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TAGGING OF ATLANTIC BLUEFIN TUNA OFF IRELAND REVEALS USE OF DISTINCT OCEANOGRAPHIC HOTSPOTS

Camille M.L.S. Pagniello[1*], Niall Ó Maoiléidigh[2], Hugo Maxwell[2], Michael R. Castleton[1], Emilius A. Aalto[1], Jonathan J. Dale[1], Robert J. Schallert[1], Michael J.W. Stokesbury[3], Alan Drumm[2], Ross O'Neill[2], Barbara A. Block[1]

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Electronic tagging of Atlantic bluefin tuna (ABT; *Thunnus thynnus*) has provided a wealth of data that has shaped our understanding of their movements and migrations throughout the Atlantic basin. In this study, we used pop-up satellite archival tagging data to examine the movements of ABT tagged off the coast of Ireland. When combined with satellite oceanographic data, we found that ABT utilize the warm North Atlantic Current as a corridor for migration to access foraging areas in the North Atlantic Ocean. We identified four potential foraging regions: (1) off the coast of Ireland, (2) the Bay of Biscay, (3) the Newfoundland Basin, and (4) the West European Basin. In addition, many ABT migrated in mid-May to their spawning grounds in the Mediterranean Sea, where they remained until early-July. In all five regions, anticyclonic ocean features (i.e., quasi-permanent eddies or recirculation) were present. These features often co-occurred with areas where the daily maximum diving depth of tuna exceeded 400 m and/or tuna spent extended time diving to mesopelagic depths (i.e., greater than 200 m). We hypothesize that ABT exploit anticyclonic structures to forage on the abundant mesopelagic fish communities. Additionally, our results suggest that ABT are travelling across the North Atlantic Ocean in a directed migration to the Newfoundland Basin to reach what may be the best mesopelagic feeding ground in the world for large pelagic predators. Incorporating oceanographic preferences into tuna spatial distribution models can allow managers to identify areas likely to have high Atlantic bluefin tuna bycatch and potentially adjust catch predictions based on local conditions.

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EVIDENCE OF BLUEFIN TUNA (*THUNNUS THYNNUS*) SPAWNING IN THE SLOPE SEA REGION OF THE NORTHWEST ATLANTIC FROM ELECTRONIC TAGS

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Atlantic bluefin tuna (ABT) are large, wide-ranging pelagic predators which typically migrate between foraging regions in the North Atlantic and two principal spawning regions, the Gulf of Mexico and the Mediterranean Sea. A new spawning area has been described in the Slope Sea (SS) region off New England; however, the relationship between ABT that spawn in the SS and ABT using the principal spawning regions remains poorly understood. We used electronic tags to examine the location, temperature, and diving behavior of ABT in the SS, and identified 24 individuals that were present during the spawning season (June-August) with tag data showing temperatures and behavior consistent with spawning ABT. In general, the SS spawners had similar spatial ranges to Mediterranean-spawning ABT; however, some individuals displayed distinct behaviours that were identified first in Gulf of Mexico spawners. Using monthly spatial distributions, we estimated that the SS spawners have high exposure to fishing pressure relative to other ABT and may represent a disproportionate share of the West Atlantic catch. This analysis provides the first description of the behavior of ABT frequenting this spawning ground, creating a foundation for integrating this region into multi-stock management and, potentially, conserving an important source of genetic diversity.

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SUCCESSES OF THE INTER-AMERICAN TROPICAL TUNA COMMISSION'S REGIONAL TUNA TAGGING PROJECT CONDUCTED DURING 2019 TO 2022

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With several fisheries in the eastern Pacific Ocean receiving Marine Stewardship Council (MSC) certification in recent years, the need for improving biological information on exploited skipjack (SKJ), bigeye (BET), and yellowfin (YFT) tuna stocks is of great importance. Maintaining MSC certification requires these fisheries to be formally assessed within five years of certification, and while BET and YFT stocks have been formally assessed, SKJ stocks have not due to various data limitations. To address data deficiencies for all three species, with an emphasis on SKJ, the Inter-American Tropical Tuna Commission (IATTC) implemented a regional tuna tagging project, partially funded by the European Union, to begin aggregating key biological information.

Three tagging cruises, ranging in duration of 80 – 89 days, were conducted in 2019, 2020, and 2022 as part of the regional tuna tagging project. Although ongoing, the objectives of this work were to provide critical data to inform stock assessments, including estimates of movement and stock structure, growth, natural mortality, gear selectivity, exploitation rates, and development of new methods to estimate indices of abundance. Using plastic dart tags (PDTs), a total of 6181 SKJ (32 – 74 cm), 1679 YFT (30 – 114 cm), and 265 BET (39 – 120 cm) were tagged during the three cruises. Additionally, 250 SKJ (39 – 72 cm), 472 YFT (30 – 117 cm), and 57 BET (39 – 116 cm) were fitted with electronic archival tags (ATs).

Tag recovery specialists, based out of IATTC field offices in Manta and Playas, Ecuador, and Mazatlán, Mexico, were responsible for collecting and validating tag recapture information during the unloading of fishing vessels. Returned tags were classified as either high or low confidence, whereby low confidence tags could further be scrutinized for accuracy by implementing a quantitative speed filter based on maximum daily speeds from high confidence PDT and AT data. ATs were analyzed with the uKFSST, a state-space model, which integrates remotely sensed sea surface temperatures, where the derived most probable tracks were used to identify habitat use and regional mixing rates. To date, 1695 SKJ (27.4%), 274 YFT (16.3%), and 104 BET (39.2%) tagged with PDTs and 60 SKJ (24.0%), 87 YFT (18.5%), and 22 BET (38.6%) tagged with ATs have been returned to the IATTC. Days at liberty ranged from 0.5 – 1285.78 days for all tagged fish, with a median value of 40.8 days. Of all tagged fish (> 30 days at liberty), 95% of SKJ, YFT, and BET remained within 1081.1, 1029.9, and 1171.6 miles of their release locations, as distances ranged from 0.2 – 4119.9 miles, 0.2 – 3479.8 miles, and 6.2 – 1556.9 miles, respectively. Moving forward, as future fisheries obtain MSC certification, the continued effort to collect high confidence, tag recovery information will be critical to improve assessments and management decisions of these exploited stocks.

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GLOBAL, SEASONAL AND DIEL PATTERNS OF HABITAT USE OF BLUE MARLIN *MAKAIRA NIGRICANS*

Samantha Andrzejaczek[1], Jonathan J. Dale[1], Chloe S. Mikles[1], Stephanie Brodie[2,3], Steven J. Bograd[2,3], Aaron Carlisle[4], Michael Castleton[1], Elliott L. Hazen[1,2,3], and Barbara A. Block[1]

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Knowledge of blue marlin, *Makaira nigricans*, movement and distribution patterns across a range of spatiotemporal scales is important for understanding the ecology of this epipelagic fish, informing responsible management strategies, and understanding the potential impacts of a changing ocean climate to the species. To gain insight into such patterns, we firstly used state-space modeled tracking position estimates from 144 pop-up archival tags to create a species distribution model to represent global habitat suitability for blue marlin. Habitat suitability was determined by fitting a generalized additive mixed model (GAMM) as a function of environmental covariates which was used to predict monthly global blue marlin habitat from 2000 to 2016. Blue marlin habitat preference had the strongest association with sea surface temperature. Seasonal variation in blue marlin habitat occurs primarily at the latitudinal edges of the distribution range. Over the duration of the study, 96% of core habitat declined in suitability, with a concurrent poleward increase in suitability of marginal habitat. The present-day loss of highly suitable habitat suggests ocean warming may be making equatorial waters less suitable even to highly mobile species. Blue marlin is likely to respond by following preferred habitat as it shifts poleward.

To look specifically at the patterns and drivers of movement patterns in the North Atlantic, we analyzed data from 66 blue marlin satellite-tagged between 2001 and 2021. We recorded migrations connecting west and east Atlantic tagging locations, as well as long-term residency within small sub-regions. Blue marlin showed a pattern of latitudinal migration, occupying lower latitudes during cooler months and higher latitudes in warmer months. Diving data indicate blue marlin primarily inhabited a shallow vertical habitat with deeper diving associated with higher sea surface temperatures and dissolved oxygen content. Consistent patterns in diel vertical habitat use support the hypothesis that these fish are visual hunters, diving deeper during the day, as well as dawn, dusk and full moon periods. The wide-ranging movements of blue marlin indicate that traditional spatial management measures, such as static marine reserves, are unlikely to be effective in reducing the fishing mortality of this species. Longer tag deployment durations are required to delineate the annual and multi-annual migratory cycle of the blue marlin. dataset.

This study was facilitated by the International Game Fish Association Great Marlin Race (IGMR), a long-term global telemetry dataset developed in collaboration between Stanford University and the International Game Fish association. The IGMR is a citizen-science based program in which recreational anglers deploy tags during billfish tournaments around the world (https://igfa.org/the-great-marlin-race/).

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SWORDFISH HORIZONTAL MOVEMENTS IN RELATION TO STOCK STRUCTURE IN THE EASTERN NORTH PACIFIC

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This study reports on electronic tagging research focused on better understanding the horizontal movements of swordfish (*Xiphias gladius*) in the Eastern North Pacific Ocean (ENPO). Tagging activities were performed in conjunction with commercial fishing gear development efforts and resulted in the deployment of over 400 electronic tags on 224 individual swordfish since 2011. To date, 32 (14%) individuals have been recaptured by national and international fleets. Swordfish tagged off California have exhibited wide-spread seasonal migrations ranging down to the equator (0.8°N/132.4°W) and out towards the Hawaiian Islands (17.0°N/154.2°W). In general, swordfish moved into west coast foraging grounds during the summer and fall months before departing towards warmer subtropical waters during the winter. Seasonal migration trends followed two general patterns with swordfish either moving along the Baja California peninsula into the Eastern Pacific Ocean management unit or to the southwest towards the Hawaiian Island archipelago (the Western and Central North Pacific management unit). Horizontal movement data from a suite of electronic tag types have yielded multi-year tracks suggesting that some individuals exhibit a high level of site fidelity towards the foraging grounds off Southern California. This presentation compares swordfish tracks with data from previous movement studies in the Pacific and compares them with existing regional stock structure boundaries. Although movement data from electronic tags have not previously been incorporated into stock assessment models for swordfish in the ENPO, recent advancements in tagging research and our understanding of swordfish movements in the region offer a new fisheries-independent perspective that may help increase the accuracy of stock structure and population modeling estimates.

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SESSION 5: Fisheries, Management and Modeling (Moderator: Kim Holland)

UNDERSTANDING THE EFFECT OF STOCK OF ORIGIN ASSIGNMENT ASSUMPTIONS AND METHODOLOGY ON MIXING RATES OF ATLANTIC BLUEFIN TUNA, *THUNNUS THYNNUS*.

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Identifying stock of origin for Atlantic bluefin tuna, *Thunnus thynnus,* through isotopic signatures derived from naturally occurring isotope variability of core $^{18}O$and ^{14}C in the sagittal otolith has been standard practice for identifying Atlantic bluefin tuna's natal spawning ground for almost 20 years. Over time different analytical methods have arisen (Linear Discriminate Analysis (LDA), Random Forest) and different baselines generated to train modeling techniques (the yearling (Rooker et al., 2008) and the spawning baseline (Brophy et al., 2020)). Technological advancements have lowered per unit costs of genetic techniques generating interest in ascertaining stock structure of Atlantic bluefin tuna through genetic assessments. In the ICCAT 2017 report the Standing Committee on Research and Statistics (SCRS) requested that a comparative evaluation of the stock assignment methods and variations within each method of stock identification (genetic and otolith isotope techniques) be conducted to understand the bias and uncertainty with different analysis processes (Anon, 2017). Identifying stock of origin is key to understanding mixing between the stocks which has been estimated in the mid-Atlantic Bight from otolith isotope chemistry to be 50-70%. Stock mixing has been noted to be one of the largest areas of uncertainty in the current operational model. This work examined the assumptions and methodology of stock of origin assignment and its implications for mixing. Individual assignment and mixing estimates were derived from LDA and Random Forest modeling of otolith isotope signatures from a yearling and spawning baseline and their agreement, disagreement, and proportion of unknowns compared in 471 Atlantic bluefin tuna sampled from the Gulf of Maine, an area of high mixing. Results demonstrated that the perceived level of mixing was not sensitive to LDA vs. Random Forest modeling. Levels of mixing were different between otolith and genetic derived mixing, with higher mixing estimated by otoliths than genetics. Individual assignment to stock of origin shifted with changes in the probability threshold for genetic and otolith techniques, impacting agreement between the two techniques and perceived mixing. Disagreement between otolith and genetic assignment to stock of origin also changed as well as the number of unknowns. Future work will examine the implications of this work in the current ABFT operating model.

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IDENTIFICATION OF REGIONS IN THE ICCAT AND IOTC CONVENTION AREAS FOR SUPPORTING THE IMPLEMENTATION OF THE ECOSYSTEM APPROACH TO FISHERIES MANAGEMENT

Maria José Juan-Jordá[1], Anne-Elise Nieblas[2], Alex Hanke[3], Sachiko Tsuji[4], Francis Marsac[5], Donna Hayes[6], Eider Andonegi[7], Diego Alvarez Berastegui[1], Emmanuel Chassot[8], Paul de Bruyn[8], Fabio Fiorellato[8], Lauren Nelson[8], Lucia Pierre[8], Antonio Di Natale[9], Laurence Kell[10], Guillermo A. Diaz[11], Umair Shahid[12], Craig Brown[11], David Die[13], Haritz Arrizabalaga[7], Oli Yates[14], Dimas Gianuca[14], Fernando Niemeyer Fiedler[15], Brian Luckhurst[16], Rui Coelho[17], Muhammad Moazzam[12], Sarah Martin[18], Pascal Thoya[19], Toshihide Kitakado[20], Lourdes Ramos Alonso[1], Jordan Moss[21], Leire Lopetegui-Eguren[7], Zaherul Hoque[22], Arshad Sheikh[22], Hilario Murua[23]

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The Ecosystem Approach to Fisheries Management (EAFM) requires the identification of a spatial context within which different ecosystems can be characterized, monitored, and reported on. Since 2019, three Scientific Committee workshops have taken place to advance the identification of ecologically meaningful regions (ecoregions) in the ICCAT and IOTC convention areas to support EAFM implementation. Ecoregions can provide a spatial framework to support regional collaborative and cross-sectoral ecosystem planning and prioritization, incentivize ecosystem research, and the development of integrated ecosystem-based advice to inform fisheries management-decisions in these two tuna RFMOs. The main framework, main steps and key activities that guided the delineation of the candidate ecoregions in the ICCAT and IOTC convention areas are presented. These include (1) the identification of main potential benefits and uses of ecoregions in the context of IOTC and ICCAT species and fisheries, (2) the choice of analytical methods to develop a list of potential candidate ecoregions, and (3) how pilot studies can assist in testing the general applicability of the ecoregion concept. A total of eight and nine candidate ecoregions have been identified within the ICCAT and IOTC convention areas, respectively. The ICCAT and IOTC Scientific Committees are currently being consulted on these ecoregion proposals to increase awareness of this planning, research, and advice tool to guide EAFM implementation, and also to receive further feedback to continue to refine the ecoregion delineation process. In addition, both Scientific Committees are working to develop pilot studies of ecosystem-based advice products (e.g., Ecosystem and Fisheries Overviews) using case study ecoregions to show their applicability to the Commissions.

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REVEALING BENEFITS, COSTS, AND TRADEOFFS OF SPATIAL MANAGEMENT ARISING FROM COUPLED ECONOMIC AND ECOLOGICAL DYNAMICS IN MARINE SYSTEMS

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There is a growing movement to expand the use of spatial management measures such as Marine Protected Areas (MPAs) in both coastal and pelagic ecosystems. However, designing effective spatial management strategies is challenging because marine ecosystems are highly dynamic and opaque, and extractive entities such as fishing fleets respond endogenously to ecosystem changes in ways that depend upon ecological and policy context. To help resolve this challenge, we present a software program, marlin, that can be used to efficiently simulate the bio-economic dynamics of coastal and pelagic marine systems in support of both management and research. A key feature of marlin is that it allows for realistic simulation of fish movement dynamics in response to changing environmental conditions or foraging opportunities through use of a continuous-time Markov chain process. We demonstrate marlin's capabilities in two case studies on the conservation and food production impacts of MPAs: a coastal coral reef and a pelagic tuna fishery. In the coastal coral reef example, we show how heterogeneity in species distributions and fleet preferences can affect distributional outcomes of MPAs. In the pelagic tuna fishery case study, we show how marlin can simulate the effects of alternative MPA design strategies on the biomass of pelagic species and the economics of fishing fleets under climate-driven range shifts. Our work demonstrates how intermediate complexity simulation of coupled bio-economic dynamics can help communities predict and potentially manage trade-offs between conservation, fisheries yields, and distributional outcomes of management policies affected by spatial bio-economic dynamics in coastal and pelagic ecosystems.

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IMPROVING PREDICTIONS OF HOW TUNA DISTRIBUTIONS WILL CHANGE IN RESPONSE TO MHWS: A JOINT FISHERY-SPECIES DISTRIBUTION MODEL APPROACH

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Marine heatwaves (MHWs) have been shown to shift the distributions of fishery resources in response to unfavorable conditions. Despite species distribution models (SDMs) being a powerful tool to understand species spatiotemporal patterns, their predictive performance has shown to behave poorly under novel environmental conditions and can be particularly challenging for migratory species that respond rapidly to changing environments. There has also been limited exploration of how fishing fleets will be impacted by MHWs and related species shifts. Here, we focus on predicting the spatiotemporal distribution of albacore tuna (Thunnus alalunga) and U.S. North Pacific albacore troll and pole-and-line fishery to improve understanding of how fish and fishers will respond to MHWs. Using fishery dependent and independent data from 2003 to 2016, we employ a novel joint fishery-species distribution model approach (JFSDM) that uses vessel and species data to simultaneously model the distribution of both. We compare the predictive performance of JFSDM to single-SDM modeling approaches that use semiparametric and machine learning frameworks. We then compare spatial predictions in overlap of the albacore and the troll and pole-and-line fishery to identify differences across model types. As fish populations and fishing fleets may respond to extreme climatic events like MHWs in divergent ways, accurately characterizing variations in species and fleet distributions is needed to support climate-readiness and resilience in U.S. fisheries.

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IMPLICATIONS FOR THE GLOBAL TUNA FISHING INDUSTRY OF CLIMATE CHANGE-DRIVEN ALTERATIONS IN PRODUCTIVITY AND BODY SIZES

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Tunas and billfishes are the main large pelagic commercial fished species. Tunas comprised around 5.5 million tonnes and USD 40 billion in 2018. Climate change studies and projections estimate that overall, global fisheries productivity will decrease due to climate change. However, there are seldom projections of the climate-driven productivity of the higher trophic levels where tunas and billfishes belong.

In this work, we use a mechanistic model to evaluate the effects of climate change and fishing for globally distributed and commercially exploited seven tuna species and swordfish which are divided into 30 stocks for management purposes, under a range of climate change (RCP 2.6 and 8.5) and fishing scenarios (from no fishing to 1.5 times the fishing mortality (F) at the Maximum Sustainable Yield, F_{MSY}) from two Earth System Models (IPSL and MEDUSA).

The results suggest that high trophic level species will be more impacted by climate change than by fishing pressure under the assumption that they remain nearby their MSY levels. However, no-fishing scenarios project much higher biomass. The overall productivity of the target species will decrease by 36% only Pacific bluefin showing a slight increase in the future. Five species; Atlantic and Southern bluefins, swordfish, bigeye and albacore are estimated to decrease in biomass and size at different rates. These species represent almost a third of the landings in the Atlantic Ocean and 10% in the Pacific Ocean being the bluefins, the highest-valued tuna species. On average, the body size is expected to decrease by 15% by 2050.

Fish price and demand are partially driven by body size and therefore, revenues can be reduced even in stocks with an increase in productivity. The fishing industry can adapt to the changing climate by increasing the value of fish through sustainability certifications and reducing fuel consumption and time at sea with higher digitalization. Reducing fuel consumption would also be an additional mitigation measure to climate change since it would reduce CO_2 emissions.

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PROJECTING THE FUTURE DISTRIBUTION OF HIGHLY MIGRATORY SPECIES IN THE CALIFORNIA CURRENT SYSTEM

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Marine biodiversity is experiencing unprecedented changes due to anthropogenic climate change. Highly migratory species are some of the most vulnerable, as they are exposed to differing stressors across biogeographic provinces. The California Current System is one of the world's most productive systems and provides important habitat and foraging for many highly migratory species. Here, we projected daily habitat suitability from 1980-2100 for ten highly migratory species in the California Current System using an ensemble of three high-resolution (~10 km) downscaled ocean projections under the high emissions scenario (RCP8.5). We calculated changes in the center of gravity, total habitat and direction and intensity of distributional shifts for each species. We found half of the 10 species modeled would lose habitat, while the other half would retain or increase their preferred habitat, shifting poleward in response to climate change. Shifting species distributions can create mismatches between existing management areas and conservation goals resulting in unanticipated impacts and significant socio-economic consequences. Our species projections provide a pathway for proactive management for protected and fished species under climate change.

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MODELLING THE HABITAT OF THE PELAGIC STINGRAY USING FISHERY DATA.

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Pteroplatytrygon violacea is the only known stingray to inhabit epipelagic waters and is caught as bycatch in both Longline and Purse-seine fisheries in the Eastern Pacific Ocean. Little is known about the ecology of this species and the aim of this study is to use presence-absence Boosted Regression Tree algorithm to model its distribution and habitat suitability using data from the Observer programs of those fisheries. A sensitivity analyses is used to build and test the performance of several models using different presence-absence ratios and an exploratory analysis using dolphin and floating object sets from the purse-seine fisheries showed that more complex and balanced models (spatial and environmental variables with 50:50 – 25:75 presence-absence ratios) perform better in describing and predicting the distribution of this species.

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Session 6: Bycatch (Moderator: Jon Lopez)

TESTING ARTIFICIAL BAITS TO REDUCE SHARK INTERACTIONS IN LONGLINE FISHERIES

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Despite recent bycatch mitigation measures to reduce fishery impacts on pelagic shark populations in the North Pacific, longline fisheries continue to interact with vulnerable shark species. The widespread use of natural baits coupled with the sharp olfactory senses of most elasmobranchs continues to drive fishery interactions regardless of prohibitions on retention and efforts to reduce discard mortality rates. This study examined the use of shark avoidance strategies that focused on removing olfactory cues from longline baits and instead relying on visual attractants. Experimental trials were performed in the Hawaiian short-line fishery, a platform that targets bigeye tuna and allows for efficient testing of longline gear on a smaller scale. Assessments of catch performance and selectivity using both natural and artificial baits were conducted around the Cross Seamount to test hypotheses that: (1) Illuminated artificial baits reduce non-target shark catch and (2) Illuminated artificial and natural baits result in similar target catch rates. Experimental deployments onboard the *F/V Vicious Cycle* trialed alternating baskets of illuminated artificial squid and natural sardine baits following initial tests focused on optimizing artificial bait sizes, colors and illumination sources. Preliminary findings from the initial eight research cruises suggest that artificial baits were highly selective, with catch consisting only of target species (i.e., bigeye tuna, yellowfin tuna), while avoiding all sharks and other bycatch. In contrast, natural bait sets resulted in higher rates of non-retained sharks and other bycatch. Catch data from ongoing gear trials will be presented along with the potential application of artificial bait use for targeting other highly-visual predators (i.e., swordfish, opah).

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RESULTS OBTAINED DURING THE LONG-TERM SAMPLING PROGRAM FOR SHARK CATCHES IN ARTISANAL FISHERIES IN CENTRAL AMERICA.

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There is a concern about the lack of importance towards creating management measures in all the world's oceans, especially in the Eastern Pacific Ocean (EPO), specifically towards the exploitation of sharks. Individual efforts are not enough to reduce the fishing pressure of this species, which is transboundary and highly dependent on migration for their reproduction, much less to carry out assessments of their populations. Since 2014, IATTC staff has conducted extensive collaborative studies together with OSPESCA and the IATTC Central American CPCs to develop a robust sampling methodology and improve data collection of shark fisheries in the Central American States of the Eastern Pacific Ocean (EPO). As a first step, the available data corresponding to these fisheries was identified and compiled, and recommendations were made to improve data collection (2014-2017). Subsequently, the CPCs of Central America promoted a pilot study to determine the feasibility of a long-term sampling program for this fishery (2018-2019), where sampling designs were established for both the medium and advanced-scale fleet and the small-scale or "artisanal" fleet (2020-2021).

Knowing the universe of fishing communities and the number of vessels along the Pacific coast of the Central American region, was extremely important to establish the bases for an optimal sample design and showing the region's problems in managing its fisheries. By 2018, through field visits and surveys, it was learned that there were 1,443 Locations of Interest[1] (LOIs), of which 789 landing sites were strictly fishing and of which 676 reported shark unloadings. During the stage to find out the magnitude of the impact of artisanal fishing on sharks, a second survey was carried out in 2019, where 445 important sites unloaded silky sharks (79 sites) and hammerhead sharks (426 sites) were identified. As part of the process of verifying the data recorded in both stages of the surveys and putting the sampling designs into practice, the first stage of the long-term sampling program was carried out, where more specific data on the composition of the species were obtained, the seasonality of the fishery and characteristics of the fishing gear by season. In total, 4,964 fishing trips were recorded at the Central American level, where 52 large pelagic species were identified, of which 22 were sharks, and 18 were rays. In addition, 65,440 individuals were counted, of which 45% correspond to the Mahi mahi species and 40% between sharks and rays; the other 15% was distributed by tuna (12%) and billfishes (3%). An important fishery was documented for the first time in the region, the mantas' fisheries in two countries of Central America. These data will help to understand the advantages of a shark field sampling program and the challenges in collecting these data during landings.

[1] LOIs: Those locations with documented historical landing (e.g., annual catch reports published by fisheries agencies and NGOs, surveys carried out by local fishing authorities, registers of companies and fishing cooperatives) were classified as "Locations of interest".

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THURSDAY, 25 MAY 2023

SESSION 6: Bycatch continued (Moderator: Melanie Hutchinson)

TESTING ELECTRONIC MICROPROCESSOR-BASED BYCATCH REDUCTION DEVICES TO REDUCE SHARK CATCH

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Globally, sharks are experiencing significant population declines as a result of increased fishing pressure and stress associated with capture and handling. In order to reduce fisheries related mortality, bycatch reduction methods focus on deterring sharks away from fishing gears. Mostly these methods have relied on overwhelming the sharks' electrosensory system as a deterrent without impacting the catchability of the target species (e.g., tuna and swordfish). Previous work on bycatch reduction methods have focused on responses to rare earth metals and permanent magnets. However, experiments implementing these methods have yielded mixed results. This uncertainty has led to the development of micro-processor based electronic bycatch reduction devices (BRDs) as a potential deterrent for sharks. Thus far, studies using these BRDs have been limited and have been conducted mostly on captive sharks. The purpose of this study was to quantify the effectiveness of these BRDs on smooth dogfish (*Mustelus canis*) in field and captive settings. A total of 11 demersal longlines were deployed, alternating gangions with active and inactive BRDs. Additionally, soak time was limited to one hour to minimize any capture stress associated with time spent hooked. A total of 222 hooks (113 active, 109 inactive) were set over the course of one field season. Catch rate was calculated as the number of sharks caught per hooks deployed in each set (s/h). While the average catch rate of smooth dogfish on active BRD lines (0.130, ± 0.166 s/h) was found to be less than the catch rate on inactive lines (0.155, ± 0.165 s/h), there was no significant difference between the two BRD types (p-value: 0.617). In captive studies, baits were offered to a size and sex matched pair of sharks within 10 cm of active or inactive BRDs. The number of baits consumed at each station along with the time taken to consume the bait was recorded. Preliminary results using an updated model of the BRD show a decrease in bait consumption at the active BRD station compared to the inactive BRD station. Additional longline sets and captive trials utilizing the new model of BRDs are needed to fully determine the effectiveness of BRDs in reducing the catch of smooth dogfish. Results of this investigation can be used to guide management strategies for potentially implementing these BRDs to reduce bycatch of sharks and improve fisheries profits and efficiency.

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THE EFFECTS OF RETAINED FISHING GEAR ON SWIMMING AND BODY CONDITION OF SMALL SHARKS

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Fishing interactions are known to result in capture-associated stress in sharks and may impact the condition of the sharks post-release. In addition, this potentially detrimental effect of capture may reduce shark populations if the stress event results in post-release mortality. While in the past it has been common practice to consider all sharks released alive as survivors, recent work has shown that mortality rates are highly species specific and can be influenced by environmental conditions, handling practices, and the type of gear used. In many cases, sharks are able to escape capture (break off) or are intentionally released by cutting monofilament leaders which can lead to the shark swimming away with retained fishing gear. The degree to which this retained fishing gear may affect swimming in these sharks remains unknown. The purpose of this study was to quantify the impact of retained fishing gear on smooth dogfish (*Mustelus canis*) by measuring potential changes in their swimming kinematics and the energetic status (lipid and protein content) of key tissues (liver, heart, and myotomal muscle). Sharks were housed in the same tank in pairs with one remaining unhooked (control) and the other hooked in the lower jaw and released in the tank with approximately 2.5 body lengths of 130 lb monofilament line attached. The sharks were then filmed for up to 7 days post-hooking and the video footage was used to quantify changes in swimming kinematics, specifically swimming speed, tailbeat frequency (TBF) and tail beat amplitude of control and hooked sharks. Overall, our findings show that sharks released without gear have a more consistent swimming speed than sharks with retained fishing gear, with the latter having more variable, typically faster, swimming speeds. The biggest change in swimming speeds appeared to have occurred one day post-hooking. Both control and hooked sharks increased their TBF on the day of hooking with TBF returning to pre-hooked values in the control individuals by the end of the experiment. Tail beat amplitude decreased for all sharks on the day of hooking with control sharks returning to pre-hooked values one day post-hooking and hooked sharks showing more variable amplitudes. The energetic status of the sharks varied only in the protein content of myotomal muscle between the control and hooked sharks. These preliminary findings demonstrate that retained fishing gear has the potential to impact the swimming and body condition of a shark following a capture event. Fisheries management has long been concerned about what happens post-release and the results of this study have the potential to be used to guide management practices in developing better handling techniques to reduce the impact of retained fishing gear.

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A COMPARISON OF STATISTICAL METHODS FOR MODELING THE SPATIO-TEMPORAL PATTERNS OF SILKY SHARK (*CARCHARHINUS FALCIFORMIS*) BYCATCH IN THE TROPICAL ATLANTIC OCEAN

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The incidental catch of shark and ray species is a key management problem for sustainable tuna fisheries. Understanding the spatial, temporal, environmental and fishery operational factors influencing the bycatch of these species is essential to develop effective mitigation measures and reduce their incidental catches. Fisheries observer data from multiple fisheries and gears provide a good opportunity to model the probability of capturing these species. In this study, we compare several statistical methods for modeling the spatio-temporal patterns of silky shark (Carcharhinus falciformis) bycatch in the tropical Atlantic Ocean using the EU tuna purse seine and Spanish swordfish longline fishery observer datasets. We explore several modeling approaches including Generalized Additive Mixed Models (GAMMs), Boosted Regression Trees (BRTs) and Bayesian Additive Regression Trees (BARTs) and assess their predictive performance in predicting the probability of catching a silky shark. The three modeling approaches predicted similar areas with higher probabilities of catching a silky shark with the best model performance results given by the BART modeling approach. The off-shore equatorial area was identified to have higher probabilities of capturing a silky shark, with probabilities peaking in August when the seasonal equatorial upwelling reaches maximum productivity values. This comparative approach helps us to identify the best model for predicting the spatio-temporal distribution of a commonly caught shark species in tropical tuna fisheries, which we plan to expand to other shark and ray bycatch species caught in these fisheries. Ultimately this study aims to support effective conservation strategies and sustainable management measures including dynamic time-area closures to reduce shark and ray bycatch in tropical tuna fisheries in the Atlantic Ocean.

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WHAT'S THE CATCH? EXAMINING OPTIMAL LONGLINE FISHING GEAR CONFIGURATIONS TO MINIMIZE NEGATIVE IMPACTS ON NON-TARGET SPECIES.

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Changes to fishing gear configurations have great potential to decrease fishing interactions, minimize injury and reduce mortality for non-target species in commercial fisheries. In this two-part study, we investigate potential options to optimize fishing gear configurations for United States Pacific pelagic longline vessels to maintain target catch rates whilst reducing bycatch mortality, injury, and harm. In part one, a paired-gear trial was conducted on a deep-set tuna longline vessel to compare catch rates and catch condition of target and non-target species between wire and monofilament leader materials. Temperature-depth recorders were also deployed on hooks to determine sinking rates and fishing depth between the two leader materials. In part two, hooks of different configurations (size, diameter, shape, metal type, and leader material) were soaked in a seawater flume for 360 days to obtain quantitative estimates of breaking strength, as well as the time taken for gear to break apart. We found that switching from wire to monofilament leaders reduced the catch rate of sharks by approximately 41%, whilst maintaining catch rates of target species (Bigeye tuna, *Thunnus obesus)*. However, trailing gear composed of monofilament did not break apart even after 360 days. In contrast, branchlines with wire leaders began to break at the crimps after approximately 100 days. Additionally, the breaking strength of soaked fishing hooks was greater for larger, forged hooks composed of stainless steel typically used in United States Pacific longline fisheries. These results have direct implications for fisheries management and the operational effectiveness of bycatch mitigation strategies for longline fisheries worldwide.

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A MACHINE LEARNING SPECIES DISTRIBUTION MODEL FOR THE CRITICALLY ENDANGERED EAST PACIFIC LEATHERBACK TURTLE (DERMOCHELYS CORIACEA)

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The Eastern Pacific (EP) population of leatherback turtles (Dermochelys coriacea) is critically endangered, with incidental capture in coastal and pelagic fisheries as one of the major causes. Given the population’s broad geographic range, status, and extensive overlap with fisheries throughout the region, identifying areas of high importance is essential for effective conservation and management. In this study, we created a machine learning species distribution model trained with remotely sensed environmental data and fishery-dependent leatherback presence (n=1,088) and absence data (>500,000 fishing sets with no turtle observations) from industrial and small-scale fisheries that operated in the eastern Pacific Ocean between 1995 and 2020. The data were contributed through a participatory collaboration between the Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC) and the Inter-American Tropical Tuna Commission (IATTC), as well as non-governmental organizations, to support quantification of leatherback vulnerability to fisheries bycatch. A daily process was applied to predict probability of leatherback occurrence as a function of dynamic and static environmental covariates. Coastal areas throughout the region were highlighted as important habitats, particularly highly productive feeding areas over the continental shelf of Ecuador, Peru, and offshore from Chile and breeding areas off Mexico and Central America. Our model served as the basis to quantify leatherback vulnerability to fisheries bycatch and the potential efficacy of conservation and management measures. In addition, this model can provide a modeling framework for other data-limited vulnerable populations and species.

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