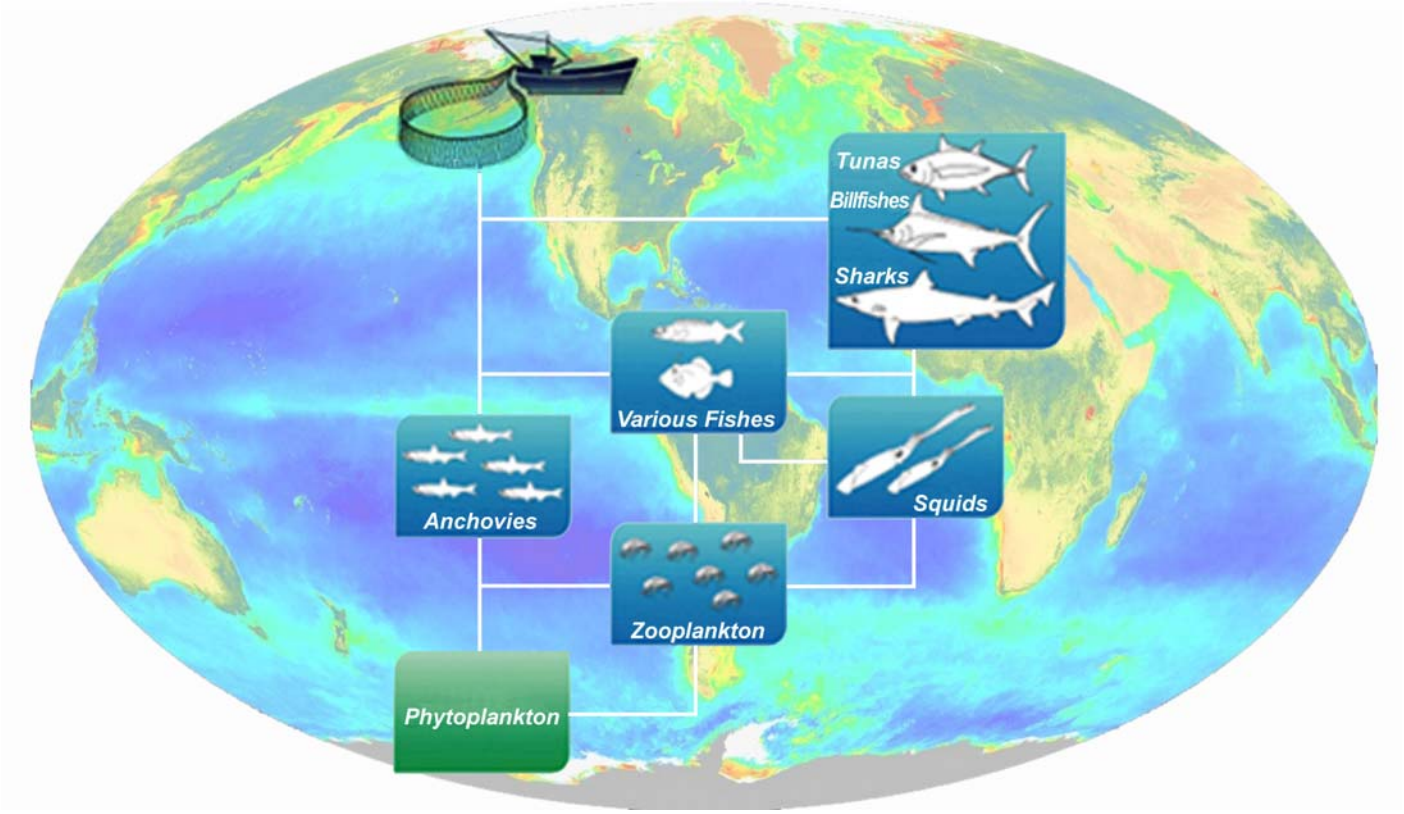
Proceedings of the 58TH Tuna Conference
Lake Arrowhead, California, May 21-24, 2007

Regime shifts and effective management in a pelagic ecosystem



Jeanne Wexler and Daniel Margulies, Co-Chairs
Maria Santiago, Tuna Conference Coordinator

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PROCEEDINGS OF THE 58TH TUNA CONFERENCE

Lake Arrowhead, California
May 21-24, 2007

Jeanne Wexler and Daniel Margulies, Co-Chairs
Maria Santiago, Tuna Conference Coordinator

Inter-American Tropical Tuna Commission
8604 La Jolla Shores Drive
La Jolla, CA 92037

PREFACE

Welcome to the 58th Tuna Conference. Each year the Tuna Conference provides an informal and comfortable atmosphere for participants to exchange information, ideas, and research results on tunas and billfish and the pelagic environment they occupy. Our theme for this year's Tuna Conference is "Regime shifts and effective management in a pelagic ecosystem". We thank all of our invited speakers (Paul Fiedler, Mark Maunder, Dave Kirby, Karine Briand, and Robert Ahrens) and their co-authors for providing some important insights into whether or not regime shifts are occurring in the pelagic environment and if so, how our fisheries can be managed most effectively in a changing environment. We also thank all of our other participants who are presenting research results related to our theme and to the biology and fisheries of tuna and billfish populations worldwide.

The *Caboz Memorial Scholarship* was awarded to Andreas Walli for his research on "Estimating Feeding from Visceral Warming in Pacific Bluefin Tuna: Lab and Field Measurements". Tuna Conference Scholarships were awarded to Fernando Arias Olaiz for "Spatial-temporal Distribution of the Relative Abundance of the Sailfish (*Istiophorus platypterus*) in the Mexican Pacific Ocean"; Juleen Dickson for "Medial Red Muscle Development in the Yellowfin tuna, *Thunnus albacares*"; Yoshiki Kato for "Effect of Ocean Turbulence on Survival and Ingestion of Tuna, *Thunnus*, Larvae"; Catherine Purcell for "Connectivity of Striped Marlin Populations in the Pacific"; Arturo Tripp Valdez for "Trophic Ecology of the Dolphinfish *Coryphaena hippurus* (Linnaeus, 1758) in Two Areas of the South of the Gulf of California"; and Nicholas C. Wegner for "Specializations for Gill Rigidity in Ram-Ventilating Teleosts". The Tuna Conference is very pleased to support their participation and we hope they will find the Conference a valuable experience.

We gratefully acknowledge the generous donations to the Tuna Conference to help support student scholarships, the Welcome Gathering Party, the Sushi Party, and the Tuna Barbecue. We received donations this year from the American Tuna Boat Association, LOTEK wireless, Monterey Bay Aquarium, Prime Time Seafood, Inc., Wildlife Computers, Inc., and VEMCO.

The Tuna Conference has always been a challenging experience for those selected to organize such an event. We chaired the Tuna Conference 17 years ago with limited resources and assistance. This year, however, has been an easier challenge given the well organized efforts from past Tuna Conference Coordinators, Anne Allen and Joy De Lee Marrow; their advice and assistance was very much appreciated. We also appreciate the assistance of the following persons who helped make this Tuna Conference a successful event: Russell Ito, Dave Itano, Kim Holland, Kurt Schaefer, Dan Fuller, and Craig Heberer for sashimi and poke preparations, Kurt Schaefer for helping to select and transport beverages, Suzy Kohin for helping out with transportation, Marty Golden for picking up and delivering the tuna, Paul Crone, Bob Olson, and Russ Vetter for their prompt and insightful reviews for the student scholarship awards, Bill Bayliff, Keith Bigelow, Kathryn Dickson, Suzy Kohin, Kurt Schaefer, John Sibert, Jenny Suter, and William Walsh for serving as session moderators, Chris Patnode for her help with the cover design, and the U.C.L.A. Conference Center personnel for accommodating our numerous requests.

The abstracts contained in the Proceedings are considered reports of preliminary work. If readers are interested in the information presented in the abstracts, they should contact the author(s) directly, and no abstract should be cited without prior consent from the author(s).

We hope all of you have a productive and enjoyable time at the Tuna Conference.

Jeanne Wexler and Dan Margulies, Co-Chairs, 58th Tuna Conference
Maria Santiago, Coordinator, 58th Tuna Conference

AGENDA

MONDAY, 21 MAY 2007

1300-1400 Registration

1400 Conference Begins – Welcome and Introduction

Session 1: Tagging Studies I. Movements and Behavior of Large Pelagics (Moderator: Kurt Schaefer)

1405 HORIZONTAL MOVEMENTS OF BIGEYE TUNA (*Thunnus obesus*) IN THE EASTERN PACIFIC OCEAN, AS DETERMINED FROM CONVENTIONAL AND ARCHIVAL TAGGING EXPERIMENTS INITIATED DURING 2000-2005.
Kurt Schaefer and Daniel Fuller

1427 HORIZONTAL AND VERTICAL MOVEMENTS OF YELLOWFIN TUNA (*Thunnus albacares*) IN THE EASTERN PACIFIC OCEAN, ASCERTAINED FROM ARCHIVAL TAGS.
Daniel Fuller, Kurt Schaefer, and Barbara Block

1449 MOVEMENTS AND BEHAVIORS OF SWORDFISH IN THE ATLANTIC AND PACIFIC OCEANS EXAMINED USING POP-UP SATELLITE TAGS.
Heidi Dewar, Eric Prince, Mike Musyl, Richard Brill, Chugey Sepulveda, Jiangang Luo, David Foley, Joe Serafy, Michael Domeier, Nicole Nasby-Lucas, Derk Snodgrass, Michael Laurs, Barbara Block, and Lianne McNaughton

1511 EFFECT OF THE GULF STREAM VARIABILITY ON THE DISTRIBUTION AND DEPTH BEHAVIOR OF ATLANTIC BLUEFIN TUNA IN THE NORTH-WEST ATLANTIC. **Francois Royer**, Steven Wilson, Ben Galuardi, and Molly Lutcavage

1533 BREAK

1553 LOCAL MOVEMENT AND REGIONAL MIGRATION OF BROADBILL SWORDFISH TARGETED BY THE AUSTRALIAN FISHERY
Chris Wilcox and Karen Evans

1615 PRELIMINARY DESCRIPTION OF HABITAT USE PATTERNS OF SILKY SHARKS (*Carcharinus falciformes*) IN THE EASTERN TROPICAL PACIFIC BASED ON SATELLITE TAGGING DATA
Suzanne Kohin, Russ Vetter, David Holts and Randall Arauz

1637 PAPUA NEW GUINEA TUNA TAGGING PROJECT.
David Itano and Kim Holland

1700 ANNOUNCEMENTS, REGISTRATION, CHECK-IN

1730 WELCOME GATHERING IN TAVERN

1830 DINNER (Wine provided by LOTEK)

SOCIALIZING IN THE TAVERN

TUESDAY, MAY 22, 2007

0800 BREAKFAST

0900 ANNOUNCEMENTS AND STUDENT AWARDS

Session 2: Tagging Studies II. Tagging and Tracking Technology
(Moderator: Suzy Kohin)

0910 BEHAVIORAL STUDY OF SMALL BIGEYE, YELLOWFIN AND SKIPJACK TUNAS ASSOCIATED WITH DRIFTING FADS MONITORED BY AN ULTRASONIC CODED TRANSMITTER IN THE CENTRAL PACIFIC OCEAN.
Takayuki Matsumoto, Keisuke Satoh, Yasuko Semba, and Mikio Toyonaga

0932 PRELIMINARY COMPARISONS OF BIGEYE TUNA VERTICAL BEHAVIOR ACROSS TIME AND SPACE IN THE NORTH PACIFIC OCEAN.
Evan A. Howell, Donald R. Hawn, and Jeffrey J. Polovina

0954 FINE-SCALE MOVEMENTS OF THE SWORDFISH *Xiphias gladius* IN THE SOUTHERN CALIFORNIA BIGHT. **Chugey Sepulveda**, Ashley Knight, Nicole Nasby-Lucas, and Michael L. Domeier

1016 BREAK

1031 IMPROVING LIGHT AND TEMPERATURE BASED GEOLOCATION BY UNSCENTED KALMAN FILTERING. **Chi H. Lam** and Anders Nielsen

1053 A NEW MODEL FOR LIGHT BASED GEOLOCATION.
Anders Nielsen and John R. Sibert

1115 A NEW INTEGRATED SYSTEM FOR DEPLOYING ELECTRONIC TAGS ON MARLIN AND OTHER LARGE PELAGIC FISHES.
Kim Holland and David Itano

1137 DEVELOPMENT OF ORTHOPEDIC MINI ANCHORS FOR DIRECT CARAPACIAL ATTACHMENT OF SATELLITE TAGS AND PSATS ON LEATHERBACK TURTLES.
Molly Lutcavage, Anders G.J. Rhodin, and Samuel S. Sadove

1200 LUNCH

1310 Session 3: Regime Shifts and Effective Management in a Pelagic Ecosystem (Moderator: John Sibert)

1315 ENVIRONMENTAL VARIABILITY AND REGIME SHIFTS. **Paul Fiedler**

1345 REGIME SHIFTS AND RECRUITMENT IN WESTERN & CENTRAL PACIFIC OCEAN TUNA FISHERIES. **David S. Kirby, Karine Briand**, Adam Langley, Valerie Allain, Marie-Laure Coudron, and Raghu Murtugudde

1415 REGIME SHIFTS, STOCK ASSESSMENT, AND THE MANAGEMENT OF TUNAS. **Mark Maunder**, John Sibert, John Hampton, and Pierre Kleiber

1445 ABUNDANCE, RECRUITMENT AND MULTI-SPECIES MANAGEMENT OF LONGLINE VULNERABLE TUNA AND BILLFISH SPECIES. **Robert Ahrens** and Carl Walters

1515 BREAK

Session 4: Population dynamics and management implications (Moderator: John Sibert)

1535 PRE-REQUISITE FOR A REGIME SHIFT: QUANTIFYING NONLINEARITY IN CPUE TIME SERIES OF NORTH PACIFIC ALBACORE. **Sarah Glaser**, George Watters, and George Sugihara

1557 IMPLICATIONS OF CANNIBALISM FOR THE PRODUCTIVITY AND REGULATION OF THE WESTERN PACIFIC OCEAN SKIPJACK TUNA POPULATION. **Timothy E. Essington**, Valerie Allain, and Robert Olson

Session 5: Molecular Studies (Moderator: Russ Vetter)

1619 CONNECTIVITY OF STRIPED MARLIN POPULATIONS IN THE PACIFIC. **Catherine Purcell** and Suzanne Edmands

1641 TAKING A HATCHET (MARLIN) TO THE BILLFISH FAMILY TREE. **John E. Graves**, Jan R. McDowell, and Bruce B. Collette

1705 POSTER SESSION AND SUSHI PARTY IN THE TAVERN

SPONSORS: Prime Time Seafood, Inc. and American Tuna Boat Association

1830 DINNER

LIST OF POSTERS

SPATIO-TEMPORAL PATTERNS IN THE GULF OF MEXICO PELAGIC LONGLINE FISHERIES: FOCUS ON YELLOWFIN TUNA (*Thunnus albacares*). **Craig Brown** and Karina Ramirez Lopez

MIGRATION PATTERNS OF JUVENILE ALBACORE IN THE EASTERN NORTH PACIFIC AS REVEALED BY ARCHIVAL TAGS. **John Childers**, Suzanne Kohin, and John LaGrange

A SURVEY ABUNDANCE STUDY OF SHORTFIN MAKO (*Isurus oxyrinchus*) AND BLUE (*Prionace glauca*) SHARKS OVER A 13 YEAR PERIOD
IN THE SOUTHERN CALIFORNIA BIGHT. **Rosa Runcie**, David Holts, Darlene Ramon, Suzanne Kohin, and Rand Rasmussen

FEEDING HABITS OF BLUE MARLIN (*Makaira nigricans*) AT CABO SAN LUCAS BAJA CALIFORNIA SUR. **Sofía Ortega-García**, Michael Domeier, Yassir E. Torres-Rojas Arturo Tripp-Valdez

THE INFLUENCE OF SEASONAL OCEAN DYNAMICS ON SOUTHERN BLUEFIN TUNA MIGRATIONS. **Sophie Bestley**, John Gunn, and Francis Marsac

TURTLE BYCATCH IN LONGLINE FISHERIES: OFFSET VS NON OFFSET CIRCULAR HOOKS. **Yonat Swimmer**, John Wang, Randall Arauz, Michael Musyl, Marti McCracken, Jorge Ballestero, and Chris Boggs

PILOT STUDY TO EVALUATE ELECTRONIC MONITORING OF TARGET AND NON-TARGET CATCH IN THE CALIFORNIA/OREGON DRIFT GILLNET FISHERY.
Craig Heberer, Lyle Enriquez, and Howard McElderry

FISHING OPPORTUNITY UNDER THE SEA TURTLE BYCATCH CAPS USING A SPATIAL BIO-ECONOMIC MODEL FOR THE HAWAII-BASED LONGLINE SWORDFISH FISHERY. **Shichao Li** and Minling Pan

SYSTEMATIC ERRORS IN ESTIMATING LATITUDE FOR SOLAR IRRADIANCE TIME SERIES. **John Sibert** and Anders Nielsen

THE SECOND SYMPOSIUM ON TAGGING AND TRACKING MARINE FISH WITH ELECTRONIC DEVICES. SAN SEBASTIÁN, SPAIN OCTOBER 8-11, 2007.
Haritz Arrizabalaga, **Nuno Fragoso**, Molly Lutcavage, and John Sibert

WEDNESDAY, MAY 23, 2007

0800 BREAKFAST

Session 6: Foraging Ecology. (Moderator, Bill Bayliff)

0900 ESTIMATING FEEDING FROM VISCERAL WARMING IN PACIFIC BLUEFIN TUNA: LAB AND FIELD MEASUREMENTS.
Andreas Walli, Daniel P. Costa, and Barbara A. Block

0922 FEEDING DYNAMICS, CONSUMPTION RATES AND DAILY RATION OF LONGTAIL TUNA (*Thunnus tonggol*) IN AUSTRALIAN WATERS.
Shane P. Griffiths, Gary C. Fry, Fiona J. Manson, Richard D. Pillans

0944 FAUNA AGGREGATED AROUND FADS AND FEEDING BEHAVIORS OF PREDATORS ON FAD-AGGREGATED PREY: REGIONAL DIFFERENCES IN THE INDIAN OCEAN. **Gorka Sancho**, Marc Taquet, Laurent Dagorn, J.C. Gaertner, David Itano, R. Aumeeruddy, and G. Moreno

1006 BREAK

1026 OCEANOGRAPHIC INFLUENCES ON ALBACORE AND ITS FORAGE IN THE AMERICAN SAMOA LONGLINE FISHING GROUND: PART II.
Réka Domokos, Jeffrey Polovina, and Michael Seki

1048 FEEDING HABITS OF THE BIGEYE THRESHER SHARK (*Alopias superciliosus*) SAMPLED FROM THE CALIFORNIA-BASED DRIFT GILL NET FISHERY, 1998-2006. **Antonella Preti**, Suzanne Kohin, Heidi Dewar and Darlene Ramon

1110 TROPHIC ECOLOGY OF THE DOLPHINFISH *Coryphaena hippurus* (Linnaeus, 1758) IN TWO AREAS OF THE SOUTH OF THE GULF OF CALIFORNIA.
Arturo Tripp Valdez, Felipe Galvan Magaña, Sofia Ortega García.

1132 IDENTIFICATION OF PACIFIC LARGE PELAGIC SHARK HABITATS USING 'PSAT' ARCHIVAL TAGS, OCEANIC SATELLITE REMOTE SENSING, AND 'SODA'OCEAN ASSIMILATION MODEL ANALYSES – AN UPDATE ON CONTINUING RESEARCH. **R. Michael Laurs**, David G. Foley and Michael Musyl

1200 LUNCH

Session 7: Biological Studies (Moderator, Jenny Suter)

1310 EFFCT OF OCEAN TURBULENCE ON SURVIVAL AND INGESTION OF TUNA, *THUNNUS*, LARVAE. **Yoshiki Kato**, Takayuki Takebe, Shukei Masuma, Takashi Kitagawa, Shingo Kimura

1332 AMBIENT TEMPERATURE HISTORIES OF SOUTHERN BLUEFIN TUNA *Thunnus maccoyii* INFERRED FROM OTOLITH STABLE ISOTOPE COMPOSITIONS. **Jen-Chieh Shiao**, Tzen-Fu Yui, Hans Høie, Ulyssess Ninnemann, and Shui-Kai Chan

1354 REVIEW OF 2006-2007 ACTIVITIES AT THE IATTC'S ACHOTINES LABORATORY. **Vernon Scholey**, Dan Margulies, Jeanne Wexler, Maria Santiago

Session 8: Physiology (Moderator, Kathryn Dickson)

1416 DIGESTIVE ENZYME ACTIVITIES IN ALBACORE, YELLOWFIN TUNA, EASTERN PACIFIC BONITO, AND CHUB MACKEREL. **Kathryn Dickson** and Danielle Neumann

1438 MEDIAL RED MUSCLE DEVELOPMENT IN THE YELLOWFIN TUNA, *Thunnus albacares.* **Juleen Dickson** and Kathryn Dickson

1500 BREAK

1520 SPECIALIZATIONS FOR GILL RIGIDITY IN RAM-VENTILATING TELEOSTS. **Nicholas C. Wegner**, Chugey A. Sepulveda, Jeffrey B. Graham

Session 9: Catch Data and Estimates of Abundance and Distribution (Moderator, Keith Bigelow)

1542 A COMPARISON OF LONGLINE VULNERABILITY BASED ON DEPTH AND HABITAT. **Keith A. Bigelow**, Mark N. Maunder and Minoru Kanaiwa

1604 DEVELOPMENT AND PRELIMINARY TESTING OF HARVEST STRATEGIES FOR THE AUSTRALIAN EASTERN AND WESTERN TUNA AND BILLFISH FISHERIES. **Campbell R. Davies**, N. Dowling, J. Prince, R. Campbell, M. Basson, D. Kolody, P. Ward, K. McLoughlin , I. Freeman[5] and A. Bodsworth

1626 HABITAT CHARACTERISATION OF YELLOWFIN TUNA IN THE TASMAN SEA USING EXPERT OPINION. **James Dell** and Chris Wilcox

1648 SPATIAL-TEMPORAL DISTRIBUTION OF THE RELATIVE ABUNDANCE OF THE SAILFISH (*Istiophorus platypterus*) IN THE MEXICAN PACIFIC OCEAN. **Fernando Arias Olaiz**, Sofía Ortega García and Heriberto Santana Hernandez

1710 ANNOUNCEMENTS

1830 DINNER: TUNA CONFERENCE BBQ

SPONSORS: Monterey Bay Aquarium and Prime Time Seafood, Inc.

2000 INFORMAL PRESENTATIONS

2000 INFORMAL BRIEFING: THE BUSINESS CARD TAG CONCEPT.

The concept of a "business card" tag (i.e. tags that will exchange data when two animals come within range of each other) is being pursued in collaboration between University of Hawaii, IRD scientists, and Vemco. This informal briefing is intended to be an opportunity for interested researchers to give input into the potential capabilities of such a tag.
Kim Holland, Laurent Dagorn, and Doug Pincock

REFRESHMENTS BY VEMCO

2030 VIDEO MOVIE: FAD RESEARCH PROGRAM – FADIO PROJECT
Marc Taquet, Laurent Dagorn, and Gorka Sancho

2100 "BONFIRE" AT FRONTIER VILLAGE

THURSDAY, MAY 24

Session 9 continued: Catch Data and Estimates of Abundance and Distribution (Moderator, William Walsh)

0900 AN EVALUATION OF THE AREA STRATIFICATION USED FOR SAMPLING TUNAS IN THE EASTERN PACIFIC OCEAN PURSE-SEINE FISHERY. **Jenny Suter**

0922 FISHERIES INDEPENDENT ASSESSMENT OF BIGEYE TUNA BIOMASS AT CROSS SEAMOUNT. **Mathieu Doray** and Réka Domokos

0944 OCEANOGRAPHIC INFLUENCES ON ALBACORE CATCH IN AMERICAN SAMOA. **Marco Kienzle**

1006 BREAK

1026 PRELIMINARY RESULTS WITH CATCH DATA FOR MAHIMAHI AND WAHOO IN THE HAWAII-BASED LONGLINE FISHERY. **William A.Walsh** and Keith A. Bigelow

1048 REDUCING BYCATCH WITH A DEEP SET LONGLINE TECHNIQUE IN HAWAII'S TUNA FISHERY. Steve Beverly, **Daniel Curran**, and Michael Musyl

1110 CONFRONTING MISLEADING, EXAGGERATED, AND FALSE INFORMATION ON STATUS OF FISH STOCKS, FISHERIES, AND "HEALTH" OF MARINE ECOSYSTEMS. **Pierre Kleiber**

1132 BUSINESS MEETING

CHECK-0UT BEFORE 1200

1200 LUNCH

1300 END OF CONFERENCE

ABSTRACTS

(In order of presentation)

The ideas presented in any given abstract may not be fully developed, and therefore no abstract should be cited without prior consent from the author(s).

MONDAY, 21 MAY 2007

HORIZONTAL MOVEMENTS OF BIGEYE TUNA (*Thunnus obesus*) IN THE EASTERN PACIFIC OCEAN, AS DETERMINED FROM CONVENTIONAL AND ARCHIVAL TAGGING EXPERIMENTS INITIATED DURING 2000-2005

Kurt Schaefer and Daniel Fuller

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Preliminary results are presented on the horizontal movements of bigeye tuna tagged and released with conventional plastic dart tags and archival (electronic data storage) tags in the equatorial eastern Pacific Ocean during 2000–2005.

The IATTC conducted tuna tagging cruises targeting bigeye tuna in the equatorial eastern Pacific Ocean during the past several years, in order to obtain a better understanding of their biology and to obtain reliable estimates of movement, growth, mortality, and gear interaction parameters for inclusion in stock assessments for this species. The tagging cruises were undertaken during March to May of 2000, 2002, 2003, 2004, 2005, and 2006 aboard the chartered live-bait pole-and-line tuna fishing vessel *Her Grace.* The primary objective was to tag and release, using conventional tags, large numbers of smaller bigeye tuna (<100 cm) in the area where purse-seine vessels catch bigeye associated with fish-aggregating devices (FADs). The second objective was to implant archival tags in the peritoneal cavities of bigeye tunas.

During these tagging cruises a total of 19,142 bigeye (33-147 cm length, mean = 78.6 cm), were tagged with conventional plastic dart tags and released, and 8,205 of these (42.9%), were recaptured and their tags returned. A total of 323 bigeye (49-136 cm length, mean = 89.8 cm) were tagged with archival tags and released, and 162 (50.2%) were recaptured and their tags returned.

HORIZONTAL AND VERTICAL MOVEMENTS OF YELLOWFIN TUNA (*Thunnus albacares*) IN THE EASTERN PACIFIC OCEAN, ASCERTAINED FROM ARCHIVAL TAGS

Daniel Fuller[1], Kurt Schaefer[1], and Barbara Block[2]

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[2]Tuna Research and Conservation Center
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Preliminary results are presented on the horizontal and vertical movements of yellowfin tuna tagged and released with archival (electronic data storage) tags in the eastern Pacific Ocean during 2002–2007.

Yellowfin tuna have been tagged with LOTEK LTD_2310 archival tags off Southern (n = 298) and Northern (n = 122) Baja California, Mexico, aboard San Diego-based long-range sport-fishing vessels. The release locations off southern Baja California, during October or November of 2002 through 2006, were from the ridge northwest of Magdalena Bay in all years, at Guadalupe Island in 2003, at Alijos Rocks in 2003-2006. The releases off Northern Baja California took place in July and August of 2004-2006. This yellowfin tuna archival tagging project is a component of the Tagging of Pacific Pelagics (TOPP) program, which is one of several programs supported by the Census of Marine Life (COML). TOPP is a program using electronic tagging to study the movements of several large open-ocean animals and the oceanographic factors influencing their behavior. TOPP also provided partial funding for the tagging of yellowfin in the equatorial eastern Pacific Ocean in 2006 (n = 45). Tagging yellowfin with archival tags was also conducted off the IATTC Achotines Laboratory, Panama (n = 38), during January of 2007.

The IATTC, in collaboration with the Instituto Nacional de la Pesca of Mexico, has also tagged and released yellowfin with archival tags within the Revillagigedo Islands Marine Reserve, Mexico, in February 2006 (n = 38) and 2007 (n = 65), utilizing a long-range sport-fishing vessel. A special permit was provided by the Comisión Nacional de Acuacultura y Pesca of Mexico for the vessel, with a group of sport fishermen aboard, to conduct fishing and tagging activities within the reserve.

During these tagging cruises 606 yellowfin (51-161 cm in length, mean = 80.7 cm), were tagged and released with archival tags and 195 (32.2%), were recaptured and their tags returned.

MOVEMENTS AND BEHAVIORS OF SWORDFISH IN THE ATLANTIC AND PACIFIC OCEANS EXAMINED USING POP-UP SATELLITE TAGS

Heidi Dewar[1], Eric Prince[2], Mike Musyl[3], Richard Brill[4], Chugey Sepulveda[5], Jiangang Luo[2], David Foley[6], Joe Serafy[2], Michael Domeier[5], Nicole Nasby-Lucas[5], Derk Snodgrass[2], Michael Laurs[6], Barbara Block[7] and Lianne McNaughton[3]

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[2]NOAA Fisheries/Southeast Fisheries Science Center
[3]Joint Institute for Marine and Atmospheric Science
[4]Virginia Institute of Marine Science
[5]Pfleger Institute of Environmental Research
[6]NOAA Fisheries/Pacific Fisheries Environmental Group
[7]Stanford University

Swordfish are globally distributed from temperate to tropical waters encompassing an impressive range of habitats. As with many large pelagic fish, efforts to determine how vertical movements may vary in habitats with different oceanographic characteristics have been challenging. For example, while it is clear that in many locations swordfish exhibit striking diurnal patterns, it is not known if this behavior occurs throughout their range or what factors impact day and nighttime depths. To address questions about vertical habitat use we combined the results from four different ongoing research programs in the Pacific and Atlantic Oceans. Combining studies provided the opportunity to compare patterns in varying oceanographic regimes.

To date results from 31 pop-up tag records have been obtained from tags deployed in the western Atlantic and the central and eastern Pacific including two short archival records (15 and 24 days). Tags were deployed on fish from 11 to 135 kg for durations from 1 to 245 days (mean=56 days). The distance between the pop-up and release points ranged from 10 to 3439 km (mean=1065 km) with minimum speeds from 0.2 to 59 km/day (mean=24 km/day). Over all the temperatures ranged from 4 to 31^{o}C and depths from 0 to greater than 1000m. Although data analysis is ongoing a number of patterns are apparent. With only a few exceptions the diel pattern was consistent across locations with the average maximum depths during the day significantly greater than those at night (day=455 versus night=70 m). Corresponding to the shift in depth, the average minimum temperature was significantly less during the day (day=10^{o}C versus night=20^{o}C). The daytime depths varied with location both within and between ocean basins. For fish that moved off-shore away from the Southern California Bight the average maximum depth during the first 10 days was always shallower than the last 10 days (312 versus 440 m) and the depth distribution off-shore was similar to that for fish tagged out of Hawaii. There were two general exceptions to this pattern. 1) One fish that moved south and remained closer to the coast showed the opposite trend and depth decreased as the record progressed. 2) For three fish where sea surface temperature exceeded 24^{o}C the depth decreased dramatically above 24^{o}C. For example, the maximum daily depth for one fish averaged 418 below and 205 m above 24^{o}C. Comparing the Atlantic and off-shore Pacific, the Atlantic fish spent more time in deep water during both the day and night (Atlantic day=643 m, night=176 m; off-shore Pacific day=455 m, night=44 m). Despite the depth difference, there was little difference in minimum temperatures day or night. Analyses to date reveal interesting differences in swordfish behavior across locations. Efforts to link patterns to environmental conditions suggest that factors such as the spectral characteristics of the water, the depth of the deep scattering layer, temperature, moon phase and perhaps oxygen concentration influence vertical habitat use.

EFFECT OF THE GULF STREAM VARIABILITY ON THE DISTRIBUTION AND DEPTH BEHAVIOR OF ATLANTIC BLUEFIN TUNA IN THE NORTH-WEST ATLANTIC

Francois Royer, Steven Wilson, Ben Galuardi, and Molly Lutcavage

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We investigated here the seasonal movements of Atlantic bluefin tuna (*Thunnus thynnus*) in the Gulf Stream area using Pop-up Satellite Archival Tags (PTT100, Microwave Telemetry, Inc.). A total of 120 units were deployed on medium-sized individuals (170-210 cm CFL) in the Gulf of Maine in the summer and fall of 2002 and 2003. To filter the (light-based geolocation) observation errors and regularize each track in time, we developed and applied a non-linear Kalman Filter using AVHRR Sea Surface Temperature and bathymetry as constraints. We used this improved database to describe the dispersal pattern of tagged fish over the two consecutive years, and we further derived seasonal maps of utilization distribution using location uncertainty.

Most fish left the Gulf of Maine at the end of October then reached the wintering grounds along the slope sea off North Carolina. The fall of 2003 saw earlier departures from the Gulf of Maine than in 2002. Further in the winter, the observed distribution widened along the northern edge of the Gulf Stream, with an apparent effect of eddies and meanders on their foraging depths. AVISO Sea Surface Height, weekly AVHRR Sea Surface Temperature and SeaWiFS maps were used to describe the oceanographic habitat in the area. The northern position and curvature of the Gulf Stream, along with the enrichment of the Sea Slope waters appeared to constrain the distribution and depth behavior of the tagged individuals (with shallow depths coinciding with enriched slope waters and a strong, northern Gulf Stream in 03-04, in contrast to 02-03). The Gulf Stream may thus play a major role in shaping the behavior of bluefin tuna in the North-Western Atlantic, and contribute further to the spatial variability of this species.

LOCAL MOVEMENT AND REGIONAL MIGRATION OF BROADBILL SWORDFISH TARGETED BY THE AUSTRALIAN FISHERY

Chris Wilcox and Karen Evans

Pelagic Fisheries and Ecosystems
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Hobart, Tasmania 7001
Australia

Broadbill swordfish stocks have become locally depleted off the east coast of Australia, and with significant harvest on the adjoining high seas, their management has become a substantial focus in Australia's East Coast Tuna and Billfish Fishery. One of the primary uncertainties in assessing the status of the SW Pacific regional stock is the underlying spatial structure of the population and its fluxes with the surrounding areas. Of particular concern to Australian interests is the extent to which the swordfish in Coral/Tasman Sea exchange with the surrounding regions. To address this management need, CSIRO initiated a study of swordfish movements in the Coral/Tasman seas, through the use of pop-up satellite archival tags (PSATs), to:

- Test alternative hypotheses regarding swordfish movement and retention times with distance offshore and proximity to major benthic features, such as seamounts;
- Develop an understanding of swordfish migratory behaviour in the Western Pacific Ocean, Tasman and Coral Seas;
- Create a dataset that will inform spatial management of the Eastern Tuna and Billfish fishery, particularly the targeting of closures to remediate depletions specifically associated with the Mooloolaba grounds.

To date 16 of the 50 electronic tags have been deployed, and including two from a previous study, we have obtained data from eight. We report on the behavioral patterns observed from these tags, and discuss preliminary information on movements. Our results to date suggest that the fish follow the hypothesized migration from the Coral Sea spawning grounds to the Tasman, returning in the following year to the Coral Sea.

PRELIMINARY DESCRIPTION OF HABITAT USE PATTERNS OF SILKY SHARKS (*Carcharinus falciformes*) IN THE EASTERN TROPICAL PACIFIC BASED ON SATELLITE TAGGING DATA

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Silky sharks are the most commonly encountered sharks in the tuna fisheries of the Eastern Tropical Pacific. Recent concern over their population status and the status of sharks in general worldwide, has resulted in increased efforts to monitor their populations and to develop shark bycatch reduction strategies. In 2004 we initiated a satellite tagging program of silky sharks in order to understand more about their behavior and distribution in the Eastern Tropical Pacific (ETP). During a longline research survey in October 2004, four immature silky sharks were tagged with either a near real-time radio transmitting tag (SPOT; n=1) or a popoff archival tag (PAT; n=3) near Clipperton Island. In cooperation with a local longline fisherman in March 2005, 7 additional subadult silky sharks were tagged with either a PAT (n=4) or SPOT/PAT pair (n=3) off Costa Rica. Nine of 10 PATs reported providing a total of 481 days (range 23 - 88 days) of depth, temperature and horizontal movement information. Three of 4 SPOT tags reported regularly providing a total of 1005 days (range 155 - 492 days) of finer resolution horizontal movement information. Overall, the sharks spent 99% of their time in the top 50 meters of the water column where water temperatures ranged from 24°- 30°C. Their behavior was not markedly different between day and night time periods. While final popoff locations showed a maximum net displacement of 700 km, the 3 sharks tagged off Costa Rica with SPOTs made long range movements within the EEZs of Central America and Mexico. One shark traveled as far as the Islas Tres Marías near the mouth of the Gulf of California before returning to Central American waters. These are some of the first detailed fishery independent data about the habitat preferences of silky sharks in the ETP. Continued efforts to describe their distribution and other aspects of their life-history will aid fishery managers in both national and international waters as well as aid in the development of effective bycatch reduction strategies.

PAPUA NEW GUINEA TUNA TAGGING PROJECT

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Landings of tropical tuna in the western and central Pacific Ocean (WCPO) continue to rise, driven by increases in purse seine effort and efficiency. Skipjack make up the majority of the catch but juvenile yellowfin and bigeye landings have also increased with negative implications to stock condition. The exploitation of purpose-built FADs (drifting and anchored) by purse seine gear is a significant factor to increased fishing mortality on juvenile tuna in the region. The Secretariat of the Pacific Community (SPC) in partnership with the Papua New Guinea (PNG) – National Fisheries Authority is conducting a tuna research and assessment project to examine movement patterns and exploitation rates of tropical tuna in relation to a large-scale anchored FAD array in the Bismarck and Solomon Seas of PNG: one of the richest tuna fishing grounds in the WCPO.

The objectives of this project are to obtain information on:

- the medium and large-scale movements of tuna within and from the PNG zone;
- the current exploitation rates of tuna within the PNG EEZ by all fisheries;
- the trophic status of tuna from free-swimming tuna schools and tuna found in association with FADs, natural floating objects and seamounts;
- the variability and extent of bycatch from PNG purse seine fleets;
- the dynamics of tunas associated with anchored FADs.

These objectives are being addressed through six months of intensive fieldwork to deploy conventional, archival and sonic tags on skipjack, yellowfin and bigeye tuna. The SPC is well placed to coordinate the project and analyses, having completed large scale tagging/assessment programs over the past thirty years. The Pelagic Fisheries Research Program is contributing to the PNG Project through funding and expertise in sonic tagging. Acoustic tags and receivers were deployed within the large-scale anchored FAD array of Papua New Guinea to examine the spatial and temporal dynamics of tuna aggregated to anchored FADs subjected to directed purse seine effort. The fieldwork for the project concluded in May 2007. Data summaries of the tagging cruise and preliminary analysis of sonic data will be discussed.

TUESDAY, 22 MAY 2007

BEHAVIORAL STUDY OF SMALL BIGEYE, YELLOWFIN AND SKIPJACK TUNAS ASSOCIATED WITH DRIFTING FADS MONITORED BY AN ULTRASONIC CODED TRANSMITTER IN THE CENTRAL PACIFIC OCEAN

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Nowadays, many purse seine sets are targeting tuna schools associated with floating objects including FADs (Fish Aggregating Devices). This type of operation has a problem of catching many small yellowfin and bigeye (especially bigeye) tunas, which may have a bad effect on the stocks. It may be possible to catch skipjack tuna selectively if the behavior of that species, including swimming depth, differs from that of yellowfin or bigeye tunas, but so far not much is known about the behavior of tunas associated with drifting FADs.

The ID pinger enables one to monitor more than one individual simultaneously. Therefore, we monitored and compared behavior of tunas around drifting FADs using an ID pinger (ultrasonic coded transmitter, VEMCO coded transmitter V16P-1H, 62mm in length, 16mm in diameter, 9g in water or V16P-3H, 74mm in length, 16mm in diameter, 14g in water) with tracking system Track 170 (VEMCO), which enabled us to monitor up to 56 individuals at the same time. This study was conducted in the equatorial area of the central Pacific Ocean (5˚N-1˚S, 175˚E-177˚W) by R/V *Shoyo-maru* (Fisheries Agency of Japan) in cooperation with chartered purse seine vessel No.18 *Taijin-maru* between June and August of 2005. Small skipjack, yellowfin, and bigeye tunas were caught by jigging or trolling and released with an ID pinger. Accurate swimming depth and approximate horizontal position of each individual were transmitted from the ID pinger and recorded once in about one minute.

There were two successful trackings in which a total of 105 individuals (30 skipjack, 34.5-65.0 cm FL; 43 yellowfin, 31.6-93.5 cm FL and 32 bigeye, 32.8-85.5 cm FL) were monitored during a total of about 26 days. During the two trackings, we succeeded in monitoring more than 10 individuals simultaneously during most of the period, and in addition, three species were monitored simultaneously during the second successful tracking. Most individuals stayed around the FAD almost continually except for temporary excursions. Some yellowfin and bigeye individuals stayed around the FAD for more than 10 days. Daily patterns of association and excursion were not observed clearly, however, all three species showed daily patterns of vertical behavior; swimming depth was shallower during the night than during daytime. During the night, all three species stayed mostly within the mixed layer, where the water temperature was more than 24˚C during the first tracking and more than 26˚C during the second tracking. During daytime, both yellowfin and bigeye tunas frequently dived into the thermocline (to about 150-200m), but skipjack tuna only occasionally did this. It seems that swimming depth was partly limited by water temperature and dissolved oxygen. The average swimming depth of skipjack tuna was a bit shallower than that of yellowfin or bigeye tunas, especially at night, when purse seine operations around floating objects usually begins. This result suggests the possibility of reducing the catch of small yellowfin and bigeye tunas to some extent by the purse seine fishery. Further studies to clarify the differences in swimming behaviors among the three species are necessary to develop the mitigation measures preventing or reducing the bycatch of small yellowfin and bigeye tunas by the purse seine fishery using FADs.

PRELIMINARY COMPARISONS OF BIGEYE TUNA VERTICAL BEHAVIOR ACROSS TIME AND SPACE IN THE NORTH PACIFIC OCEAN

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The Pacific Islands Fisheries Science Center Ecosystems and Oceanography Division has deployed numerous popup satellite archival tags (PATs) on various pelagics in the central North Pacific Ocean. Forty Wildlife Computers PATs were deployed on bigeye tuna (*Thunnus obesus*) from April of 2002 through June of 2006. These tags were deployed from 6 trips aboard 3 different commercial vessels operating as part of the Hawaii Longline fishery during normal fishing operations. In order to compare bigeye vertical behavior across time and space, these PAT tags were pre-programmed to process raw vertical depth and temperature information into 1, 2, 4, and 12 hour time bins with release dates set at 2, 4, or 6 months after deployment. Thirty-seven PATs successfully transmitted data after times at liberty ranging from 4 to 91 days. Tag transmission performance varied, with PATs successfully transmitting between 17-100% of recorded vertical histogram information with later PAT models exhibiting better overall performance. Two PATs were successfully recovered allowing the download of 100% of the raw, 1 minute resolution vertical data.

This talk presents preliminary results of the depth and temperature data recorded by the PATs. Vertical behavior and bigeye thermal habitat is compared against other tags in the study in addition to other reported historically reported vertical patterns. A comparison of techniques to quantitatively group time bins of similar dive behavior such as cluster and correspondence analysis will also be discussed.

FINE-SCALE MOVEMENTS OF THE SWORDFISH *Xiphias gladius* IN THE SOUTHERN CALIFORNIA BIGHT

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In this study we report on the fine-scale movements of swordfish (Xiphias gladius) outfitted with Wildlife Computers PAT4 and MK10 Pop-off satellite archival transmitters (PSAT). PSATs were deployed on basking swordfish using traditional harpoon methods in the Southern California Bight. Transmitters were programmed for short-term deployment (2 to 90 days at liberty) and, upon the release from the fish, re-acquired using a vessel equipped with a signal direction finder. Fine-scale, high-resolution data from nine swordfish (40 to 100kg) resulted in over 199 days of depth and temperature data (one minute resolution). All nine individuals displayed strong diurnal movement patterns similar to those reported in previous studies. The average depth (± SE) at night for all fish was 34 ± 6m and the average depth during the day was 253 ± 17m. Surface basking (<3m during the day) was recorded for 139 of the 199 days, and the amount of time spent at the surface varied widely among individuals (ranging from 0 to 50% of the daytime records being spent at the surface). The use of PSATs for short-term, fine-scale movement experiments proved successful, with all transmitters releasing from the swordfish as scheduled, and all attempts to re-acquire the PSATs were successful. Further data analyses of the diurnal patterns, vertical distribution and temperature preference will be discussed.

IMPROVING LIGHT AND TEMPERATURE BASED GEOLOCATION BY UNSCENTED KALMAN FILTERING

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Satellite tags (archival and pop-up archival) have been widely used to study movement dynamics of many marine pelagic species. Light-based geolocation provides a rough estimate of positions of these animals, and various models that incorporate sea surface temperature (SST) are frequently used to improve on the raw initial position estimates.

The "kftrack" (Sibert et al. 2003) and "kfsst" (Nielsen et al. 2006) models, which combine the raw light-based geolocations with an underlying movement model, have proved helpful in reconstructing the most probable track of archival-tagged marine animals. Tracks can be further improved by including the tag-measured sea surface temperature and matching it to an external reference of sea surface temperature data. The current methodology for doing this in one coherent model requires the external sea surface temperature to be smoothed before it is used in the model, and further that its gradient field be pre-calculated. This two-step approach has a number of technical drawbacks, and the final statistical inference about the most probable track is less convincing because of it.

This talk presents a new methodology where every model parameter, including the necessary smoothing for SST data, is handled within the model. An additional benefit is that even the degree of smoothing, which was previously pre-determined and fixed, can now be optimized for the track. This approach also allows flexible utilization of remotely sensed SST data of various spatial resolutions.

A NEW MODEL FOR LIGHT BASED GEOLOCATION

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We present a new coherent model to estimate the most probable track of geographic positions directly from a series of light measurements. This is performed without making any light-level threshold assumptions, or constraining the movement of the tag between dawn and dusk. The new model generates two estimates of geographic positions per day (at dawn and dusk). The covariance structure of the model is designed to handle high correlations between light measurements, such as might be caused by local weather conditions. The yearly pattern in latitude precision is estimated by propagating the data uncertainties through the geolocation process. The model has been applied to simulated data, mooring studies, and real deployments on swimming and diving fish. We demonstrate that tracks can be reliably estimated, even in cases where the other methods have completely failed and have produced misleading position estimates. The model is available as an R-package and its use is briefly discussed.

A NEW INTEGRATED SYSTEM FOR DEPLOYING ELECTRONIC TAGS ON MARLIN AND OTHER LARGE PELAGIC FISHES

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To date, it has proved difficult to deploy externally mounted electronic tags (such as satellite-linked pop-up archival tags - PATs) that stay attached to marlin for more than a few weeks. However, understanding the long-term migration pathways (if they exist) of marlin and other pelagic species requires that we acquire long-term tracks of their movements – preferably tracks that last for over a year. In this presentation we describe the development and testing of a novel technique for restraining large pelagic fish and the design and testing of a new method of anchoring externally mounted electronic tags to marlin and tuna. Successful initial results of the use of the system will be described (unsuccessful ones may not be).

Funding for this research was provided by the Large Pelagics Research Center, University of New Hampshire and the Pelagic Fisheries Research Program, University of Hawaii.

DEVELOPMENT OF ORTHOPEDIC MINI ANCHORS FOR DIRECT CARAPACIAL ATTACHMENT OF SATELLITE TAGS AND PSATS ON LEATHERBACK TURTLES

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The highly pelagic leatherback turtle (*Dermochelys coriacea*) has a unique leathery carapace comprised of a bioactive matrix, resistant to fouling. Conventional tag attachment methods that work well on the hard keratinous scutes of cheloniid turtles are not effective on its smooth oily skin, and as a result, satellite tracking methodology has been largely dependent on various indirect attachment techniques. Over the past decade or so, the majority of tracking studies on leatherbacks have used cumbersome harness or backpack techniques, or towed, buoyant satellite tags attached through a large hole in the caudal peduncle. Based on basic principles and preliminary data, these methods appear to impact the turtle's behavior and swim speed, increase chances of entanglement, and affect metabolism. In addition, harness methods cannot be easily applied to leatherbacks released from longline or other fishing gear, where post-release behavioral information is critically needed. Our objectives were to develop a safe and simple methodology of direct carapacial attachment of satellite and PSAT tags on leatherback turtles that would have the smallest possible impact on the animal and its hydrodynamics. Beginning in 1997, we began development and testing of orthopedic mini anchors (OMAs) that were based on a design used in human orthopedic shoulder surgery. Since then, we have used OMAs to deploy Satellite Time Depth Recorders, PSATs, and GPS tags on nesting leatherback females as well as two animals recently captured at sea with hoop net methods. Our OMA tagging method provides the following advantages: (1) a low-profile secure bony attachment of a small transmitter on the highest part of the carapace, (2) optimal antenna exposure and signal strength, (3) minimal invasiveness with tiny drill holes through thin subcutaneous bone using safe surgical techniques without evidence of morbidity, (4) no permanent biofouling, (5) minimal entanglement problems, and (6) eventual release of transmitters after long-term monitoring. Our ultimate objective is to develop a single point PSAT attachment with harpoon pole and modified OMA so that observers or vessel captains can easily tag leatherbacks at sea.

ENVIRONMENTAL VARIABILITY AND REGIME SHIFTS

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The physical environment of oceanic populations and ecosystems varies significantly on time scales from days to millennia, as all marine scientists and managers well know. This variability can be characterized as “spectral” (trends, periodic oscillations and random fluctuations) or as “shifts” between stable regimes. In the regime shift paradigm, a regime is a stable state of a physical or biological system, and a regime shift is a change that occurs more quickly than a regime persists. This review focuses on the eastern Pacific, where the El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) are two modes of variability that dominate the physical environment on interannual time scales. These modes, and their interaction, are briefly reviewed.

Whether the environment changes smoothly or abruptly, the important question is whether these changes can result in bottom-up forcing of ecosystem regime shifts. Regime shifts in the North Pacific have been associated with the PDO, but regime shifts in the tropical Pacific have been difficult to detect; evidence for climate shifts since 1970 is examined. The potential for environmental variability to cause fundamental shifts in ecosystems should be considered along with the effect of top-down forcing by human activity such as fishing, which has driven some of the most dramatic regime shifts in the global ocean.

REGIME SHIFTS AND RECRUITMENT IN WESTERN & CENTRAL PACIFIC OCEAN TUNA FISHERIES

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This talk presents final year results from a PFRP-funded study into long-term (decadal scale) oceanographic variability in the western and central Pacific Ocean (WCPO) and its relation to recruitment in the principal market species of tuna (albacore, bigeye, skipjack & yellowfin). One of the major uncertainties in non-equilibrium recruitment estimates for tunas (especially yellowfin) is the extent to which estimated variability is a model artifact, resulting from the introduction of purse seine fisheries targeting smaller fish half-way through the assessment period, or a consequence of broader ecosystem change. In the course of the project various methods were applied to detect long-term variability and especially abrupt shifts in time series from both stock assessment and oceanographic model output. In addition, diet studies from the early 1970s and 1990s were compared with more recent studies to see whether diet shifts had occurred that might be suggestive of regime shifts in the pelagic ecosystem from which predators draw prey. The results demonstrate that there clearly is long-term variability in the western tropical Pacific, specifically in the spatial extent of the western Pacific warm pool, that in turn directly affects recruitment for yellowfin and possible other species of tuna. Such variability has consequences for equilibrium based biological reference points, which may fail under non-equilibrium scenarios, such that F_{MSY} becomes inadequate as a limit reference point. However, it may be overly simplistic to characterize long-term variability in pelagic ecosystems as shifting between two alternative stable states, even where such a representation is statistically supported for single species or for multivariate time series. Our observation systems are often inadequate to describe decadal changes with confidence, given the long and multiple time series required, a point that is illustrated by the diet studies. While it is possible to derive ecosystem indicators and statistical models for large scale decadal change, and such indicators/models may relate well to population characteristics for certain species of interest (i.e. yellowfin tuna recruitment), we would urge caution in assuming that whole ecosystems flip from one definable stable state to another, and we would encourage researchers to apply a range of analytical methods at multiple time and spatial scales when trying to characterize natural variability for their systems of interest.

REGIME SHIFTS, STOCK ASSESSMENT, AND THE MANAGEMENT OF TUNAS

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Tuna stocks are highly influenced by their environment through changes in both population processes and the availability of the stocks to fishing methods. Both stock assessment and management must take these environmental influences into consideration. Impacts of fisheries on the stocks must be separated from environmental influences to enable effective fisheries management. Regime shifts are particularly problematic because management reference points are dependent on the regime that is currently in existence. Therefore, stock assessment methods must identify and incorporate regime shifts and management strategies must be robust to regime shifts. We present stock assessment methods and management strategies in a context of regime shifts and environmental influences. Several recent developments, such as fishery impact plots, are discussed.

ABUNDANCE, RECRUITMENT AND MULTI-SPECIES MANAGEMENT OF LONGLINE VULNERABLE TUNA AND BILLFISH SPECIES

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Increasing harvest of tuna and tuna-like species will require future management to specify optimal fishing mortality rates for all species of concern. Optimal fishing mortality rates depend on mean recruitment relationships requiring relationships to be determined for all species. A state reconstruction method was used to explore recruitment relationships for major tuna and billfish species vulnerable to longline gear using relative abundance time series and observed harvest removals under various assumptions about current fishing mortality rates. Relative abundance was derived from Japanese spatial catch and effort data following recommendations outlined in Walters (2003) and correcting for changes in mean hook depth. Results to date, assuming some mean relationship exists, indicate temporal patterns in variation around mean relationships are robust for most species to assumption about current fishing mortality rates and periods of higher and lower than average recruitment can be seen. Such a state reconstruction method is appealing as assumptions about process and observation variation are transparent and no pretense is made that statistical methods can discriminate between the "correct" underling relationships. One potential criticism of such a method is that current fishing mortality must be known to determine which recruitment reconstruction is "correct" requiring fishing mortality to be determined from stock composition information or methods such as tagging, which directly measure fishing mortality rate.

Provided current and optimal fishing mortality rates can be determined for species of concern, management is faced with the tactical difficulty of achieving target mortality rates. Given the multi-species nature of pelagic longlines, a global 5x5 simulation model was developed to explore the effect of area closures and effort redistribution on achieving target exploitation rates. Results to date suggest a mosaic of closures in areas of high species overlap and areas of concentration for severely depleted species such as southern bluefin, with size of closed areas depending on assumed movement rates and gear configuration.

PRE-REQUISITE FOR A REGIME SHIFT: QUANTIFYING NONLINEARITY IN CPUE TIME SERIES OF NORTH PACIFIC ALBACORE

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Research on regime shifts in freshwater ecosystems has established criteria for identifying these shifts: nonlinear amplification, alternative basins of attraction, multiple stable states, and hysteresis. For these criteria to be met, the dynamics underlying the system must be nonlinear in origin. We have demonstrated that physical time series from the North Pacific possess a linear stochastic signature, rendering decadal-scale characterizations of variability indistinguishable from red noise. On the other hand, North Pacific biological time series for plankton, larval fishes, and salmon contain nonlinear signatures, suggesting two observations. First, the nonlinear dynamics displayed by biological populations means they have the potential for rapid and unpredictable shifts. Second, biological populations may display nonlinear amplification of linear physical forcing; that is, they are integrators of red noise.

The objective of this study is to extend this analysis to time series of albacore in the California Current Ecosystem (CCE) to determine whether albacore dynamics are nonlinear. Our previous work was limited to biological populations low on the food chain, or that spend few years in the marine environment. Albacore are top predators, and their population dynamics may contain different signatures than species lower on the food chain and with shorter generation times.

An index of abundance of albacore in the CCE is constructed using a random forest regression tree approach to standardize a catch per unit effort (cpue) time series. We first calculate the dimensionality of the cpue time series using simplex projection, a nearest neighbor forecasting technique. Low dimensional time series are likely nonlinear, while high dimensional time series are either high in observational noise or are difficult to distinguish from random. We next quantify the degree (if any) of nonlinearity contained in the composite time series. This research is on-going. Preliminary results indicate the index of abundance for albacore in the CCE is low-dimensional and therefore contains a nonlinear signature. If so, it suggests biological amplification of linear physical processes, and the potential for albacore populations to exhibit regime-like shifts. These results have important implications for management. If albacore have highly nonlinear dynamics, our ability to forecast population changes into the future is severely constrained. Management must therefore account for the possibility of rapid and nonlinear shifts in population size. On the other hand, if albacore dynamics are linear, relationships between albacore and physical variables may provide fruitful guidance for establishing harvesting guidelines.

IMPLICATIONS OF CANNIBALISM FOR THE PRODUCTIVITY AND REGULATION OF THE WESTERN PACIFIC OCEAN SKIPJACK TUNA POPULATION

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The western Pacific Ocean skipjack fishery is one of the largest in the world, yet it occurs in a biological desert with low rates of primary and secondary production. Here we explore whether the internal feedback generated by cannibalism can explain the high productivity of the western pacific skipjack population as well as the high resilience that this population exhibits towards fishery exploitation. We synthesized information on feeding rates, size-at-age, fecundity ogives, ontogeny of cannibalism, and the sizes of cannibalized skipjack, and used that information to parameterize an age-structured model. We find that even small contributions of skipjack to the diets of large skipjack translate into large natural mortality rates of vulnerable-sized skipjack. However, the magnitude of cannibalism-derived mortality is highly sensitive to the presumed total natural mortality rate. For instance, with a very small (5%) contribution of young skipjack to large skipjack diets, the proportion of pre-recruits that survive the period of vulnerability to cannibalism ranges from 4% to 16%, depending on whether baseline natural rate is 25 yr^{-1} or 15 yr^{-1}. Parameterizing the model with field-based estimates of cannibalism results in even higher predation mortality rates, with as little at 0.7% of individuals surviving through the vulnerable period. Thus, high cannibalism rates can provide a "bottom-up" forcing promoting the growth of large individuals while simultaneously incurring a strong top-down control on recruitment success. Both of these mechanisms may potentially explain the high productivity of this stock in this region.

CONNECTIVITY OF STRIPED MARLIN POPULATIONS IN THE PACIFIC.

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This study examines population genetic structure in a highly migratory and economically important fish, striped marlin (*Tetrapturus audax*). Due to previous evidence for population subdivision, this species can be used to address questions such as: (1) Will different loci show the same genetic pattern previously found? (2) Is the genetic structure temporally stable? (3) What is the underlying mechanism creating this population divergence? We are measuring genetic variation using mitochondrial (control region sequencing) and nuclear (microsatellite) markers. Repetitive sampling is ongoing to collect adult tissue from 7 representative locations throughout the Pacific. Larval samples will be collected in known spawning locations to test spawning-site fidelity as the mechanism maintaining the population subdivision. Inclusion of genetic data is important in assessing stocks and developing effective management strategies for this and other economically important species. While tagging data describes details of migration patterns for pelagic species such as striped marlin, molecular studies reveal whether migrants are making genetic contributions. This distinction is important as the picture differs for striped marlin stocks between these two data types. Understanding the intricacies of genetic structure and migration in this species, and using this information to make careful management decisions may help sustain this international resource.

TAKING A HATCHET (MARLIN) TO THE BILLFISH FAMILY TREE

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A recent revision of the family Istiophoridae recognized five genera: *Makaira* (blue marlin), *Istiompax* (black marlin), *Istiophorus* (sailfish), *Kajikia* (white and striped marlin), and *Tetrapturus* (spearfishes). There has been little debate over the alpha taxonomy of the first three genera, but the specific composition of *Kajikia* and *Tetrapturus* has been problematic. Within the genus *Tetrapturus*, the shortbill, longbill and Mediterranean spearfishes are recognized, and Shivji and colleagues recently demonstrated the validity of roundscale spearfish based on an analysis of mitochondrial DNA. The existence of another Atlantic istiophorid, the "hatchet marlin", similar in appearance to the white marlin but with truncated dorsal and anal fins, has been discussed in the literature; however a lack of specimens for detailed morphological and genetic analyses has prevented validation of this putative species. We collected specimens of "hatchet marlin" at fishing tournaments along the U.S. mid-Atlantic coast over the past several years and compared them with white marlin and roundscale spearfish to better understand the genetic relationships among these three putative species. Phylogenies derived from both mitochondrial and nuclear gene regions support the existence of two species: the white marlin and the roundscale spearfish. The "hatchet marlin" is not a distinct taxon but represents a morphological variant of both white marlin and roundscale spearfish. There has been confusion regarding the identification of white marlin and roundscale spearfish, and recently there has been concern that misidentification of roundscale spearfish as white marlin could significantly impact previous assessments of the white marlin, a species that is considered highly overfished. Retrospective genetic analyses of white marlin samples collected from throughout the Atlantic Ocean over the past 15 years suggest that only a few percent of white marlin are misidentified as roundscale spearfish.

POSTER ABSTRACTS

The ideas presented in any given abstract may not be fully developed, and therefore no abstract should be cited without prior consent from the author(s).

SPATIO-TEMPORAL PATTERNS IN THE GULF OF MEXICO PELAGIC LONGLINE FISHERIES: FOCUS ON YELLOWFIN TUNA (*Thunnus albacares*)

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This poster presents data on the spatio-temporal patterns of effort and catches by United States and Mexican pelagic longline fleets operating in the Gulf of Mexico. These data were collected through the scientific observer programs of each country, beginning in 1992 for the U.S. and in 1993 for Mexico. The present cooperative project is conducted under the auspices of the MexUS-Gulf Program in response to the common interest of the Mexican and United States governments to improve the stock assessments and scientific databases for sustainable exploitation of pelagic resources in the Gulf of Mexico.

The distribution of effort across recent years (2003-2005) and seasons/quarters is examined, along with its relationship to depth contours and to other factors such as typical sea surface temperature patterns. Likewise, the distribution of catches is studied, scaled by relative catch rate levels. The primary focus is on yellowfin tuna (*Thunnus albacares*) as this is the main target species of these fisheries, but attention is also given to various other species which are caught.

A general description of the fisheries, as well as the scientific observer programs, is included. Information on other incidentally caught species is also presented, including relative frequency in the catch.

Also presented are standardized indices of abundance for yellowfin tuna in the Gulf of Mexico, developed from the U.S. pelagic longline observer program for 1993-2006. Efforts to integrate data from both U.S. and Mexican fisheries are ongoing, and future research goals are discussed.

MIGRATION PATTERNS OF JUVENILE ALBACORE IN THE EASTERN NORTH PACIFIC AS REVEALED BY ARCHIVAL TAGS

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The Southwest Fisheries Science Center (SWFSC) and the American Fishermen's Research Foundation (AFRF) have been using electronic archival tags to study juvenile albacore tuna (*Thunnus alalunga*) since 2001. The objective of the study is to collect and analyze detailed data on the migration routes of juvenile (3 to 5 years of age) North Pacific albacore and to determine movement patterns and environmental preferences of the migrating fish throughout their migration cycle. As of December 2006, 504 archival tags have been deployed in juvenile albacore off the U.S. west coast. Seventeen tags have been recovered containing data on locations and habitat use. Times at liberty ranged from 63 to 697 days and averaged 361 days. Fish ranged from the southern tip of Baja to Vancouver Island and from the coast of North America to the central North Pacific. Most fish demonstrated a common diurnal pattern of repetitive deep diving (routinely to depths of 250 to 300 meters) during the day while remaining near the surface at night. Refinements to the location estimates were made using composite SST data from satellite imagery. Analysis of the detailed time series data (over 7 million records) reveals that albacore spend most of their time in areas where surface water temperatures are 15 to 19°C. However, their vertical movements bring them into deeper waters with temperatures as low as 9°C. During dives, internal heat is conserved with visceral temperatures averaging 3-4 degrees above ambient water temperatures with apparent feeding episodes discernable as transient visceral temperature changes. Five fish that were at liberty from 274 to 350 days remained along the Baja coast throughout the winter. Nine fish ventured offshore to various extents during the winter then, during the spring, exhibited rapid, highly directed migratory movements to the same foraging areas that they utilized the previous summer. While in the central Pacific during the winter months, tagged albacore exploited deeper waters than during the summer months along the coast. Deeper thermoclines and less surface mixing are characteristic of the mid-Pacific areas that were utilized by the tagged fish during the winter months, whereas albacore in the coastal areas during the summer months experienced upwelling conditions and shallow thermoclines associated with surface mixing. These data reveal the preference of albacore for the north Pacific transition zone in the winter and the coastal boundary waters in the summer where seasonal productivity is expected to be high.

A SURVEY ABUNDANCE STUDY OF SHORTFIN MAKO (*Isurus oxyrinchus*) AND BLUE (*Prionace glauca*) SHARKS OVER A 13 YEAR PERIOD IN THE SOUTHERN CALIFORNIA BIGHT

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A juvenile shark abundance survey was initiated by National Marine Fisheries Service (NMFS) and the California Department of Fish and Game (CDFG) in 1994 to track the relative abundance, distribution and size of juvenile shortfin mako (*Isurus oxyrinchus*) and blue (*Prionace glauca*) sharks in the Southern California Bight (SCB). The survey was designed based on data from an experimental commercial shark longline fishery which operated in the SCB during the years 1988-1991. Seven CDFG fishing blocks (each 10 x 10 minutes) were selected as focal survey locations based on their consistently high catch-per-unit-of-effort (CPUE) during the months of June through August. The survey attempted to sample each of the seven blocks four times per summer with additional blocks surveyed as time permitted. During the past 13 years (1994 to 2006 with the exception of 1998 and 1999) a total of twelve cruises occurred using the following vessels: R/V David Starr Jordon, R/V Yellowfin and R/V Mako. The fishing methods and gear used during the survey cruises replicated that of the former longline fishery for sharks. The sampling gear consisted of a 2 mile long, stainless steel mainline to which approximately 180 to 200 five meter long stainless steel leaders with 9/0 J style hooks and mackerel bait were attached at 50 ft intervals. Buoys were placed after every fifth hook. The survey has also been used as a platform for ancillary research on the biology of shortfin mako and blue sharks, pelagic rays and mola molas. This review is designed to compare the CPUE of the fishery independent survey to that of the California-based longline shark fishery which provided baseline numbers on abundance, distribution and size of blue and mako sharks. Additionally, the survey data were analyzed to examine environmental effects on annual trends of abundance and size.

FEEDING HABITS OF BLUE MARLIN (*Makaira nigricans*) AT CABO SAN LUCAS BAJA CALIFORNIA SUR

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To better understand the feeding habits of blue marlin (*Makaira nigricans*), stomachs from 138 specimens were examined in 2005 and 2006. Blue marlin were captured by the sportfishing fleet of Cabo San Lucas B.C.S during the months of June to November. Although it is common for hooked marlin to purge their stomach, 65% of the stomachs contained prey items totaling 33 species. Constructing an Index of Relative Importance revealed that *Auxis spp*. (54%), *Dosidicus gigas* (25%), and *Selar crumenophthalmus* (13%) made up the most important prey species in 2005 whereas *Auxis spp*. (92%) dominated in 2006. The Morisita Horn index indicates a medium overlap between years. These organisms had a narrow amplitude of trophic niche (Levin = 0.14), considering them as selective predators; this was also confirmed with the Shannon-Wiener diversity index with a value of 2.21.

THE INFLUENCE OF SEASONAL OCEAN DYNAMICS ON SOUTHERN BLUEFIN MIGRATIONS

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The annual long-distance migrations of juvenile southern bluefin tuna (*Thunnus maccoyii*, SBT) were examined within the context of the large-scale seasonal ocean processes of the south Indian Ocean. In particular, we investigated whether SBT migrate to regions where environmental conditions are optimal for food production. Our analysis of remotely-sensed sea surface temperature (SST) and sea surface colour (SSC), in combination with tracking information from a large-scale archival tagging experiment, identified three primary oceanographic features in the south Indian Ocean, and their cycle of development and/or primary productivity, that may provide important seasonal feeding habitats for juvenile SBT. These were (1) the southern margin of the subtropical gyre, (2) the region of mode water formation in the central-eastern basin, and (3) the Agulhas retroflection system in the south-western basin. In at least two of these environments, the timing of SBT migrations coincided with enhanced seasonal primary production, which potentially provides the basis for the rapid development of pelagic trophic webs and therefore trophic transfer to higher order predators. This study demonstrates how the multi-disciplinary approach integrating oceanographic and biological data can provide new insights into the motivations for movement and the specific timing and spatial extent of long-distance oceanic migrations.

TURTLE BYCATCH IN LONGLINE FISHERIES:
OFFSET VS NON OFFSET CIRCULAR HOOKS

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With the adoption of circle hooks in many longline fisheries, fishery managers, conservation advocates, and fishermen hope to decrease the incidental catch of sea turtles. Current circle hook designs included both offset and non offset hook types. Experiments were conducted in the Costa Rican longline fisheries to determine whether there were any differences in catch rates of targeted fish, incidental catch of sea turtles, or hooking locations of sea turtles between non-offset 14/0 circle hooks and 10^{o} offset 14/0 circle hooks. The commercial longline vessels were contracted to conduct experiments in the Pacific waters of Costa Rica from 2004-2006. A total of 44 sets were conducted with a total of 35,466 hooks deployed. Offset and non-offset 14/0 circle hooks were alternated along each set and squid bait was used throughout the experiments. Initial analysis of catch data indicate that 733 sea turtles were incidentally captured in the 44 sets (mean CPUE: 20.3). Non-offset circle hooks and 10^{o} offset circle hooks had similar catch rates of sea turtles and similar catch rates of targeted fish species.

PILOT STUDY TO EVALUATE ELECTRONIC MONITORING OF TARGET AND NON-TARGET CATCH IN THE CALIFORNIA/OREGON DRIFT GILLNET FISHERY

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NOAA Fisheries Service, Southwest Region has placed observers on commercial fishing vessels participating in the California/Oregon drift gillnet fishery since 1990. Observers collect data on, among other things, protected species interactions with the fishing gear and the catch of target and non-target fish species. Vessels which are unsafe or have inadequate accommodations are deemed unobservable and are not covered in the sampling program. In recent years, a significant portion of the fleet's fishing effort has been conducted by vessels which are unobservable. In 2006, NOAA Fisheries Service, Southwest Region collaborated with Archipelago Marine Research, Ltd. on a pilot study to place electronic monitoring equipment, including automated video systems, onboard 5 observable vessels in the drift gillnet fleet. Observers were assigned to the selected vessels to ground-truth the video data. A total of 11 trips and 53 drift gillnet sets were observed during the pilot study with over 189 video hours of fishing activity recorded. The video monitoring data identified and enumerated 454 animals while the observer data estimated 475 animals. Comparison of the observer complied data with the video complied data demonstrated that the electronic monitoring system could accurately capture in a statistically valid manner the target and non-target catch composition on unobserved drift gillnet vessels. If the video monitoring system proves reliable and cost-effective, NOAA Fisheries Service, Southwest Region hopes to implement its use on vessels which cannot take an onboard observer.

FISHING OPPORTUNITY UNDER THE SEA TURTLE BYCATCH CAPS USING A SPATIAL BIO-ECONOMIC MODEL FOR THE HAWAII-BASED LONGLINE SWORDFISH FISHERY

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There exists a high risk of attaining the caps of sea turtle interactions for Hawaii-based longline swordfish fishing. This study constructed a bio-economic model of multiple time-area closures to explore fishing opportunities under the turtle interaction caps. Generalized Additive Models (GAMs) were applied to turtle interaction predictions by using Hawaii longline logbook data and sea turtle observer data from 1994 to 2006. A set of variables related to physical environment, fishing practices and gear characteristics were evaluated in the GAMs. Both loggerhead and leatherback turtle interactions are closely associated with sea surface temperature, moon phase, hooks per float and degrees of latitude. To assess the economic impact of time and area closures, a cost function through regression statistics was built into the model based on 2005 cost-earnings survey data. Along with set type (targeting swordfish or tuna), fishing days, vessel sizes, and distances to departure ports from fishing sets significantly affect trip variable costs.

Flexible classification in fishing areas and seasons is crucial to policy options in the fishery management. This study designed multiple time-area closures to allow for assessing the effects of closures that are combinations of different areas (by one degree of latitude and/or longitude) and seasons (1 to 12 months). Three flexible area and season closures in total could be applied and simulated simultaneously. The simulation model also incorporated the caps of sea turtle interactions and annual fishing effort limit. As fishing effort distribution by season significantly affects sea turtle interactions, monthly fishing sets in the model could be allocated from zero to the maximum amount of historical effort. All allotted fishing effort was directly operated in open areas and seasons without facing the challenge of redistributing effort from closed areas and seasons. The tradeoffs between sea turtle take reductions and economic return under various fishing effort patterns were then assessed to search for optimal scenarios.

There are a huge number of multiple combinations in time and area closures. The applications of the simulation model in this study narrowed down the closure scenarios to temporal and spatial overlaps between hotspots of sea turtle interactions and economic returns. The simulation results indicate that closure of north 30.5°N latitude from January to March along with closure of north 35°N latitude from October to December could be an optimal scenario in balancing tradeoffs between turtle-take reductions and economic return. Under this optimal scenario, utilizing all 2120 swordfish fishing certificates by April could result in US$6 million net revenue (2005 nominal value) as maximum economic return without exceeding the sea turtle interaction caps.

The simulation model demonstrated its capability in helping direct fishing effort to areas and times that avoid reaching the caps of turtle interactions and minimize economic loss. Continuous observer program and the Turtle Watch Program conducted in the Pacific Islands Fisheries Science Center will enhance the applications of time and area closure approach. For the effect of new techniques in fishing gear and baits, more years of assessments need to be conducted to determine the consistent effectiveness of optimal closure options.

SYSTEMATIC ERRORS IN ESTIMATING LATITUDE FOR SOLAR IRRADIANCE TIME SERIES

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Light based latitude estimates are often wildly inaccurate and are plagued by both systematic (bias) and random errors (variance). These errors are rooted in the astronomical coordinate transformations relating the position of the sun in the celestial sphere to geographic position on the earth. The coordinate transformation systematically amplifies observational errors to bias latitude estimates to the north during summer and to the south during winter. Amplification becomes infinite at the equinox. We present analytical expressions for bias and variance of the estimated latitude and use these expressions to "correct" light based latitude estimates.

THE SECOND SYMPOSIUM ON TAGGING AND TRACKING MARINE FISH WITH ELECTRONIC DEVICES. SAN SEBASTIÁN, SPAIN OCTOBER 8-11, 2007

Haritz Arrizabalaga[1], Nuno Fragoso[2], Molly Lutcavage[2], and John Sibert[3]

Co-hosts: [1]AZTI Tecnalia,
[2]University of New Hampshire Large Pelagics Research Center,
[3]University of Hawaii Pelagics Fisheries Research Program

The Symposium on Tagging and Tracking Marine Fish with Electronic Devices in Honolulu was an important summary of the state of the art in 2000. The intervening years has seen an order of magnitude increase in electronic tag deployments and exciting new developments in tagging technology. The time has come to convene a second symposium. AZTI Tecnalia, the University of New Hampshire Large Pelagics Research Center, and the University of Hawaii Pelagic Fisheries Research Program are jointly hosting a Second symposium in Donostia-San Sebastián, Spain, 8-11 October 2007. The meeting will focus on the use of electronic devices to track movements and behaviours of marine fishes - present and future challenges and perspectives. This symposium will provide an opportunity for scientists working in the marine environment to review the state of the art of electronic tagging and tracking, to examine the type and quality of information currently obtained and to identify future research challenges and tag developments.

Tentative Sessions include:

- Beyond temperature and depth - new technologies for physiology, geolocation and environmental monitoring
- Processing, storage, and display of tag data
- Modeling behavior
- Applications to resource management
- What did we learn that we didn't already know?
- Methods of attachment and implantation

This symposium will appeal to:

- Biologists currently using or considering the use of electronic tagging and tracking devices,
- Assessment scientists and fishery managers interested in improving stock assessment estimates through the inclusion of behavior,
- Fishery managers interested in creating more effective regulations,
- Engineers interested in developing and marketing new devices,
- Physical oceanographers interested in the possibility of using large marine animals as autonomous environmental samplers.

Please visit the Symposium website at http://unh.edu/taggingsymposium/index.html to learn more and to register. Significant discounts are available with Early Registration, so register today! Vendor and Sponsor opportunities exist.

WEDNESDAY, 23 MAY 2007

ESTIMATING FEEDING FROM VISCERAL WARMING IN PACIFIC BLUEFIN TUNA: LAB AND FIELD MEASUREMENTS

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Pacific bluefin tuna (PBFT) are endothermic fish capable of retaining heat associated with metabolic processes of digestion. Establishing where and when tuna feed provides essential data for assessing foraging habitat use. We used a combination of experiments inclusive of stomach and peritoneal placed archival tags in captive tuna and peritoneal implanted archival tags on wild PBFT, to examine the heat increment of feeding (HIF) associated with the specific dynamic action of digestion.

We directly measured the stomach temperature elevations associated with digestion by feeding temperature loggers to captive PBFT (n=12, 11.0±2.7 kg, mean±sd) in a tank with stable ambient temperature (Ta). The temperature excess (Te) above baseline Te associated with the digestion of 1.0±0.3 kg of a mixed diet of known caloric value (986.3±404.1 kcal) reached a maximum (Te_{max}) of 8.9±2.4°C (n=42). This was significantly higher than Te_{base} (2.9±0.1°C) between meals ($p<0.0001$). The resulting HIF's had a mean duration of 21.4±1.6 h. The integrated area under the thermal curve of the HIF was directly related to the calories (kcal) ingested (n=25, $R^2=0.91$, $p<0.0001$).

Comparison of archival tag placement indicates peritoneal archival tags provide area measurements of the HIF that are routinely lower (by 1.65±0.11) than stomach placed tags. The results of these laboratory experiments were used to develop an algorithm capable of detecting foraging events in presence of a variable Ta environment and estimating calories (kcal) ingested by wild PBFT.

The algorithm was tested in farm pens in Mexico, where tuna were fed regularly and ambient temperature changed due to tidal inversions (Ta varied from 11.2-22.3°C). The HIF's of the known feeding events were detected with 99.2% accuracy (1101 days). The mean visceral based Te_{max} was 5.5±1.5°C and the mean duration of the HIF's was 32.4±9.0 h. This reflected larger rations fed.

Using the algorithm, we then examined the foraging behavior of 4 wild PBFT (n=1148 days; 18±4.4 kg body mass) tracked off the Californian coast in 2002-2003. Our results indicate that these fish forage regularly (2.1±0.4 feeding events/day) with a mean Te between feeding events of 2.49±1.2°C. The mean Te_{max} was 5.24±1.37°C and the mean duration of the HIF was 30.7±13.0 h. We estimated a daily intake of 1059±482 kcal (4.8±1.8% body mass). Feeding events occurred most often in surface waters between 0-10m (45.0±5.6%) and 10-50m (35.6±3.6%) between 04:00-08:00am (56.7±5.6%). Overall, we found feeding efficiency to be independent of ambient temperature.

We tested whether characteristics of movement and/or diving behavior were predictive of foraging success. First Passage Time (FPT) was a significant and consistent predictor for the number of feeding events per day ($p<0.004$). Among the diving indices tested, daily diving frequency was also a significant and consistent predictor for number of feeding events per day ($p<0.002$). The results indicate that peritoneal placed archival tags can be used to estimate foraging success of bluefin tuna.

FEEDING DYNAMICS, CONSUMPTION RATES AND DAILY RATION OF LONGTAIL TUNA (*Thunnus tonggol*) IN AUSTRALIAN WATERS

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The feeding ecology of longtail tuna (*Thunnus tonggol*) was studied in northern and eastern Australia. Diet biomass data were used to estimate daily ration and consumption of individual prey taxa, particularly penaeids targeted by Australia's valuable Northern Prawn Fishery (NPF). Overall, the 497 stomachs contained 101 prey taxa. In both regions, small pelagic and demersal fishes comprised the majority of the diet biomass. Fish in both regions showed a marked increase in prey diversity, variation in prey composition and stomach fullness index in autumn and winter. This increase in apparently opportunistic feeding behaviour and feeding intensity showed an inverse relationship with reproductive activity, indicating a possible energy investment for gonad development. Daily ration decreased with increasing fish size (2.17-1.30% BW d^{-1}), while annual consumption by fish increased with size (45.26-82.97 kg yr^{-1}). Total prey consumption in the Gulf of Carpentaria was estimated at 148,178 t yr^{-1}, including 599 t yr^{-1} of commercially important penaeids. This study demonstrated that longtail tuna play an important ecological role in neritic ecosystems. Their interaction with commercial fisheries highlights the need for targeted dietary studies of high order predators to better understand trophic pathways to facilitate ecosystem-based fisheries management.

FAUNA AGGREGATED AROUND FADS AND FEEDING BEHAVIORS OF PREDATORS ON FAD-AGGREGATED PREY: REGIONAL DIFFERENCES IN THE INDIAN OCEAN

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Drifting Fish Aggregating Devices (FADs) play a major role in the purse-seine tuna fishery in the Indian Ocean. Drifting FADs, both natural and man-made, eventually form fish communities associated with them. We performed underwater visual surveys to estimate fish abundance and composition of these FAD associated communities in two regions of the Western Indian Ocean. FADs deployed by fishermen were surveyed in the fishing grounds of industrial purse seiners in the equatorial waters, and compared to experimental FADs deployed in tropical waters south off the island of la Réunion. Within each region, and between these two regions, there was little variation among faunal lists recorded under drifting FADs. In equatorial waters the abundance of some species varied greatly between individual FADs, likely depending on the history of FADs (drift paths, fishing pressure, etc). In tropical waters, fish abundance also varied between FADs, likely dependent on the age of the experimental FADs (up to one month). A factorial analysis showed that differences in fish abundance around FADs are explained by the region where FADs are located (40% of the difference). This difference was mainly due to 4 species*:* *Canthidermis maculatus, Decapterus macarellus, Kyphosus vaigiensis and Elagatis bipinnulata*. Ubiquitous predatory species found at FADs included dolphinfish (*Coryphaena hippurus*), wahoo (*Acanthocybium solandri*) rainbow runners (*Elagatis bipinnulata*) and silky sharks (*Carcharhinus falciformis*).

Fish communities associated with FADs might be trophically exploited by predatory fishes also associated with FADs. In order to assess the importance of FAD communities as a source of prey to large predatory species, stomach content analyses were made of dolphinfish, wahoo and yellowfin tuna (*Thunnus albacares*) caught with hook and line around drifting FADs. In equatorial waters yellowfin tuna did not feed on FAD associated prey, while wahoo and dolphinfish did so, though they predominantly fed on other non-associated organisms. In tropical waters, only dolphinfish and wahoo were studied as tuna were rare. Although prey-associated fish did not constitute the main diet source of these species in this region, they represented a higher percentage than in the equatorial waters. These results allow us to discuss the role of trophic relationships in the behavior of predatory fishes around FADs (e.g. residence time), and therefore the role of FADs in their ecology.

OCEANOGRAPHIC INFLUENCES ON ALBACORE AND ITS FORAGE IN THE AMERICAN SAMOA LONGLINE FISHING GROUND: PART II.

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Based on previous results indicating the importance of the seasonally and interannually varying South Equatorial Counter Current (SECC) and the resulting eddies on the American Samoa longline fishery performance for albacore, *Thunnus alalunga*, this study is focused on investigating the effects of the SECC and eddy activity on large predatory nekton, such as albacore tuna, and its feed, micronekton, in the region. For this study *in situ* oceanographic and bioacoustics data were obtained during a cruise conducted in the American Samoa EEZ during February, 2006. The *in situ* data were complimented by weekly satellite altimetry and albacore catch records from the American Samoa longline fleet shipboard logs.

Preliminary results indicate that anticyclonic eddies formed at the boundary region between the eastward propagating SECC and the westward traveling South Equatorial Current (SEC) are predominantly composed of SECC waters with relatively low sea-surface salinity and high oxygen levels. The locations of the anticyclonic eddies correspond to relatively high levels of chloropigments and micronekton biomass, as indicated by CTD fluorometer data and active acoustic backscatter at 38 and 120 kHz frequencies, respectively. However, the highest micronekton abundances are found near the island of Tutuila, most likely due to the proximity of the tuna cannery on the island. Acoustic backscatter levels show no correlation between micronekton densities and high sheer regions corresponding to eddy boundaries in the region. In depth, the high sonic scattering layers (SSL), composed mainly of micronekton, are found at 500 -- 900 m depth during the daytime, consisting of two prominent layers at 500 -- 650 m (shallow daytime SSL) and at 750 -- 900 m (deep daytime SSL) depths, although the level of backscatter from the shallow daytime SSL is found to be consistent throughout night and day. During nighttime, the high SSL is located in the upper 200 m (nighttime SSL) and shows an approximate 5 fold increase in backscatter values from those during the day. Most of the migratory organisms migrate between the shallow daytime and nighttime SSL, although a significant portion of organisms is seen to migrate between the deep daytime and nighttime SSL. During nighttime the value of backscatter at 38 kHz is more than double than that at 120 kHz in the upper 200 m, while daytime they are similar in magnitude with higher 38 kHz and 120 kHz values at the 0-100 m and at 100-200 m depths, respectively. The decrease in the difference between backscatter strengths at the two frequencies indicates the decrease of fish (mostly myctophidae) and likely squid biomass during daytime, as those organisms preferentially migrate to deeper depths during the day.

High nekton biomass does not seem to be related to the locations of anticyclonic eddies or to high micronekton biomass, as estimated from the acoustic backscatter data. If fact, highest nekton backscatter levels and most numerous nekton aggregations were observed at a high shear region between an anticyclonic and cyclonic eddy pair, corresponding to the region with the lowest estimates for micronekton biomass. Nekton aggregations were found mostly during daytimes and predominantly between 200 and 300 m from the surface, apparently feeding on a thin, persistent scattering layer at these depths. This depth is consistent with previously observed preferred depths of tagged albacore tuna in the American Samoa longline fishing ground.

FEEDING HABITS OF THE BIGEYE THRESHER SHARK (*Alopias superciliosus*) SAMPLED FROM THE CALIFORNIA-BASED DRIFT GILL NET FISHERY, 1998-2006

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The bigeye thresher shark (*Alopias superciliosus*) is a deep-water pelagic species, but it is also found in coastal waters over continental shelves in tropical and subtropical waters worldwide. Based on both fisheries and tracking data they make daily vertical migrations from the surface to around 500 m spending daylight hours at depth and returning to near the surface at night. From the information available, their behavior appears to be similar to that of swordfish. Although bigeye thresher sharks are caught in fisheries worldwide there is little information available on their feeding habits. Based on their vertical movements, some authors suggest that they may exploit prey in the deep scattering layer (DSL). However, only one feeding study on bigeye thresher sharks caught in the western North Atlantic is available. Those authors found that bigeye thresher sharks in that area were feeding on pelagic aulopoids (lancetfishes), scombroids, small istiophorids, demersal fishes and squids.

To quantify the foraging ecology of the bigeye thresher shark from northeastern Pacific coastal waters we collected stomachs from the California-based pelagic drift gill net fishery which targets swordfish and common thresher sharks. Samples were collected during the fishing seasons of 1998-1999 and 2002-2006 within the US EEZ between San Diego (32º 4.3' N) and San Francisco (39º 48.3' N). Sharks sampled ranged in size from 147 to 230 cm fork length (FL). For each prey item, we calculated the weight, number, frequency of occurrence, the geometric index of importance (GII) and the index of relative importance (IRI). Of the 25 stomachs examined, 22 contained food representing a total of 19 taxa. The six most important prey species were the barracudinas (*Paralepididae* family; GII=52.0), followed by Pacific hake (*Merluccius productus*; GII=33.8), Pacific saury (*Cololabis saira*; GII=23.1), jumbo squid (*Dosidicus gigas*; GII=21.4), Pacific mackerel (*Scomber japonicus*; GII=18.0), and northern anchovy (*Engraulis mordax*; GII=16.6).

Previous studies have suggested that DSL species may be important in the diet, however it appears that, off California, midwater and epipelagic species are important as well as some benthic species. Most of the prey species found in the bigeye thresher stomachs have also been found in the stomachs of shortfin mako, blue and common thresher sharks sampled from the same fishery. The large number and diverse taxa, with minimal overlap between our results and those reported for the northwestern Atlantic suggest that the bigeye thresher is an opportunistic feeder that forages over a broad range of habitats to exploit locally abundant prey.

TROPHIC ECOLOGY OF THE DOLPHINFISH *Coryphaena hippurus* (Linnaeus, 1758) IN TWO AREAS OF THE SOUTH OF THE GULF OF CALIFORNIA

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In Mexico the dolphinfish *Coryphaena hippurus*, occurs in the Pacific Ocean and the Gulf of Mexico. It's a very important resource for the sport and commercial fishing fleets. In this study we present biological information about the feeding habits of the dolphinfish in two areas in the south of the Gulf of California: Cabo San Lucas, Baja California Sur and Mazatlan, Sinaloa. We analyzed 215 dolphinfish stomachs captured by the sportfishing fleet in Cabo San Lucas and 232 stomachs from the sportfishing and commercial fishing fleets in Mazatlán during 2000, 2001 and 2003. For the trophic analysis we applied different quantitative methods like the numeric, gravimetric and frequency of occurrence, used to calculate the Index of Relative Importance. To determine the breadth of diet, we applied the Levin´s index and to determine the trophic overlap between areas, sizes and sex, we used the Morisita-Horn index. Twenty-four percent of the stomachs from Cabo San Lucas were empty while only 10% of the stomachs from Mazatlan were found like this. Three principal trophic groups were found in both zones: Cephalopods, Fishes and Crustaceans. The Index of relative importance indicated that the most important prey in Cabo San Lucas were the pelagic red crab *Pleuroncodes planipes* with 70% in the 2001 and 2003 years and the jumbo squid *Dosidicus gigas* with 63% for 2000 followed by *P. planipes* (25%). In Mazatlan the most important prey were the crustacean *Hemisquilla ensigera californiensis* with 64% in 2001 and 2003 and the fish *Hemiramphus saltator* with 24% in 2000. The Levin´s index indicated that the diet breadth was low ($Bi<0.03$) which means that the dolphinfish is considered a specialist predator; however, because of the wide trophic spectrum found in both areas (more than 86 prey), we considered this fish as an opportunistic predator. The Morisita-Horn index indicated high diet overlap between sexes in both areas ($C\lambda>0.87$) for dolphinfish; this indicated that both sexes feed on similar prey. The overlap among sizes in both areas varies with the growth, so the bigger fish feed on different prey than the smaller ones. The overlap among the areas was low, and this seems to be more related to the abundance and distribution of the prey than to the predator food preferences.

IDENTIFICATION OF PACIFIC LARGE PELAGIC SHARK HABITATS USING 'PSAT' ARCHIVAL TAGS, OCEANIC SATELLITE REMOTE SENSING, AND 'SODA' OCEAN ASSIMILATION MODEL ANALYSES – AN UPDATE ON CONTINUING RESEARCH

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Identification of the habitats of marine fishes and knowledge of the utilization of the habitats by the respective species are crucial factors necessary for the application of ecosystem approaches for managing marine fish stocks. Gaining this essential information and understanding is difficult and presents many challenges to marine fisheries researchers, especially regarding large pelagic marine fishes, e.g., tunas, billfishes, and sharks. This presentation describes an approach for defining the horizontal and vertical habitat of Pacific large pelagic sharks using a combination of 'PSAT' electronic archival tag technology, oceanic satellite remote sensing methods, and 'SODA' ocean assimilation model analyses.

Results are presented for three sharks that show contrasting distributional patterns and different habitats. The oceanic white-tip shark (*Carcharhinus longimanus)* was found to have a relatively restricted 'home range' in the near surface tropical waters mostly in the range of about 24.5° – 26°C. Results indicate that oceanographic information in two dimensions can effectively map the habitat of this species, e.g., satellite-derived SST.

The shortfin mako shark (*Isurus oxyrinchus)* was found to migrate throughout a large oceanic region from Tropical Waters near Hawaii to California Current waters off the coast of California. The depth distribution of this species was deeper during daytime than during night-time hours and appeared to be linked to the characteristics of the thermocline structure, e.g., when in Tropical waters, where the thermocline was weak, broad and deep, the species was found mostly below 100m; whereas, when in California Current waters, where the thermocline was strong, sharp, and relatively shallow, the species was almost entirely confined above 100m.

The blue shark (*Prionace glauca)* also migrated over a sizeable oceanic region from Tropical Waters near Hawaii to Subtropical Convergence Zone waters in the central North Pacific. The vertical distribution of the blue shark extended over a wider, deeper depth range during daytime hours than nighttime hours. Oceanic convergence and ocean vertical thermal structure were found to be important factors affecting blue shark habitat.

Preliminary results indicate that oceanographic information in three dimensions will be required to effectively map the habitat of the shortfin mako and blue sharks, e.g., a combination of satellite remote sensing data and 'SODA' analyses. Research is continuing along these lines.

EFFCT OF OCEAN TURBULENCE ON SURVIVAL AND INGESTION OF TUNA, *THUNNUS*, LARVAE

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Physical conditions, such as turbulence related to food availability, are considered important factors affecting fish larval survival. Rearing experiments were conducted to elucidate the effects of oceanic turbulence on survival and ingestion rates during the initial feeding period for bluefin tuna, *Thunnus orientalis*, larvae. Seven levels of turbulence intensity were provided by changing the flow rate from pipes set on the bottom of rearing tanks. The result showed a dome-shaped relationship between turbulence level and ingestion rate, in which ingestion rate appeared higher at a turbulence energy dissipation rate of 6×10^{-7} m^2s^{-3}, and decreased at both higher and lower turbulence levels. Compared with the turbulence intensity in the ocean, the optimal turbulence level for bluefin tuna larvae corresponded to the turbulence caused by sea surface winds with speeds of 4 to 11 ms^{-1}. At the highest turbulence level, corresponding to mixing by strong winds greater than 15 ms^{-1}, i.e., an approaching typhoon, larvae could not ingest any rotifers and did not survive four days after hatching. These results suggest that the turbulence level caused by typhoons would not be appropriate conditions for larval survival. Since the estimated optimal intensity for bluefin tuna larvae is comparable to that for yellowfin tuna, *Thunnus albacares*, it could be concluded that the turbulent intensity of the order of 10^{-7} m^2s^{-3} is a common feature among the genus *Thunnus* spawning in the open ocean.

AMBIENT TEMPERATURE HISTORIES OF SOUTHERN BLUEFIN TUNA, *Thunnus maccoyii*, INFERRED FROM OTOLITH STABLE ISOTOPE COMPOSITIONS

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The migratory life history of southern bluefin tuna (SBT, *Thunnus maccoyii*) was reconstructed from otolith powders sequentially collected from core to edge for stable carbon (C) and oxygen (O) isotope analysis. Profiles of $\delta^{18}O$ indicate that SBT experience an increasing ambient water temperature (25 to 33°C, among individuals) in the larval stage followed by a period with decreasing temperatures of approximately 8-10°C until 1 year of age. Water temperatures varied between approximately 15-25°C with no evident trend over the remaining life of SBT. The otolith $\delta^{13}C$ profile is similar to that for $\delta^{18}O$, showing depletion in the larval stage followed by abrupt enrichment from the juvenile to young stage. Otolith $\delta^{13}C$ reaches a plateau earlier than does $\delta^{18}O$ during the first year and shows higher variation over the remaining life. Interpretation of otolith $\delta^{13}C$ is complicated but the results suggest the progressive transitions of ontogeny, metabolism and trophic levels for SBT. Otolith stable C and O analysis provide continuing information throughout the whole migratory life history and contribute to the presently limited understanding of SBT.

REVIEW OF 2006-2007 ACTIVITIES AT THE IATTC'S ACHOTINES LABORATORY

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Yellowfin tuna broodstock have been spawning nearly daily in a concrete, in-ground tank at the Achotines Laboratory since October of 1996. 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. Preliminary results from recent density-dependence experiments on early-juvenile tuna as well as transfer trials on eggs and larval tuna will be presented.

Captive adult yellowfin are also utilized in trials and experiments. In early 2007 IATTC scientists implanted geolocating archival tags in the body cavities of 10 captive yellowfin tuna (55 to 78 cm in length). This trial continues work started in 2002 to investigate whether feeding and spawning events of yellowfin can be detected by evaluating peritoneal cavity temperatures recorded by the archival tags. The primary objective of this latest effort is to collect data on possible thermal spawning signals.

A three-year grant to Achotines Laboratory from the Panamanian government organization Secretaría Nacional de Ciencia, Tecnología e Innovación (SENACYT) will fund efforts to restart studies of the feasibility of capturing, transporting, and culturing live Indo-Pacific sailfish, *Istiophorus platypterus,* during 2007. IATTC and Achotines Laboratory staff will collaborate in this study with Dr. Daniel Benetti, Director of the Aquaculture Program at the University of Miami Rosenstiel School Of Marine and Atmospheric Science (RSMAS). The SENACYT grant will also fund parallel efforts to capture and hold wahoo, *Acanthocybium solandri.*

The IATTC and RSMAS will hold the 5th Annual Workshop on “Physiology and Aquaculture of Pelagics with Emphasis on Reproduction and Early Developmental Stages of Yellowfin Tuna” at Achotines Laboratory from June 11-24, 2007. International researchers, professionals and students gather to combine advanced technologies and improve methods for raising larval tuna and other species of marine fish. Achotines Laboratory also continues to be popular for seminars and field trips and in 2007 was scheduled for use by various institutions including Princeton University and the University of Quebec.

DIGESTIVE ENZYME ACTIVITIES IN ALBACORE, YELLOWFIN TUNA, EASTERN PACIFIC BONITO, AND CHUB MACKEREL

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All tunas conserve metabolic heat within the aerobic locomotor muscle, and certain tuna species, including albacore (*Thunnus alalunga*), can also maintain elevated visceral temperatures. These species are thus regional endotherms. We compared digestive enzyme activities in the albacore and in scombrid fishes that cannot elevate visceral temperatures in order to test the hypothesis that enzyme activities are higher in the albacore as a result of its higher visceral temperatures. If the hypothesis is supported, this study would provide evidence that higher digestive rates are a selective advantage associated with visceral endothermy in tunas.

The albacore was compared with yellowfin tuna (*Thunnus albacares*), a species that maintains elevated temperature in the aerobic muscle but not in the viscera, and with the ectothermic eastern Pacific bonito (*Sarda chiliensis*) and chub mackerel (*Scomber japonicus*). In all four species, the specific activities of pepsin in the stomach and lipase in the intestine and caecal mass were measured at 15°C and 25°C. The specific activities of trypsin in the intestine and caecal mass were measured at 20°C and 25°C. After capture by hook and line, the whole stomach, intestine, and caecal mass of each fish were removed, stripped of contents, and frozen in liquid nitrogen or on dry ice. Each of the three sections of the digestive tract analyzed were weighed and separately pulverized with liquid nitrogen in a mortar and pestle. The resulting powdered tissue was stored at -80°C, and subsamples were used in enzyme assays run in a temperature-controlled spectrophotometer under conditions of saturating substrate concentration. Interspecific comparisons of digestive enzyme activities were made at approximations of *in vivo* temperatures.

As expected, digestive enzyme activities increased with temperature in each species. In interspecific comparisons, stomach pepsin activity did not differ significantly among albacore (at 25°C), yellowfin (at 25°C), and bonito (at 15°C), but was higher in these species than in chub mackerel (at 15°C). Intestine trypsin and lipase activities were highest in chub mackerel and lowest in albacore. No significant interspecific differences in caecal mass enzyme activities were detected. Therefore, there is no evidence that the activities of pepsin, trypsin, or lipase are greater in the albacore than in the other three species that cannot elevate visceral temperatures.

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MEDIAL RED MUSCLE DEVELOPMENT IN THE YELLOWFIN TUNA, *Thunnus albacares*

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In fishes, fast twitch, glycolytic (white) muscle is used for rapid swimming bursts and the myoglobin-rich, slow-twitch, oxidative (red) muscle powers sustained swimming. Although most fishes are ectothermic, four fish lineages can elevate red muscle temperature above water temperature by conserving metabolic heat using counter-current heat exchangers. The red muscle of ectothermic fishes is located in lateral wedges just under the skin, whereas the red muscle is more medial in all endothermic fishes that can elevate red muscle temperature. The purpose of this study was to determine when and how medial red muscle forms by describing the red muscle development in a size series of juvenile yellowfin tuna, *Thunnus albacares*. These fish were hatched and raised at the Inter-American Tropical Tuna Commission (IATTC) laboratory at Achotines Bay, Republic of Panama. Observations on freshly dead and fixed fish before and during transformation revealed that a majority of the red muscle was within the lateral wedge of red muscle located beneath the skin. A size series of yellowfin tuna ranging from 40.96 mm FL to 74.03 mm FL was frozen in liquid nitrogen, sectioned at 50%, 60%, and 70% of fork length (%FL), and the red muscle fibers were labeled a deep purple color using a succinic dehydrogenase (SDH) stain that differentially stains for the higher mitochondrial densities in red muscle. Larger yellowfin juveniles (up to 188 mm FL) were collected by hook and line near fish aggregating devices off Oahu, Hawaii, frozen at -80ºC, sectioned at 60% FL, and stained for SDH. Digital images were taken of the 60% FL sections, and the Scion Image analysis program was used to calculate the amount of red muscle as a percentage of total cross-sectional area. In the smallest fish that was frozen and SDH-stained (40.96 mm FL), the red muscle fibers are present in the myotomal anterior pointing cones, but a majority of the red muscle is located in the lateral wedge adjacent to the skin. There is a gradual progression to larger fish, which have a larger red muscle as a percentage of total cross-sectional area at 60% FL. Tuna development may provide insight into the mechanisms involved in formation of internalized red muscle and enhance our understanding of how endothermy evolved in fishes. It is possible that tunas may need to develop the ability to elevate red muscle temperatures before they are able to leave warmer waters and expand their niche into cooler water. Knowing when tuna juveniles are able to leave warmer waters may help us understand the recruitment, life history, and physiological ecology of these economically important species.

SPECIALIZATIONS FOR GILL RIGIDITY IN RAM-VENTILATING TELEOSTS

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For ram-gill ventilators such as tunas (family Scombridae) and marlins (family Istiophoridae), a rigid gill structure prevents filament and lamellar deformation by the fast, continuous ventilatory flow stream. Hydrodynamic modeling and comparative studies of water-flow resistance imposed by fusions binding the gill filaments and lamellae are in progress. In tunas, lamellar fusions bind adjacent lamellae on the same filament to opposing lamellae of the neighboring filament. Examination of other scombroid genera reveals lamellar fusions in the bonitos and a previously undescribed inter-lamellar fusion in the wahoo (*Acanthocybium solandri*), striped marlin (*Tetrapturus audax*), and sailfish (*Istiophorus platypterus*). Unlike lamellar fusions, the inter-lamellar fusion binds juxtaposed lamellae on the same filament, but does not connect to the opposing lamellae of the adjacent filament. This shared character in the wahoo, striped marlin, and sailfish supports the phylogenic hypothesis of Johnson (1986) who proposed that the billfishes are sister group to *Acanthocybium*.

A COMPARISON OF LONGLINE VULNERABILITY BASED ON DEPTH AND HABITAT

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The predominant factor governing the efficiency of a pelagic longline fishing operation and the species composition of the catch is the relationship between the distribution of hooks and species vulnerability, whereby the hook distribution can be considered in terms of either depth or some suite of environmental variables. We therefore fitted longline catch rate models to determine whether catch is estimated better by vertically distributing a species by depth or environmental conditions (e.g. temperature, thermocline gradient, and oxygen concentration). Catch rates were estimated by two methods: (1) calculating catch-per-unit-effort (CPUE) from monitored pelagic longlines where the vertical distribution of hooks and fish catch in relation to depth and environmental conditions is known, and (2) applying a statistical Habitat-Based Standardization (statHBS) model to fishery and environmental data to develop indices of relative abundance for bigeye tuna (*Thunnus obesus*) and blue shark (*Prionace glauca*), two ecologically diverse species in the Pacific Ocean. Our results indicated that an understanding of fisheries data, gear dynamics, and environmental influences are important to analyze and interpret CPUE data correctly. Analyses based on depth-specific catch rates can lead to serious misinterpretation of abundance trends inferred from CPUE data despite the use of sophisticated statistical techniques (*e.g.* generalized linear mixed models). On the other hand, spatiotemporal mismatches in data used to generate habitat preferences and data for environmental variables limits the use of environmental factors. Lastly, it is inappropriate to adjust abundance trends by extrapolating catchability estimates to areas outside the region where catchability was estimated.

We present proposed improvements to the statHBS framework which include a multi-species approach, additional comparisons with detailed longline hook monitoring and simulations to test various CPUE standardization methods (e.g. GLMs, GAMs, statHBS).

DEVELOPMENT AND PRELIMINARY TESTING OF HARVEST STRATEGIES FOR THE AUSTRALIAN EASTERN AND WESTERN TUNA AND BILLFISH FISHERIES

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In December 2005 the Australian Government announced a range of new policy initiatives to cease over-fishing, and rebuild over-fished fish stocks for all Commonwealth managed fisheries. This included a ministerial direction to the Australian Fisheries Management Authority to implement a range of complementary management measures. A central component of this direction was the development and implementation of formal harvest strategies, including default target and limit reference points, and decision rules.

We describe the development and key components of the harvest strategy framework developed throughout 2006 for the two tropical tuna longline fisheries managed by the Australian Fisheries Management Authority. The harvest strategy framework includes a standardised CPUE-based decision rule that is moderated by a size-based decision tree. Preliminary generic simulation testing indicates that the size–based decision tree provides additional robustness in terms of both conservation and long-term yield objectives relative to the performance of the CPUE-based rule alone. Work is underway on specific single and multi-species evaluations using operating models conditioned for the Eastern Tuna and Billfish Fishery.

HABITAT CHARACTERISATION OF YELLOWFIN TUNA IN THE TASMAN SEA USING EXPERT OPINION

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The decline in the abundance of large pelagic fish populations is a growing concern as national and international fishing fleets continue to increase their effective effort levels and vessel range to provide for an increasing global market. Sustainable fishing of large mobile fish species, such as the tuna and billfish, will require accurate habitat characterisations to inform assessments of stock status and effective management decisions. Our work uses location information from catch records combined with oceanographic data and the expert opinion of fishers to inform a Bayesian general linear model of the spatial distribution of yellowfin tuna availability in the Tasman Sea. We conclude that Bayesian frameworks allow the inclusion expert opinion as a valuable data source largely overlooked in conventional habitat characterisations and provides a rigorous basis for incorporating such information into CPUE standardisations and stock assessments.

SPATIAL-TEMPORAL DISTRIBUTION OF THE RELATIVE ABUNDANCE OF THE SAILFISH (*Istiophorus platypterus*) IN THE MEXICAN PACIFIC OCEAN

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One of the species that is incidentally captured by the commercial fishery is the sailfish (*Istiophorus platypterus*), an important species in the sport-recreational and commercial fisheries. With the incidental catch information of sailfish by the long-line boats in the Eastern Pacific Ocean during 1983 to 1996, we can determine the spatial-temporal distribution of this species, its interannual and seasonal variability, and its relation with the sea surface temperature, the phases of the moon, sea floor topography, SOI, and MEI. The data base was standardized because of the differences of effort found in the period studied. The indicator of abundance used was *CPUE*, defined as the number of organisms captured by 1000 standardized hooks. In the Mexican Pacific Ocean there are areas of importance in sailfish abundance; the entrance of The Gulf of California (during August to January) and the Gulf of Tehuantepec (during the entire year), which have statistically significant seasonal and interannual periodic variations. The sailfish abundance shows a close relationship with the sea surface temperature, which also determines the migration patterns of the species. No significant difference was found between the lunar phase and the *CPUE*, but the analysis shows an apparent maximum of the *CPUE* during the waxing and full moon. The relation between the *CPUE* and the bathymetry shows that between 0 and 2000 meters depth the abundance was medium (The coastal zone), between 2000 and 4000 meters it was low (the oceanic zone), and between 4000 and 6000 meters it increased (the Gulf of Tehuantepec abyss). The ambient index shows that when the MEI was higher than 1 the *CPUE* decreases and when the MEI value goes below -1 the *CPUE* increases. No relation was found between the SOI and *CPUE*.

THURSDAY, 24 MAY 2007

AN EVALUATION OF THE AREA STRATIFICATION USED FOR SAMPLING TUNAS IN THE EASTERN PACIFIC OCEAN PURSE-SEINE FISHERY

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The Inter-American Tropical Tuna Commission (IATTC) staff has been sampling the size distributions of tunas in the eastern Pacific Ocean (EPO) since 1954, and the species composition of the catches since 2000. The IATTC staff uses the data from the species composition samples, in conjunction with observer and/or logbook data, and unloading data from the canneries to estimate the total annual catches of yellowfin (*Thunnus albacares*), skipjack (*Katsuwonus pelamis*), and bigeye (*T. obesus*) tunas. These sample data are collected based on a stratified sampling design. I propose an update of the stratification of the EPO into more homogenous areas in order to reduce the variance in the estimates of the total annual catches.

The sampling model used by the IATTC staff is a stratified two-stage (cluster) random sampling design with first stage units varying (unequal) in size. The strata are month, area, and set type. Wells, the first cluster stage, are selected to be sampled only if all of the fish were caught in the same month, same area, and same set type. Fish, the second cluster stage, are sampled for lengths, and independently, for species composition of the catch. The EPO is divided into 13 sampling areas, which were defined in 1968, based on the catch distributions of yellowfin and skipjack tunas. This area stratification does not reflect the multi-species, multi-set-type fishery of today.

In order to define more homogenous areas, I used agglomerative cluster analysis to look for groupings of the size data and the catch and effort data for 2000-2004. I plotted the results from both datasets against the original 13 sampling areas, and then created new areas. For each dataset, I either divided the EPO into a few large areas, or further divided the large areas in order to keep 13 smaller areas. I also updated the substitution scheme for strata with catch, but no sample to agree with the new area stratifications. I then compared the estimates of total annual catch by species among the different area groupings, and selected the two that had the greatest reduction in variance of the catch estimates. In addition, I explored a few new methods for calculating the variance of the catch estimates.

Initial results show that stratifying the EPO based on the catch and effort data, and not the size data, produced the greatest reduction in the variance of the total catch estimates. In general, stratifying the EPO into smaller versus larger areas also produced smaller estimates of variance. I will present these results, along with the new methods for calculating the variance of the total annual catch estimates.

FISHERIES INDEPENDENT ASSESSMENT OF BIGEYE TUNA BIOMASS AT CROSS SEAMOUNT

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The feasibility of estimating bigeye tuna, *Thunnus obesus*, biomass at Cross Seamount, a population heavily targeted by the local handline fishery, is assessed using dual frequency active acoustic surveys. Moderate exploitation rates of juvenile and subadult bigeye tuna, known to preferentially aggregate at the unique seamount environment, indicate that the seamount population should be closely monitored. Presently used methods of bigeye tuna biomass estimation, based on fishery logbook records, are heavily biased by numerous factors, such as the fishing pattern of the fleet, the type of gear used, fishing depths, and the availability and density of prey. Contrary to these established methods, the active acoustic survey technique yields large amounts of fishery independent data on the abundance and distribution of both tuna and its prey on a controlled grid with relatively low demands on resources.

Preliminary results from acoustic surveys over Cross Seamount show loose V-shaped aggregations and scattered fish targets. The aggregations are consistent in shape with those of bigeye and/or yellowfin tuna previously observed around Fish Aggregating Devices in the Atlantic and Indian Oceans. They are observed predominantly during daytime over the 400 m deep plateau, which is known to aggregate bigeye and, to a lesser degree, yellowfin tuna. The aggregations typically occupy the depths of 50-200 m, coinciding with the depths of relatively thin sound scattering layers. Mean acoustic Target Strength (TS) values of scattered fish recorded inside and outside the aggregations are consistent with theoretical TS values of 37 cm FL bigeye or 39 cm FL yellowfin tuna, sizes that are typical for these species at Cross Seamount.

OCEANOGRAPHIC INFLUENCES ON ALBACORE CATCH IN AMERICAN SAMOA

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Albacore (*Thunnus alalunga*) landings from the longline fishery based in American Samoa varied sharply during the past 10 years. The fleet composition operating in this region shifted toward larger vessels operating on a larger spatial and temporal scale resulting in an impressive 10 fold increase of the number of hooks deployed by fishermen compared to the small scale fishery that used to operate in this region. These fishery fluctuations were investigated in relation to the variability of the ocean environment to determine whether available oceanographic information could be used to explain part of the variability of catch and CPUE. Fishing efficiency was found to vary according to an interaction between the depth of the 15°C isotherm and a proxy for longline depth (*i.e.* hooks between floats). Model selection procedures applied to Generalized Linear Models incorporating both fishery and oceanographic influences on catch concluded that current oceanographic information (and understanding) plays a negligible role in explaining the large variations of catch and CPUE reported by the fishermen. This study suggests that the declining fishing efficiency observed in the past ten years are induced by declining abundance of this natural resource.

PRELIMINARY RESULTS WITH CATCH DATA FOR MAHIMAHI AND WAHOO IN THE HAWAII-BASED LONGLINE FISHERY

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The common dolphinfish, *Coryphaena hippurus*, known in Hawaii as 'mahimahi', and wahoo, *Acanthocybium solandri*, are widely-distributed, mid-sized epipelagic predators that comprise a substantial fraction (*ca*.15%, numerical basis) of the incidental catch of the Hawaii-based longline fishery. These species, which are popular as both food and sport fishes, are also of ecological interest in light of concerns about possible over-exploitation of larger predators targeted by pelagic fisheries (e.g., adult tunas, *Thunnus* spp., swordfish, *Xiphias gladius*) or taken incidentally (e.g., adult marlins, *Makaira* spp. or *Tetrapturus* spp.). The underlying premise is that the mid-sized species might be expected to proliferate if and when the relative abundance of their own predators is reduced.

This talk presents preliminary results with mahimahi and wahoo catch data gathered by fishery observers or reported in commercial logbooks from the Hawaii-based longline fishery from March 1994 through February 2006. Results include evaluations of reporting biases, tabulations of catch rates in relation to the type of fishing activity (i.e., tuna- or swordfish-targeted), summaries of bycatch, time series of standardized catch rates, and maps of catch distributions.

REDUCING BYCATCH WITH A DEEP SET LONGLINE TECHNIQUE IN HAWAII'S TUNA FISHERY

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The deep-setting longline experiment was conducted in coordination with the Secretariat of the Pacific Community (SPC), the Pacific Islands Fisheries Science Center, and the University of Hawaii Joint Institute for Marine and Atmospheric Research. We altered current commercial tuna longline setting techniques to test a method developed by the SPC to eliminate all shallow set hooks (less than 100 m depth) from tuna longline sets. By eliminating all shallow set hooks, we hoped to maximize target catch of deeper dwelling species such as bigeye tuna, reduce the bycatch of turtles and other protected species, and reduce the incidental catch of many species of marketable, but less desired fish (e.g., billfish and sharks).

A single vessel was contracted to perform 90 longline sets (45 sets using the deep setting technique and 45 control sets using standard methods). In the experiment, fishermen were allowed to keep and sell their catch and choose their fishing areas, setting times, and hauling times. A deep set was achieved by attaching paired 3 kg lead weights directly below paired floats on long portions of the mainline, thereby sinking the entire fishing portion of the line below the target depth of the shallowest hook (100 m). Except for additional lead weights, floats, and floatlines which the project provided, only very slight modification of existing longline fishing gear and methods was required. The vessel alternated between the deep set technique on one day's set and their standard technique (control) on the next day's set. A control set deployed about 2000 hooks in 27 hook baskets and a deep set deployed 2000 hooks in 30 hook baskets. A researcher accompanied the vessel on all trips. The researcher documented catch by gear type and attached temperature depth recorders during every set to determine fishing depth of the gear.

The deep setting technique was easily integrated into daily fishing activities with only minor adjustments in methodology. The main drawback for the crew was the increase in time to both deploy and retrieve the gear. The deep set technique added about 30 minutes to the deployment operations and approximately 2 hours to the hauling operations. Catch totals on the deep set gear were greater for both bigeye tuna (*Thunnus obesus*) and moonfish (*Lampris guttatus*); whereas catch of less valuable incidental fish (e.g., striped marlin (*Tetrapturus audax*) and wahoo (*Acanthocybium solandri*)) was lower. Temperature depth recorders placed on the gear verified that the deep set method did achieve the goal of ensuring that all hooks sink to below 100 m. The first and last hooks of each deep set basket of gear consistently fished at just below 100 m (average 1st hook depth for all sets was 105 m), but control set gear consistently fished from about 40 m of depth. The average middle hook depths (assumed to be maximum depths of gear) of each basket were 251 m for deep set gear and 211 m for control set gear, thus the deep set method does not dramatically change the general vertical sag profile of a basket of gear, but simply shifts the whole profile down about 60 m at the first hook and 40 m at the middle hook. The deep set method effectively placed all of a set's hooks at depths where bigeye tuna were more likely to be encountered. The results have shown that the deep set technique does work and would be practical to incorporate into existing fishing practices in Hawaii's tuna longline fleet without jeopardizing catch rates of bigeye tuna.

CONFRONTING MISLEADING, EXAGGERATED, AND FALSE INFORMATION ON STATUS OF FISH STOCKS, FISHERIES, AND "HEALTH" OF MARINE ECOSYSTEMS

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Four years ago, Myers and Worm[2] reported in the journal *Nature* an excess of 90% depletion of world-wide stocks of tunas and other large predatory fishes by commercial fisheries. Myself and other scientists involved in assessment and management of tuna populations in the Pacific recognized that the analysis was fraught with error. Most of the core Pacific Ocean habitat of key species was excluded in the analysis. Among the species-specific results, the southern albacore tuna population was said to be in grievous state, whereas the Pacific bigeye tuna population was said to be in relatively good condition. However, on the basis of integrated analysis of all available data we estimate the reverse to be true. In this case we expect that management measures implied by the Myers/Worm analysis are likely to be inadvisable.

We sent a group letter to the editor of *Nature* explaining our objections, but it was rejected because it did not "take our knowledge forward in some discernable way". It then took us two years to get *Nature* to publish a much cut down reply[3] to Myers and Worm. The saga of our attempts to rectify the public record is indicative of evident bias on the part of the editors of *Nature*. In the process, we have discovered that many articles that exaggerate the ill effects of fisheries on fish populations, endangered species, and marine ecosystems have been published in *Nature* and other prominent scientific journals such as *Science*. At the same time, these journals have been reluctant to accept manuscripts that attempt to correct the record. These journals appear to be guided by a policy of ecological political correctness that trumps scientific correctness.

There is some good news. A more extensive response to Myers and Worm was recently accepted and published in *Science*[4] However that news is tempered somewhat by a report also published in S*cience* at approximately the same time[5] giving a hyped up prognosis of collapse of the world's fisheries within 50 years.

Unfortunately, spinning of science for political ends is widespread in more fields than fisheries and is promulgated in more ways than publications in a few prestige journals. The abuse, misuse, and disregard of science are reflective of social and political currents in our society that are beyond what a small group of fishery scientists can deal with. But given that management policies in fishery management agencies are affected by the popular public record, it seems incumbent on us to do what we can to keep that record straight.

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[1] The opinions expressed herein are those of the presenter and do not necessarily reflect those of NOAA, the National Marine Fisheries Service or any of their subsidiaries

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