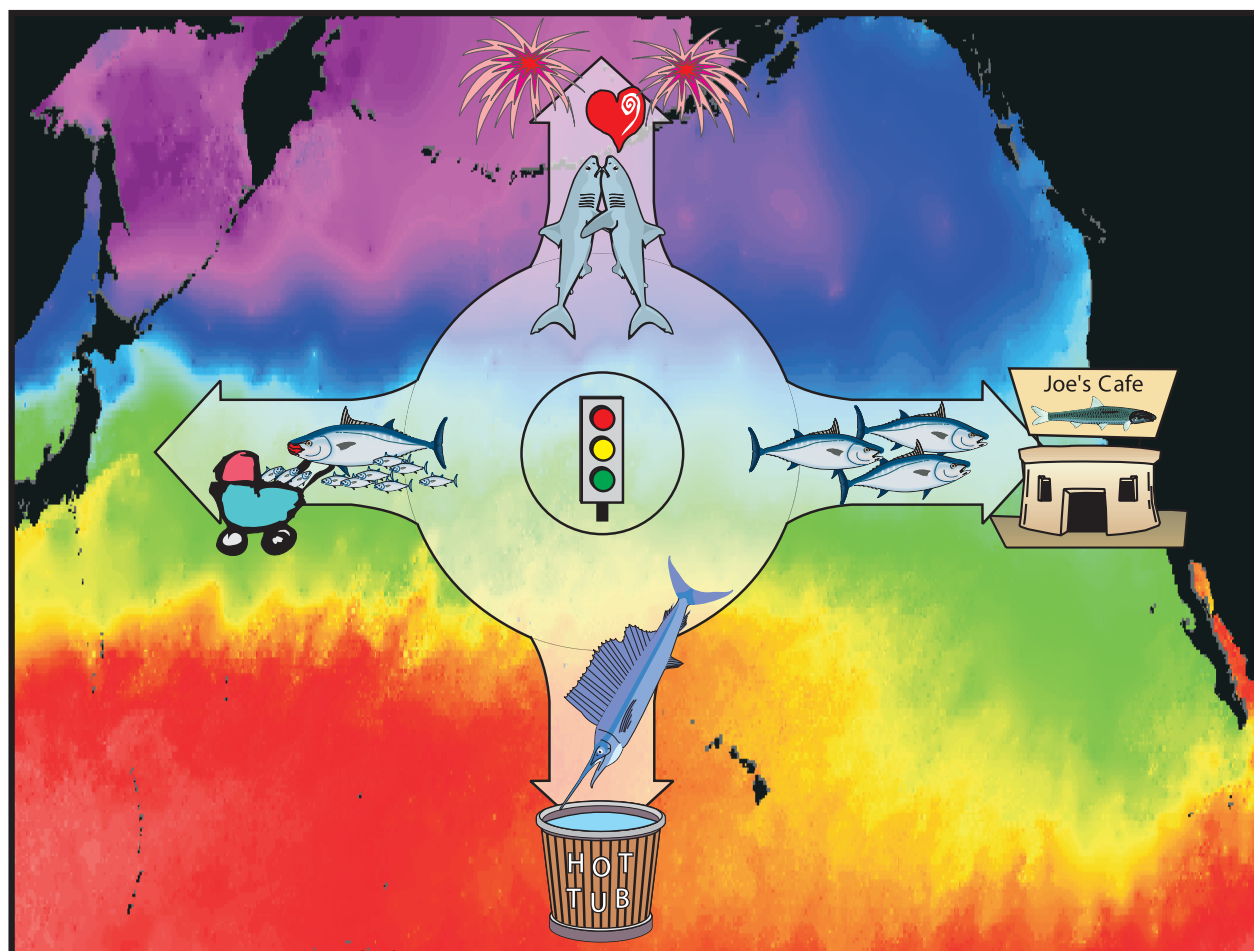# Proceedings of the 57th Annual Tuna Conference
Lake Arrowhead, California, May 22-25, 2006

What do Large Pelagics Want?
The Motivations for Migration
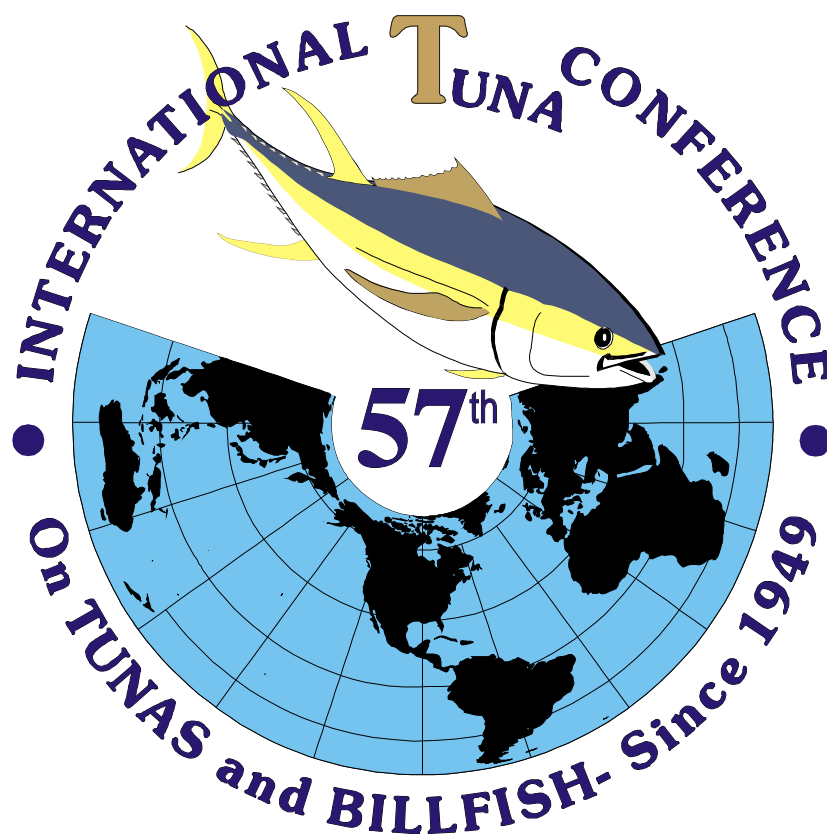

Russ Vetter and Suzy Kohin, Co-chairs

Proceedings of the 57th Annual Tuna Conference

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PREFACE

Welcome to the 57th Tuna Conference. The history of the Tuna Conference has been to provide an informal forum for scientists from around the world to exchange recent research findings on the biology of tuna and tuna-like species, the operation of the various fisheries for tuna and tuna-like species, and the ecosystems that support these remarkably productive fisheries. This year's attendees represent seven nations and a handful of international management bodies. The free and open exchange of ideas has been the key to the Conference's past success.

This year the theme of the conference is **"What do large pelagics want? The motivations for migration."** Recent technical advances in the study of large pelagics have provided new insights into the empirical description of the movements of highly migratory species. However, future advances will depend on a functional understanding of the motivations for migration, and determination of the variability on the one hand, or predictability on the other, of migratory behaviors. For example, which movements are obligate, (movements to spawning grounds?) and which are environmentally determined, (foraging movements to Eastern Boundary currents?). Newer technologies such as the molecular identification of eggs and larvae, biochemical indicators of physiological limits, hydroacoustic sampling of prey fields, and spatial analysis of landings with respect to environmental indices can be integrated with tracking studies for a fuller understanding of spawning, feeding, predator avoidance and the distribution of large pelagic fishes. True biological understanding of the motivations and plasticity of migration patterns should improve prediction, and facilitate implementation of fishery management and ecosystem conservation measures.

The Conference is also hosting two panel sessions addressing (1) ecosystem based science and management and (2) tuna fishery economics and fleet capacity. We feel these sessions are timely, given the move of international management bodies to work together and to consider fisheries in an ecosystem context. The panels draw on representatives from NOAA Fisheries, ICCAT, IATTC and WCPFC, and we encourage all attendees to participate in the discussions. We are grateful to Brad Wiley, Rebecca Lent and Bill Fox for organizing and moderating the Ecosystem Panel. Likewise, we thank Joe Terry and Dale Squires for organizing the Fleet Capacity Panel.

Five student scholarships were awarded this year. The *Manual Caboz Memorial Scholarship* was awarded to Sarah Glaser for her research on "Predation by juvenile albacore in the California Current system and impacts on growth". The four additional scholarships were awarded to John Richert for "Spatio-temporal variability in the trophic ecology of large pelagic fishes of the southern Gulf of California", Daniel Cartamil for "Acoustic telemetry studies of common thresher shark (*Alopias vulpinus*) movement patterns in the Southern California Bight", Luis Antonio Valdovinos-Jacobo for "Conceptual migratory model of Monterey Spanish mackerel (*Scomberomorus concolor*) in the Gulf of California", and Dámaris López-Medina for "Spatial-temporal variability of yellowfin tuna catches in adjacent waters to the Islas Marias, Mexico". These students demonstrated impressive research goals and progress, and we wish them continued success in their graduate careers.

Hosting the Tuna Conference is an arcane and tradition bound process, and cannot be carried out without the assistance of a team of volunteers. The conveners extend a special thank you to Anne Allen, keeper of the flame and executive organizer of the 57th Tuna Conference. We also thank John Sibert, Emmanis Dorval, Sarah Glaser, Barbara Block, Kevin Weng, Marty Golden, Bill Bayliff, Allison Routt and Jenny McDaniel for moderating the scientific sessions. Bob Humphreys, Bob Olsen and Bill Perrin served as members of the student Scholarship Committee. As always, Rand Rasmussen has done an excellent job maintaining the Tuna Conference web site. We thank Kim Holland, Russell Ito and Dave Itano for continuing the sashimi cutting tradition to help supply the Poster Sashimi Social. And we thank a whole team of IATTC and SWFSC staff members, too numerous to be named here, for general assistance with transporting supplies and people to this year's Conference.

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

The abstracts contained in these proceedings were edited solely for formatting. The abstracts are considered reports of preliminary work, and if readers would like further information about the presentations or to cite information or ideas contained in the abstracts, they should contact the individual authors directly.

In closing, we would like to thank you all for participating. Through all of your presentations, posters, and informal discussions around the poker table and jacuzzi, we hope you find the Conference fruitful and, most importantly, that you enjoy yourselves!

Russ Vetter and Suzy Kohin
57th Tuna Conference Co-chairs

AGENDA

Monday, 22 May 2006

13:00   Registration Opens in the Library

SESSION 1: Acoustic Telemetry
(Moderator: John Sibert)

14:00   Welcome and Introduction

14:10   SWIMMING DEPTHS OF DIFFERENTLY SIZED YELLOWFIN TUNA
        OCCURRING IN MIXED-SIZED AGGREGATIONS — Kim Holland, David
        Itano, and Laurent Dagorn

14:30   FINE-SCALE TEMPORAL STRUCTURE OF FAD-ASSOCIATED
        AGGREGATIONS OF SUB-ADULT YELLOWFIN TUNA — David Itano, Kim
        Holland, and Laurent Dagorn

14:50   YELLOWFIN TUNA AGGREGATION AT DEEPWATER PETROLEUM
        PLATFORMS IN THE NORTHERN GULF OF MEXICO — Randy Edwards and
        Kenneth Sulak

15:10   ACOUSTIC TELEMETRY STUDIES OF COMMON THRESHER SHARK
        (*Alopias vulpinus*) MOVEMENT PATTERNS IN THE SOUTHERN
        CALIFORNIA BIGHT — Daniel Cartamil, Nick Wegner, Scott Aalbers, Chugey
        Sepulveda, Andres Baquero, and Jeffrey Graham

15:30   Coffee Break

SESSION 2: Life History Studies, Part I
(Moderator: Emmanis Dorval)

15:50   A REVIEW OF EARLY LIFE HISTORY STUDIES OF TUNAS CONDUCTED
        AT THE ACHOTINES LABORATORY — Daniel Margulies, Vernon Scholey,
        Jeanne Wexler, Robert Olson, Sharon Hunt, Jenny Suter, and Maria Santiago

16:10   OCCURRENCE OF BILLFISH EGGS AND LARVAE IN WATERS OFF THE
        KONA COAST OF THE ISLAND OF HAWAII — Robert Humphreys, Jr., John
        Hyde, Syd Kraul, Eric Lynn, Michael Musyl, Russ Vetter, and Andrew West

16:30   AGE, GROWTH, AND REPRODUCTIVE BIOLOGY OF BIGEYE TUNA IN
        THE EASTERN AND CENTRAL PACIFIC OCEAN — Daniel Fuller and Kurt
        Schaefer

*Presenter if not senior author

16:50 PRELIMINARY ANALYSIS ON GROWTH RATES AND VERTEBRAL BAND DEPOSITION IN THE SHORTFIN MAKO SHARK, *Isurus oxyrinchus*, BASED ON OXYTETRACYCLINE LABELED SPECIMENS — Darlene Ramon and Susan Smith

17:10 Registration and Conference Center Check-in Continued

17:30 'Welcome Gathering Party' in the Tavern (Continued After Dinner)

18:30 Dinner
       Socializing in the Tavern

Tuesday, 23 May 2006

 8:00 Breakfast

SESSION 3: Catch rates
   (Moderator: Sarah Glaser)

 9:00 OCEANOGRAPHIC INFLUENCES ON ALBACORE CATCH RATES IN THE AMERICAN SAMOA LONGLINE FISHERY — Réka Domokos, Jeffrey J. Polovina, and Michael P. Seki

 9:20 USE OF CATCH-PER-UNIT-OF-EFFORT DATA OF LONGLINE VESSELS AS INDICES OF ABUNDANCE OF LARGE PELAGIC FISHES — Bill Bayliff

 9:40 CPUE TRENDS FOR BILLFISHES (ISTIOPHORIDAE) IN THE HAWAII-BASED LONGLINE FISHERY — William A. Walsh

10:00 CATCH EFFICACY OF LARGE CIRCLE HOOKS IN THE HAWAII BASED TUNA LONGLINE FISHERY — Daniel Curran, Marti McCracken, and Christofer Boggs

10:20 SPATIAL-TEMPORAL VARIABILITY OF YELLOWFIN TUNA CATCHES IN ADJACENT WATERS TO THE ISLAS MARIAS, MEXICO — Dámaris López Medina and Sofía Ortega García

10:40 Coffee Break

SESSION 4: Anatomy and Physiology
   (Moderator: Barbara Block)

11:00 STUDIES ON THE FINE-SCALE MOVEMENTS AND RESPIRATORY SPECIALIZATION OF THE WAHOO, *Acanthocybium solandri* — Chugey Sepulveda, Nick Wegner, and Scott Aalbers

*Presenter if not senior author

11:20 CRANIAL ENDOTHERMY IN THE MOONFISH (*Lampris guttatus*) — Rosa M. Runcie, Kathryn A Dickson, Heidi Dewar, and Don Hawn

11:40 OLFACTORY ORGANS OF TWO PELAGIC TELEOST FISH–OPAH *Lampris guttatus* AND DOLPHIN FISH *Coryphaena hippurus* — Ralph R. Mana and Gunzo Kawamura

12:00   Lunch

SESSION 5: Ecosystem Studies
(Moderator: Kevin Weng)

13:10 INTEGRATING ENVIRONMENTAL, LONGLINE, TIME-DEPTH RECORDER, AND POP-UP SATELLITE ARCHIVAL TAG DATA TO DESCRIBE THE HAWAII-BASED LONGLINE FISHERY FOR BIGEYE TUNA (*Thunnus obesus*) NORTH OF HAWAII IN THE SUMMER — Evan A. Howell, Donald R. Hawn, and Jeffrey J. Polovina

13:30 FISHERY INDUCED CHANGES IN BIOMASS, SIZE AND TROPHIC LEVEL OF LARGE PREDATORY FISH IN THE PACIFIC OCEAN — John Sibert

13:50 SPATIO-TEMPORAL VARIABILITY IN THE TROPHIC ECOLOGY OF LARGE PELAGIC FISHES OF THE SOUTHERN GULF OF CALIFORNIA — John E. Richert, Rafael Cervántes-Duarte, Rogelio González-Armas, Felipe Galván-Magaña, and A. Peter Klimley

14:10 Coffee Break

PANEL SESSION: Ecosystem Approaches to the Science and
Management of Large Pelagics
(Moderator: William Fox, Jr.)

14:30

Panel Members: Kelly Denit, Martin Hall, Charles Karnella, Rebecca Lent, Allison Routt, Michael Seki, Robert Skillman

16:30

16:30 Poster Session (See List of Posters) and 'Sushi Party' in Lakeview

18:30 Dinner
Socializing in the Tavern

*Presenter if not senior author

Wednesday, 24 May 2006

8:00   Breakfast

SESSION 6: Archival and Satellite Tagging
(Moderator: Marty Golden)

9:00   IDENTIFYING BEHAVIOR OF GIANT BLUEFIN TUNA ON THE SPAWNING
       GROUNDS IN THE GULF OF MEXICO WITH ARCHIVAL TAGS — Barbara
       Block, Steven Teo, Andreas Walli, Andre Boustany, Michael Stokesbury, Charles
       Farwell, Kevin Weng, and Pedro Casthillo

9:20   MOVEMENTS OF JUVENILE NORTH PACIFIC ALBACORE REVEALED BY
       ARCHIVAL TAGS — John Childers, Suzanne Kohin, and John LaGrange

9:40   MOVEMENTS OF BIGEYE AND YELLOWFIN TUNAS IN THE EASTERN
       PACIFIC OCEAN, ASCERTAINED FROM ARCHIVAL TAGS — Kurt Schaefer
       and Daniel Fuller

10:00 MOVEMENTS AND FOCAL AREAS OF TWO LAMNID SHARK SPECIES IN
       THE EASTERN PACIFIC — Kevin Weng, Andre Boustany, Salvador Jorgensen,
       Scot Anderson, Adam Brown, David Holts, Kenneth Goldman, and Barbara Block

10:20 Coffee Break

10:40 TRANS-PACIFIC MIGRATIONS OF PACIFIC BLUEFIN TUNA — Christopher
       Perle, Robyn Matteson, Mike Castleton, Barbara Block, and Chuck Farwell

SESSION 7: Advancements in Electronic Tagging
(Moderator: Bill Bayliff)

11:00 PRELIMINARY TESTING OF A PROTOTYPE POPUP SATELLITE
       ARCHIVAL TAG — Michael Domeier

11:20 PROCESSING AND DISPLAYING OF POP-UP SATELLITE ARCHIVAL
       TAGS (PSAT) DATA WITH *EASy* GEOGRAPHICAL INFORMATION
       SYSTEM — Dale A. Kiefer, Frank J. O'Brien, Vardis M. Tsontos, Chi H. Lam*
       and Michael L. Domeier

11:40 FROM LIGHT MEASUREMENTS TO MOST PROBABLE TRACK — Anders
       Nielsen and John Sibert

12:00 Lunch

*Presenter if not senior author

SESSION 8: Modeling Tuna Movements and Behavior
(Moderator: Allison Routt)

13:10 PARAMETER ESTIMATION PROCEDURE IN THE MODEL OF PELAGIC ECOSYSTEM SPATIAL DYNAMICS WITH APPLICATION TO PACIFIC SKIPJACK — Inna Senina, John Sibert, and Patrick Lehodey

13:30 THE INFLUENCE OF THE ENVIRONMENT ON HORIZONTAL AND VERTICAL BIGEYE TUNA MOVEMENTS INVESTIGATED BY ANALYSIS OF ARCHIVAL TAG RECORDS AND ECOSYSTEM MODEL OUTPUTS — Gwenhael Allain, Patrick Lehodey, David Sean Kirby, and Bruno Leroy

13:50 FOR AN ENLIGHTENED TUNA, THE GREATEST JOURNEY BEGINS WITH A SINGLE STEP: MODELING TUNA NAVIGATION AND MOVEMENT — Jay Willis

SESSION 9: Economics of Tuna Fisheries
(Moderator: Jenny McDaniel)

14:10 THE FORTUNES OF FISHES AND FISHERS: THE POLITICAL ECONOMY OF INNOVATION IN ATLANTIC RESOURCE MANAGEMENT — D.G. Webster

14:30 SPATIAL MODELING OF THE TRADEOFF BETWEEN SEA TURTLE TAKE REDUCTIONS AND ECONOMIC RETURNS TO THE HAWAII LONGLINE FISHERY — Shichao Li, Minling Pan, and Samuel G. Pooley

14:50 MONITORING TRENDS IN U.S. ATLANTIC BLUEFIN TUNA LANDINGS AND ATLANTIC AND PACIFIC BLUEFIN TUNA TRADE — C. Dianne Stephan, Bradley S. McHale, Kathy Goldsmith, and Mark Murray-Brown

15:10 Coffee Break

PANEL SESSION: Fleet Capacity and the Economics of Tuna Fisheries
(Moderator: Joe Terry)

15:30

Panel Members: Brian Hallman, Charles Karnella, Rebecca Lent, Dale Squires, and Joe Terry

17:30

18:30 Dinner – Tuna Barbeque
Socializing in the Tavern / Campfire at Amphitheater

*Presenter if not senior author

Thursday, 25 May 2006

8:00   Breakfast

SESSION 10: Diet Studies
(Moderator: Suzy Kohin)

9:00   FOOD AND FEEDING HABITS OF THE BLUE SHARK, *Prionace glauca*, CAUGHT OFF ENSENADA, BAJA CALIFORNIA, MEXICO — Unai Markaida and Oscar Sosa-Nishizaki*

9:20   DIET DIFFERENCES AMONG THREE SPECIES OF PELAGIC SHARKS INHABITING THE CALIFORNIA CURRENT: THE SHORTFIN MAKO (*Isurus oxyrinchus*), BLUE (*Prionace glauca*), AND THRESHER (*Alopias vulpinus*) SHARKS — Antonella Preti, Susan Smith, Darlene Ramon, and Suzanne Kohin

9:40   PREDATION BY JUVENILE ALBACORE IN THE CALIFORNIA CURRENT SYSTEM AND IMPACTS ON GROWTH — Sarah Glaser

10:00   FEEDING HABITS OF THE LONGNOSE LANCETFISH (*Alepisaurus ferox*) IN THE WESTERN INDIAN OCEAN — Evgeny V. Romanov, Michel Potier, Veniamin V. Zamorov, Richard Sabatié, Yves Cherel, Francis Marsac, and Frederic Ménard

10:20   Coffee Break

SESSION 11: Life History Studies, Part II
(Moderator: Russ Vetter)

10:40   GENETIC STOCK STRUCTURE AND INFERRED MIGRATORY PATTERNS OF SKIPJACK TUNA (*Katsuwonus pelamis*) AND YELLOWFIN TUNA (*Thunnus albacares*) STOCKS IN SRI LANKAN WATERS — Sudath T. Dammannagoda and P.B. Mather

11:00   CONCEPTUAL MIGRATORY MODEL OF MONTEREY SPANISH MACKEREL (*Scomberomorus concolor*) IN THE GULF OF CALIFORNIA — Luis A.Valdovinos-Jacobo, C. Quiñonez-Velazquez, and G. Montemayor-López

11:20   SENSITIVITY ANALYSES FOR TUNA STOCK ASSESSMENTS — Simon Hoyle

11:40   Business Meeting

12:00   Lunch

13:00   End of Conference

*Presenter if not senior author

LIST OF POSTERS

mtDNA VARIABILITY OF EASTERN PACIFIC DOLPHINFISH *Coryphaena hippurus*—Píndaro Díaz-Jaimes, Manuel Uribe-Alcocer, and Sofía Ortega-García

EVALUATING THE IMPORTANCE OF OCEANOGRAPHIC, BIOLOGICAL AND FISHERY CONDITIONS IN RELATION WITH EASTERN PACIFIC YELLOWFIN TUNA, *Thunnus albacares*, RECRUITMENT—Michel Dreyfus-León and Mark N. Maunder

FEEDING HABITS OF PACIFIC BLUEFIN TUNA OFF THE WESTERN COAST OF BAJA CALIFORNIA, MEXICO—Sofía Ortega-García, Arturo Tripp-Valdez, Rubén Rodríguez-Sánchez, and Marcela Zúñiga-Flores

CANNIBALISM WITHIN LONGNOSE LANCETFISH (*Alepisaurus ferox*) POPULATION IN THE WESTERN INDIAN OCEAN—Evgeny V. Romanov, Michel Potier, Veniamin V. Zamorov, Francis Marsac, Pascal Bach, and Frederic Ménard

CLIOTOP — CLimate Impacts on Oceanic TOp Predators—John Sibert

ELECTRONIC TAGGING DATA REPOSITORY—John Sibert and Johnoel Ancheta

MERCURY LEVELS IN THE COMMON THRESHER AND SHORTFIN MAKO FROM SOUTHERN CALIFORNIA—Seung H. Suk, Susan E. Smith, and Darlene A. Ramon

*Presenter if not senior author

SWIMMING DEPTHS OF DIFFERENTLY SIZED YELLOWFIN TUNA OCCURRING IN MIXED-SIZED AGGREGATIONS

Kim Holland[1], David Itano[2] and Laurent Dagorn[3]

Hawaiian Institute of Marine Biology (HIMB), University of Hawaii[1]
Pelagic Fisheries Research Program (PFRP), University of Hawaii[2]
Institute de recherche pour le développement (IRD), Seychelles, Indian Ocean[3]

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It has been previously hypothesized that tuna in mixed aggregations will segregate by size, with smaller fish tending to be found at shallower depths. Whether or not such size-dependant vertical separation occurs could have practical ramifications in terms of strategies for reducing the take of unwanted juvenile tuna and by-catch. To test if this type of vertical separation occurs and if so, to what extent, we equipped two different size classes (< 40 cm and > 60 cm FL) of yellowfin tuna with depth-sensitive acoustic pingers. All the fish captured and tagged were in mixed-size aggregations associated with a Hawaiian anchored FAD. Data analysis was restricted to periods of time when both size classes were simultaneously present at a single FAD. Preliminary results of this analysis will be presented and discussed.

FINE-SCALE TEMPORAL STRUCTURE OF FAD-ASSOCIATED AGGREGATIONS OF SUB-ADULT YELLOWFIN TUNA

David Itano[1], Kim Holland[2], and Laurent Dagorn[3]

Pelagic Fisheries Research Program (PFRP), University of Hawaii[1]
Hawaiian Institute of Marine Biology (HIMB), University of Hawaii[2]
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Recent analyses of FAD-associated yellowfin tuna tagged with coded acoustic transmitters showed that over 65% of the tagged fish departed the FAD within the same 24-hour period. That is, at day-length scales, behavioral synchronicity was demonstrated by a majority of the tagged fish present in the FAD aggregation. Notwithstanding possible problems with "collisions" of the acoustic signals when several tagged fish are simultaneously present at a FAD, it is possible to analyze these 'presence/absence' data to discern whether there is finer-scale behavioral synchronicity in departures and arrivals within the tagged population of fish. Such synchronicity would indicate that there may be 'sub-schools' of tuna present in the larger aggregation. This paper will discuss preliminary results of this fine-scale temporal analysis.

YELLOWFIN TUNA AGGREGATION AT DEEPWATER PETROLEUM PLATFORMS IN THE NORTHERN GULF OF MEXICO

Randy E. Edwards[1] and Kenneth J. Sulak[2]

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Recently, oil and gas production in the northern Gulf of Mexico has expanded into deep waters of the outer continental shelf, where the petroleum structures act as FADs for tunas and other species. We studied aggregation patterns of yellowfin tuna (YFT) around a large (179 m long x 29 m diameter) spar platform (Murphy Oil Co. *Medusa*) 160 km south of New Orleans and 69 km off the Mississippi delta moored in 678 m depth, to which we attached four Vemco V2 automatic receivers (141-d deployment), separated by about 90º around the cylindrical platform at 9 m depth. We tagged 31YFT (mean length = 108 cm CFL) at *Medusa* with surgically implanted Vemco V16-5H-01-R04K (40-114 sec, nominal 474 d) coded acoustic transmitter tags, over a 7-d period in mid July, 2005.

Two fish escaped after frantic, spasmodic struggling before suturing was completed, and they were not detected except briefly immediately after escape. Four of the 29 other YFT were detected only briefly after release (except one fish detected four days later for only one ping). Of the other 25 YFT, 10 never returned after their first day-scale absence, nine returned one time, four two times, four three times, and one four times. Periods between first and last detections were 1-3 d (2 fish), 3-7 d (4), 1-2 wk (8), 2-4 wk (3), >4 wk (8). Longest period between first and last detection was 78 d. Longest continuous presence was 32 d, and longest interval between visits was 73 d. The last detection was in early October (77 days after tagging), a time of year after which YFT normally are no longer abundant at the deepwater petroleum platforms and begin to become abundant at natural and man-made structures in shallower, shelf waters.

While present, many fish generally tended to be continuously detected at the platform, without showing distinct day-on/night-off (DO/NO) patterns, but this may have been influenced by the fact that area around the platform was illuminated at night by the many lights on the platform. During a week including the day of the full moon and the following six days, 17 fish were present (10 for all 7 d, and five for 5-6 d) without DO/NO patterns. However, during the subsequent week of the new moon, five of six fish present showed clear DO/NO patterns, with the sixth present almost continually except for short (< 4 hr) absences that occurred only at night.

Only a few pairs of fish departed and returned synchronously after absences of at least four hours, suggesting that they were in the same school of fish. However, there was only one instance of synchronous departure and return after day-scale absence, and that was after only two days of absence.

In general, the results indicate that most fish were highly associated with the platform, with many present for relatively long, continuous periods without day-scale absences early in the monitoring period; many returning for periods of several days after day-scale absences; and several returning after long absences. This may reflect the fact that *Medusa* is relatively large (compared to FADs) and isolated (nearest deepwater platform 31 km offshore, no distinct bathymetric features in the area, and normally no nearby major oceanographic features such as current systems). Overall, the pattern of residence and absence was dissimilar to other, disparate patterns reported in comparable studies of YFT at FADs and seamounts, suggesting that YFT aggregation, residence, movement, and migration patterns are complex and vary greatly from location to location.

ACOUSTIC TELEMETRY STUDIES OF COMMON THRESHER SHARK (*Alopias vulpinus*) MOVEMENT PATTERNS IN THE SOUTHERN CALIFORNIA BIGHT

Daniel Cartamil[1], Nick Wegner[1], Scott Albers[1], Chugey Sepulveda[2], Andres Baquero[3], Jeffrey Graham[1]

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The largest commercial shark fishery in California waters is for the common thresher shark, *Alopias vulpinus*. We used acoustic telemetry to study the fine-scale movement patterns and habitat preferences of the common thresher in the Southern California Bight. One juvenile (fork length, FL: 84 cm) and eight sub-adult or adult thresher (FL: 122 to 203 cm) sharks were tagged with temperature and depth sensing acoustic transmitters and tracked for up to 49 h. Temperature-depth profiles were made every 2-3 h to characterize the thermal structure of the water column. Position and depth data were plotted in GIS and analyzed in relation to oceanographic data and time of day. Larger threshers utilized areas offshore of the continental shelf, while the juvenile shark remained in shallow waters over the continental shelf. All sharks displayed highly directed movements over entire tracks or extended portions of tracks, although there was no consistent direction of travel among the different sharks. Horizontal rate of movement (ROM) of the eight sub-adult or adult sharks averaged 2.15 ± 0.46 km h^{-1} (mean $\pm$ SD), and was significantly higher than ROM of the juvenile shark (1.45 ± 0.31 km h^{-1}). ROM peaked at dawn (2.61 ± 0.36 km h^{-1}), and generally decreased until sunset, as did linearity of shark movements. Maximum ROM for all sharks was 4.42 km h^{-1}. No relationship was found between ROM and FL for the larger sharks. Diurnal movements of several sharks were characterized by repeated vertical excursions below the thermocline into waters less than 10° C (maximum dive depth of 217 m). Nocturnally, local thermocline depth appears to have a strong limiting effect on the vertical distribution of common thresher sharks, and thus affects their susceptibility to the drift gillnet fishery.

A REVIEW OF EARLY LIFE HISTORY STUDIES OF TUNAS CONDUCTED AT THE ACHOTINES LABORATORY

Daniel Margulies, Vernon Scholey, Jeanne Wexler, Robert Olson, Sharon Hunt,
Jenny Suter, and Maria Santiago

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In this paper, we review the research conducted on tunas at the Inter-American Tropical Tuna Commission's (IATTC) Achotines Laboratory in Panama from 1984 to the present.

Research on tropical scombrids at the Achotines Laboratory has involved two distinct phases. The first phase of research was directed predominantly at coastal, tropical scombrids, mainly black skipjack (*Euthynnus lineatus*), bullet and/or frigate tunas (*Auxis* spp.), and sierra (*Scomberomorus sierra*), during the period from 1984 to 1995. From 1996 to present, the focus of research shifted to the reproductive biology and early life history of yellowfin tuna (*Thunnus albacares*), utilizing eggs spawned by captive yellowfin broodstock.

Early studies of coastal species from 1984 to 1995 contributed new information on feeding, growth, and survival during early life stages of tropical tunas. We described, for the first time, the growth dynamics and daily growth increments in the otoliths of larval and juvenile tropical scombrids in the Pacific Ocean; we also developed methods for the collection and husbandry of larvae and juveniles. We provided the first estimates for tropical waters of the incidence of starvation in larval and juvenile scombrids, as well as the first descriptions of visual development in early life stages. Larval surveys, conducted from 1989-1993, provided important insights into the temporal and spatial distribution of larval scombrids in the Panama Bight.

Beginning in 1996, the IATTC and the Overseas Fishery Cooperation Foundation (OFCF) of Japan initiated studies of the reproductive biology and early life history of yellowfin tuna at the Achotines Laboratory.   A spawning population of captive yellowfin was developed and experimental studies were conducted on the reproductive biology of adults as well as the development, growth, and survival of egg, larval and juvenile stages. The studies of yellowfin have continued to the present.

We summarize the key research findings from these studies and their contributions to our understanding of the reproductive biology, larval ecology and pre-recruit survival of tropical scombrids. We also discuss recommendations for future research on the early life history and biology of tropical tunas at the Achotines Laboratory.

OCCURRENCE OF BILLFISH EGGS AND LARVAE IN WATERS
OFF THE KONA COAST OF THE ISLAND OF HAWAII

Robert Humphreys Jr.[1], John Hyde[2], Syd Kraul[3], Eric Lynn[4],
Michael Musyl[5], Russ Vetter[4], and Andrew West[6]

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Daylight surface tows have collected fertilized eggs of swordfish *Xiphias gladius*, blue marlin *Makaira nigricans*, and shortbill spearfish *Tetrapterus angustirostris* during five ~1-week research cruises. Tows were conducted within 1 to 25 nmi off the Kona coast of the Island of Hawaii. Suspected billfish eggs were sorted from each tow; then measured, photographed, and identified using a multiplex-PCR technique developed by John Hyde. Billfish eggs were captured during three cruises (May 2003, July 2004, and May-June 2005) and absent during September 2004 and March 2005. Swordfish eggs predominated in each of the three successful cruises (n=54, 47, 178) while blue marlin (n=0, 8, 61) and shortbill spearfish (n=8, 5, 30) were less frequent. These eggs were predominantly captured within 3-6 nmi off the Kona coastline and overlap with the larval distribution of these species. Swordfish and shortbill spearfish eggs were encountered primarily off the central and southern Kona coast while blue marlin eggs occurred primarily off the northern and central portions. Mean diameter of swordfish eggs (1.71 mm) exceed those of shortbill spearfish (1.35 mm) and blue marlin (1.30 mm). The May-June 2005 cruise was unique in both the presence of eggs of all three billfish species and the highest egg catch rates for each of these species. For each of the three species during the three successful cruises, all eggs were found to be in an advanced stage of development (embryos surrounded yolk from 180° to slightly beyond 270°). Attempts during the May-June 2005 cruise to rear captured eggs at a shoreside aquaculture facility met with limited success. Egg mortality was high with ~20 of 84 swordfish eggs and 1-2 of 42 blue marlin eggs surviving through hatching. None of the larvae survived beyond 2 days post-hatch.

AGE, GROWTH, AND REPRODUCTIVE BIOLOGY OF BIGEYE TUNA IN THE EASTERN AND CENTRAL PACIFIC OCEAN

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Tagging and oxytetracycline hydrochloride (OTC)-marking experiments conducted in the central and eastern Pacific Ocean (EPO) demonstrated that bigeye tuna, in the length range of 38 to 135 cm, deposit daily increments in their sagittal otoliths. Frontal sections, along the primordium to the postrostral axis, of sagittal otoliths provided an optimal counting path for resolving daily increments, with light microscopy, for fish up to 4 years of age. The numbers of increments counted in the sagittae of 254 bigeye (30 to 149 cm), captured by purse-seine vessels in the EPO between 2000 to 2004, were used as direct estimates of their ages in days. The growth of bigeye in the EPO is described in terms of their length, based on fitting the von Bertalanffy model to the length-at-age data. Growth of bigeye in the eastern Pacific is also estimated from fitting a von Bertalanffy growth model to a data set for 205 bigeye tagged in the EPO and recaptured between 2000 to 2004. The growth rate derived from the tagging data was compared with that from the length-at-age data, and the two independent sets of data show similar decreases in growth rate with increasing length.

The reproductive biology of bigeye tuna was investigated by sampling 1,986 fish caught by purse-seine vessels and 124 fish caught by longline vessels in the eastern and central Pacific Ocean during February 2000 through March 2003. Histological evaluations of ovaries from 683 females provided the foundation for the estimates of length-specific reproductive characteristics. Spawning was observed between about 15°N and 15°S and between about 105°W and 175°W, and occurred during most months of the year in which the sea-surface temperatures exceeded about 24°C. The estimated length at which 50% of the females were mature was 135 cm. The estimated mean relative fecundity was 24 oocytes per gram of body weight. Reproductively active females spawned every 1.3 d. The overall sex ratio deviated from 1:1, due to a preponderance of males.

PRELIMINARY ANALYSIS ON GROWTH RATES AND VERTEBRAL BAND DEPOSITION IN THE SHORTFIN MAKO SHARK, *Isurus oxyrinchus*, BASED ON OXYTETRACYCLINE LABELED SPECIMENS

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Previous studies on the growth of shortfin mako sharks (*Isurus oxyrinchus*) have produced conflicting results. An analysis of fisheries landing data in the Western Atlantic provided a growth curve suggesting relatively rapid growth with deposition of 2 growth band pairs each year (Pratt and Casey 1983). Whereas, marginal increment analysis of vertebrae (Ribol-Carballal et al. 2005) and ageing based on a carbon signal (Campana, et al. 2002) have suggested slower growth and formation of a single band pair each year. Depending upon which growth model is assumed, population dynamic models based on the life history characteristics of the shortfin mako shark will differ markedly. In 1997, a study was begun to examine growth and vertebral band deposition of juvenile shortfin mako sharks using oxytetracycline labeling. Between June 1997 and October 2005, 502 makos were injected with OTC, tagged, and released in the southern California Bight during scientific surveys. Thirty one of the OTC labeled sharks have been recaptured, and vertebral samples were obtained from fourteen. Time at liberty ranged from 7 to 1594 days and the size of OTC-marked fish ranged from 81 to 189 cm FL at time of recapture. Preliminary analyses of the labeled vertebrae indicate the formation and deposition of two band pairs (opaque and semi-translucent) per year distal to the OTC mark. In addition, growth during the time at liberty from these recovered fish, combined with recapture information from a larger scale conventional tagging effort, demonstrates average growth rates of 18 cm/year for juvenile makos (size range of roughly 90-160 cm FL at the time of tagging). Growth rates will also be estimated using length frequency modal progression analysis of data collected from observers of the California and Oregon drift gillnet fishery. The preliminary results suggest that growth of the shortfin mako shark is more rapid than suggested in some of the previous studies with an annual deposition of 2 band pairs per year over the size range of sharks studied.

OCEANOGRAPHIC INFLUENCES ON ALBACORE CATCH RATES IN THE AMERICAN SAMOA LONGLINE FISHERY

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A sudden expansion of the American Samoa longline fishery during the period of 1999-2001 set forward a substantial increase in both fishing effort and albacore (*Thunnus alalunga*) landings, resulting in supplying a significant portion of canned tuna for US consumers. Observed negative trends in longline catch rates from 2002 compelled an investigation of the oceanography and pelagic habitat of the American Samoa fishing grounds, focusing on the EEZ. This research found a possible link between the seasonally and annually varying eastward flowing South Equatorial Counter Current (SECC) and albacore catch rates and locations. The American Samoa fishing grounds is a dynamic region with strong mesoscale eddy activity that shows temporal variability on the scale < 1 week. This variability peaks during March and April – when the SECC is the strongest – and is at least partially fueled by instability resulting from high horizontal shear between the SECC and the westward flowing South Equatorial Current towards the north of the American Samoa EEZ, with a signature of high sea surface height in the northern half of the EEZ relative to that of the southern half. Longline albacore catch tend to be located at the eddy boundaries while albacore catch per effort show intra-annual variability with high catch per effort during May through July relative to catch per effort from August through April. Further, during the May-July period, catch per effort tend to be significantly higher in the northern half than in the southern half of the American Samoa EEZ. This intra-annual variability in catch per effort lags that of the SECC by about two months. Further indication of the possible importance of the SECC for longline performance is the significant drop in eddy variability during the year of 2004 – resulting from a weak SECC – which is accompanied by a substantial drop in albacore catch and CPUE rates, as well as a lack of northward intensification of CPUE, relative to that of 2003.

USE OF CATCH-PER-UNIT-OF-EFFORT DATA OF LONGLINE VESSELS AS INDICES OF ABUNDANCE OF LARGE PELAGIC FISHES

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Catch-per-unit-of-effort (CPUE) data are frequently used as indices of abundance of various species of fish. These estimates of abundance may be biased, however. The possible biases for the pelagic longline fisheries for large predatory fish (mostly tunas, billfishes, and sharks) are discussed. One possible bias, changes in the abundance of prey species, has been nearly overlooked. Removal of a portion of the population of large predatory fish reduces their abundance, which, in turn, presumably increases the abundance of their prey. If that is the case, a large predatory fish would be more likely to become satiated before encountering a baited hook. Accordingly, if the abundance of the large predatory fish is declining the CPUEs would decline even more rapidly, and if it is increasing the CPUEs would increase even more rapidly.

CPUE TRENDS FOR BILLFISHES (ISTIOPHORIDAE) IN THE HAWAII-BASED LONGLINE FISHERY

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Standardized CPUE trends for blue marlin, *Makaira nigricans*, striped marlin, *Tetrapturus audax*, and shortbill spearfish, *T. angustirostris*, from the Hawaii-based longline fishery have remained essentially stable from 1994 through 2005. Although the linear regressions of standardized CPUE against time had significant (all *P*<0.05) negative slopes, this was not considered strong evidence of adverse effects of the fishery on their relative abundance. Rather, each of these species exhibited at least one year with relatively high catch rates in the last decade, with peaks that were influential points in the regression analysis. As such, these points contributed disproportionately to the apparent slightly negative trends. Because these standardized CPUE peaks were associated with low mean weights, we infer that the peaks reflected the presence of recruits in the catch of the longline fishery during these periods. At present, we are attempting to expand the scope of these analyses so as to permit comparisons with other Pacific island-based fisheries.

CATCH EFFICACY OF LARGE CIRCLE HOOKS IN THE HAWAII BASED TUNA LONGLINE FISHERY

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We contracted eighteen vessels within the Hawaii based tuna longline fleet to test the catch efficacy of large circle hooks versus the hooks currently in use by the fishery. The majority of the fleet uses "Japanese" style tuna hooks (3.6 sun <about the same size as most 14/0 circle hooks>), but some of the vessels contracted use "J" style hooks (size 8/0). The large circle hooks we provided were stainless steel (size 18/0) circle hooks made in Korea. Seven of the boats were provided with 10% offset hooks and the other boats were given non-offset hooks. Boats were mandated to alternate hook type throughout every basket of gear and to maintain a 50/50 ratio of circle hooks to their regular hooks. Every trip was accompanied by a National Oceanic and Atmospheric Administration (NOAA) certified observer who collected information on catch by hook type, the daily tally of the total numbers of each type of hook used, and a vessel's ability to follow experimental protocols. To date, 1,205 of 1,976 total contracted sets have been completed. Due to observer funding issues, the experiment was suspended in January of 2006 and its continuation is in doubt. Of the completed sets, 340 have been checked and cleared by the NOAA observer program for our analysis and we hope to receive the rest of the completed set data in the next few months. These results are based on the first 20 trips totaling 300 sets and 610,132 hooks.

Large circle hooks consistently caught a slightly larger proportion of bigeye tuna (*Thunnus obesus*) than any other hook used. Overall, offset large circle hooks caught 54% of bigeye tuna when alternated with 3.6 sun tuna hooks, non-offset large circle hooks caught 53% of bigeye tuna versus the same tuna hooks, and non-offset large circle hooks caught 52% of bigeye tuna versus 48% for "J" style hooks. Catch per unit effort (CPUE) as number of fish per 1000 hooks reflected the relative success of individual sets and showed that CPUE was more dependent on overall success of a fishing operation than hook type. For example, the CPUE of bigeye tuna for offset large circle hooks was 3.42 versus a CPUE of 2.98 for tuna hooks in the same sets, but the bigeye tuna CPUE for the non-offset large circle hooks was only 2.04 versus 1.74 for the same size tuna hooks. Even though CPUE varied by operational success, overall proportions by hook type were consistent regardless of CPUE.

For blue sharks (*Prionace glauca*), large circle hooks (offset and non-offset combined) caught a lower proportion (47%) than other types of hooks (53%). Large circle hooks were also less effective at catching all other species of fish reported including; striped marlin (*Tetrapturus audax*), blue marlin (*Makaira nigricans*), mahi-mahi (*Coryphaena hippurus*), and yellowfin tuna (*Thunnus albacares*). Average fork lengths showed little or no difference by hook type. For example, the average fork length for bigeye tuna was 121.2 cm for large circle hook caught fish and 121.5 cm for all other hook types combined. These preliminary results indicate that large 18/0 circle hooks (which have already been shown to be effective at reducing sea turtle takes) may be a viable replacement for the type of tuna hooks currently in use by the majority of the world's pelagic tuna longline fleets. Large circle hooks show promise in reducing unwanted catch, such as blue sharks, while maintaining the catch of bigeye tuna.

SPATIAL-TEMPORAL VARIABILITY OF YELLOWFIN TUNA CATCHES IN ADJACENT WATERS TO THE ISLAS MARIAS, MEXICO

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Within the large exploitation zone of yellowfin tuna (*Thunnus albacares*) important areas have been detected where the abundance of this resource maintains high levels normally associated with reproduction and feeding. These sites of great abundance are strongly associated with the submarine topography, especially with the presence of islands. The "island mass effect" with elevated primary production may contribute to elevated spawning activity close to islands and archipelagos. The waters adjacent to the Islas Marias are highly productive. It is a zone of traditional importance in the capture of yellowfin tuna, has particular oceanographic characteristics, and the fishing effort is made almost all during the year. We analyzed the relationship between the yellowfin tuna catch recorded by the Mexican tuna purse-seine fleet during 1998-2003 with the chlorophyll-*a* concentration obtained from the remote sensor (SeaWiFS-SeaStar) and submarine topography (Geophysics of North American database). Two groups of vessels operated in the area; >1000 t with a CPUE average of 14.5 t and <1000 t with a CPUE average of 7.1 t. Although during the period analyzed an interannual spatial variability of sets was found, and also a variation in the type of sets (breeze and dolphin), most of them were made around the islands with the greatest concentration of sets made at depths between 200 and 400 meters (continental slope), mainly in front of Cabo Corrientes. The largest fishing effort was made during the second and third quarter during which the largest catches were made. A significant seasonal variation was found in the catch per standard unit effort (CPSUE) and in the chlorophyll-*a* concentration. The highest value of the CPSUE was recorded during the second quarter with an average of 16.7 t per set. Although no correlation between the monthly average of the chlorophyll-a concentration series and the CPSUE was found, a high correlation ($r = 0.73$) was calculated between the two variables with a lag of 2 months when we used an average year ("type year").

STUDIES ON THE FINE-SCALE MOVEMENTS AND RESPIRATORY SPECIALIZATION OF THE WAHOO, *Acanthocybium solandri*

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In 2005 we initiated a fine-scale movement study of the wahoo (*Acanthocybium solandri*) in the eastern Pacific (EP). The goal of the project is to assess the vertical distribution of this species in the EP through the deployment of temperature-depth archival transmitters. 50 Starr ODI DST loggers were surgically implanted in wahoo ranging in size from 117 to 172 cm FL off the coast of Baja California. The wahoo were captured using recreational gear aboard a San Diego based long range sportfishing vessel and the transmitters were surgically implanted in the peritoneal cavity. To date, one recapture has yielded high-resolution temperature-depth data for a thirty-five day period. The data record revealed an average peritoneal cavity temperature of 22.8 ± 0.42 and an average depth of 8.9 ± 7.8 m for the wahoo. Although for most of the depth record the wahoo remained in the upper mixed layer, the greatest depth was 106 m. In addition to the movement data, we also performed studies to assess the degree to which wahoo gills are specialized to permit the O_2 uptake required by fast continuous swimming and to maintain gill rigidity during ram ventilation. Fixed gill tissue and vascular replica gill casts of nine wahoo were examined by both scanning electron microscopy and light microscopy. Wahoo possess larger gill surface areas and shorter gas diffusion distances than most teleosts. Wahoo also have strong filament fusions and inter-lamellar fusions which bind adjacent lamellae on the same filament, but not opposing lamellae on the adjacent filaments as in tunas.

CRANIAL ENDOTHERMY IN THE MOONFISH (*Lampris guttatus*)

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Billfishes, butterfly mackerel, tunas and lamnid sharks have evolved cranial endothermy by convergence. The moonfish (*Lampris guttatus*) shares certain behaviors and characteristics with these fishes: the moonfish migrates vertically within the water column, experiencing a wide range of seawater temperatures and rapid ambient temperature changes, and the temperature of the tissue behind the eyes is elevated above water temperature. The purpose of this study was to identify the heat source and the heat retention mechanism necessary for cranial endothermy in moonfish. Several moonfish heads were dissected, and tissue samples were examined by light microscopy and electron microscopy to identify the heat source and the heat retention mechanism. To visualize and document the three-dimensional arrangement of these structures we used magnetic resonance imaging (MRI). To identify highly aerobic tissue that may serve as the heat source we measured citrate synthase activity from each extra-ocular muscle. The proximal lateral rectus extra-ocular muscle (PLRM) appears to be the primary heat source because it is adjacent to the brain, has a high aerobic heat production capacity, and is perfused by blood vessels arranged as a putative counter-current heat exchanger. We also found that the PLRM is well insulated from the ambient water by a thick layer of fat that overlies the PLRM, thereby reducing conductive heat loss from the PLRM. These findings reveal that moonfish possess a heat source and a heat retention mechanism necessary for cranial endothermy. All other teleost fishes known to exhibit cranial endothermy are in the suborder Scombroidei, and *Lampris guttatus* is the most divergent teleost species documented to elevate cranial temperatures. Thus, this study contributes to understanding the convergent evolution of endothermy in fishes. Research is supported by the National Institutes of Health Minority Scientist Development Program (NIH grant # R25 GM56820).

OLFACTORY ORGANS OF TWO PELAGIC TELEOST FISH–OPAH *Lampris guttatus* AND DOLPHIN FISH *Coryphaena hippurus*

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Previous studies have provided evidence that olfactory systems play a vital role in fish behavior. In pelagic fish, little tuna and yellowfin tuna were attracted to chemical attractants; yellowfin tuna also formed a chemical search image in procurement of food as a convenient system that enables the species to switch to a major food source while ignoring food source of little abundance. In this investigation we observed the olfactory organs of two pelagic teleost species–opah (*Lampris guttatus*) and dolphin fish (*Coryphaena hippurus*). Gross morphological observation showed that in both fish the paired olfactory organ is situated on the snout. Anterior and posterior openings are present in both fish. Numerous number of lamellae radiate around a short raphe. Olfactory ventilation sac is present in both fish but is more developed in opah. Olfactory sensory epithelium is found intermingled as islets or patches within the nonsensory epithelium. Ciliated olfactory receptor neuron and microvillous olfactory receptor neuron are observed in both fish with the former being more abundant. The population of receptor neurons is estimated to be ~3.0 and ~7.7 million in opah and dolphin fish respectively. Ciliated nonsensory cell is rare or absent in all lamellae examined while goblet cells are observed in both sensory and nonsensory epithelia. Epidermal cells forming microridge of finger-print like patterns are the primary cells forming the nonsensory epithelium. The results indicated that both species have a functional olfactory systems best evolved for pelagic way of life.

INTEGRATING ENVIRONMENTAL, LONGLINE, TIME-DEPTH RECORDER, AND POP-UP SATELLITE ARCHIVAL TAG DATA TO DESCRIBE THE HAWAII-BASED LONGLINE FISHERY FOR BIGEYE TUNA (*Thunnus obesus*) NORTH OF HAWAII IN THE SUMMER

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An emerging fishery of bigeye tuna (*Thunnus obesus*) has been observed using Hawaii-based longline data collected from 30º N in the 2002−2004 summer months. Time-at-depth measurements of six bigeye tuna that were obtained by archival tags showed a bimodal depth distribution in this area, with more than 20% of their time spent between 0−50 m and more than 20% between 300−400 m. Horizontal movement estimates show that these tagged bigeye tuna spent 80% of the time in fishing grounds at 145º − 164º W, 25º −32º N from August to October 2003. These fishing grounds at 30º N are warm and stratified with no apparent physical nutrient input during the summer, yet large chlorophyll *a* bloom events are often observed. These blooms are heavily made up of mats of the diatom *Rhizosolenia,* which reportedly provides nitrogen to the ecosystem through vertical migration or endosymbiotic nitrogen fixation. This infusion of nutrients may form a forage base for higher trophic levels, which coupled with other preferential habitat conditions, may explain the apparent residence of bigeye tuna in this region during the summer.

FISHERY INDUCED CHANGES IN BIOMASS, SIZE AND TROPHIC LEVEL OF LARGE PREDATORY FISH IN THE PACIFIC OCEAN

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Integrated stock assessments reconstruct the history of the biomass and age structure of the fish populations. We use stock assessment results to explore changes in recruitment, biomass, size composition and trophic status of several tuna and associated species in the Pacific Ocean. Recruitment has varied substantially in the last 50 years. Fishery-induced changes in biomass vary from species to species. The total and adult biomass of some species has declined to less than 40% and 25% respectively of that predicted in the absence of fishing, while the biomass of other species has increased. Size spectra have changed over time with the largest fish largely disappearing from the population. More recent changes in the fishery have extended exploitation from the largest fish to the entire size spectrum. Changes in trophic level of the large predators not changed substantially. We conclude by generally discussing management responses.

SPATIO-TEMPORAL VARIABILITY IN THE TROPHIC ECOLOGY OF LARGE PELAGIC FISHES OF THE SOUTHERN GULF OF CALIFORNIA

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Seamounts and offshore islands in the southern Gulf of California are oceanic "hot spots" that attract an abundance and diversity of pelagic fishes. The potential of these topographic features as marine protected areas emphasizes our need to understand the role they play within the ecosystem. We are currently integrating oceanographic survey, fisheries observation, and ecological analyses to examine how and why pelagic fish utilize seamounts in the southern Gulf. The current study area spans a 200 km transect of offshore waters along the eastern coast of Baja California Sur, Mexico. Three major seamounts and several lesser banks are surveyed along with the open-water areas between these pinnacles in order to compare how fishes feed in different pelagic habitats.

Primary productivity and plankton abundance are measured seasonally throughout the study area to record spatial and temporal variability at the base of the pelagic food chain and identify locally productive habitats in the region. Fisheries catch data is used to track species' seasonal migrations into the southern Gulf, monitor movements between local hot spots, and relate these movements to oceanographic conditions. Gut contents of ten large, pelagic species, including tunas, billfish, jacks, and dolphinfish, are simultaneously analyzed to determine dietary overlap and detect dissimilar feeding habits between species. Dietary analyses are also used to determine differential feeding between sites. Gut contents collected at seamounts are being compared with each other to determine if differences occur between seamounts. These locations are then compared with samples collected from open-water areas. These diet analyses are related to oceanographic surveys in order to compare feeding at sites with higher and lower primary productivity.

We are also using stable isotopes to determine trophic structure among pelagic fish communities. Quantitative trophic position of a given species is calculated using the ratio of nitrogen stable isotopes ($\delta^{15}N$) in body tissues and an appropriate baseline. Spatial and temporal variability in the trophic positions of a variety of pelagic organisms are used to depict variation in the food chain throughout the study area and across seasons. In addition, oceanic nitrate levels and stable isotope data from lower trophic levels are being analyzed in order to construct a nitrogen isotopic map for the region, to determine the utility of stable isotopes in the study of pelagic fish migration and food webs, and to encourage appropriate interpretation of stable isotope data for upper trophic levels.

PANEL SESSION:

**ECOSYSTEM APPROACHES TO THE SCIENCE
AND MANAGEMENT OF LARGE PELAGICS**

*Panel***:**   Dr. William Fox, moderator (Science Director, NMFS SWFSC)
        Dr. Martin Hall (Chief Scientist, IATTC Tuna-Dolphin Program)
        Dr. Michael Seki (Deputy Director, NMFS PIFSC)
        Dr. Robert Skillman (International Fisheries, NMFS PIFSC)
        Dr. Rebecca Lent (Director, NMFS Office of International Affairs)
        Dr. Charles Karnella (International Fisheries Administrator, NMFS Pacific Islands
            Regional Office)
        Ms. Allison Routt (Sustainable Fisheries, NMFS Southwest Region)
        Ms. Kelly Denit (Fisheries Management Specialist, NMFS Office of International
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This panel will discuss the components of pelagic ecosystems that must be understood and measured in order to apply an ecosystem approach to stewardship. Measures that might comprise successful ecosystem management of tuna will also be discussed. This panel is composed of fisheries professionals with expertise in the research and management activities of the Inter-American Tropical Tuna Commission, the International Commission for the Conservation of Atlantic Tunas, and the Western and Central Pacific Fisheries Commission. Panelists will give brief presentations on research efforts and management measures designed to guide regional fisheries management organizations (RFMOs) in their transition towards an ecosystem approach to stewardship of tuna. Following the presentations, there will be an open discussion moderated by Dr. Fox, tapping into the scientific expertise of the Tuna Conference participants. Sharing the successes, failures, innovations, and future plans of individual RFMOs will facilitate the efforts of each as they move forward.

IDENTIFYING BEHAVIOR OF GIANT BLUEFIN TUNA ON THE SPAWNING GROUNDS IN THE GULF OF MEXICO WITH ARCHIVAL TAGS

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Archival tagging of Atlantic bluefin tuna has demonstrated site directed fidelity of bluefin tuna to breeding grounds in the Gulf of Mexico and Mediterranean Sea. We examine the movement patterns, diving behaviors and thermal biology of Atlantic bluefin tuna at different stages of their breeding migration in the west Atlantic, to test the hypothesis that the spawning behavior has behavioral patterns that can be identified and localized to discrete areas in the Gulf of Mexico (GOM). Mature Atlantic bluefin tuna archival tagged in the western Atlantic and the GOM, show occupancy on their breeding grounds (n=28) from February to June for an average of 40 ± 17 days. Bluefin tuna have made been recorded making consecutive yearly visits to the Gulf of Mexico for up to three years. We can identify "breeding signals" in archival tag time series data that enable the recognition of the time when bluefin are on their breeding grounds and possibly exhibiting spawning behavior. The bluefin tuna experienced significantly warmer mean sea surface temperatures (SSTs) within the GOM (26.1 ± 1.5 °C) than outside the GOM (20.3 ± 2.2 °C) that are consistent from year to year. As the bluefin tuna entered and exited the GOM, we identified three phases based on diving and thermal behaviors: an entry phase, a breeding phase and an exit phase. The bluefin tuna experience some of the deepest daily maximum depths during entry and exit of 573 ± 64 and 553 ± 149 m respectively while in the Gulf of Mexico, and show directed movement paths to and from the breeding areas. During the breeding phase, the bluefin tuna had significantly shallower daily maximum depths (192 ± 68 m), and exhibited shallow oscillatory dives during the night. The movement paths during the breeding phase were also significantly less linear and more residential. During this period, in the dawn hours the bluefin often experienced the warmest internal temperatures. We calculated the heat transfer coefficients (K) for a bluefin tuna in the GOM and demonstrate that K was significantly higher during the nighttime of the breeding phase. Recent physiological work on bluefin tuna cardiac cells indicates that bluefin have limitations in cardiac function as temperatures approach 30°C. The capacity to cycle calcium ions and ultimately to deliver oxygen to tissues may be at the top end of the cardiac curve when these fish are experiencing the warm surface waters of the mixed layers associated with the breeding period. We hypothesize that bluefin exit the Gulf by June in part due to the high temperatures and thermal stress imposed upon adults. During longline trips to the GOM, bluefin tuna experienced significant mortality the GOM that may be due to an increase in thermal stress and hypoxia experienced by the bluefin when captured on longlines. Bluefin experience rapid mortality on scientific longlines set in the GOM, on the breeding grounds.

MOVEMENTS OF JUVENILE NORTH PACIFIC ALBACORE REVEALED BY ARCHIVAL TAGS

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The Southwest Fisheries Science Center (SWFSC) and the American Fishermen's Research Foundation (AFRF) initiated a multi-year, collaborative project in 2001 to tag juvenile north Pacific albacore (*Thunnus alalunga*) with electronic archival tags. The goal of the project is to collect and analyze detailed data on the migration routes and habitat preferences of juvenile fish (3 to 5 year old fish). To date, 384 of a planned 500 archival tag deployments have been made. Tagging efforts have been concentrated in two areas: off the coast of southern California and Baja California, Mexico where a large sport fishing fleet operates; and off the coast of Oregon and Washington where the U.S. and Canada troll fleets operate. Fifteen archival tags have been recovered. Times at liberty ranged from 63 to 446 days and averaged 293 days. The areas utilized by recovered fish ranged from the southern tip of Vancouver Island, Canada to the southern tip of Baja California, Mexico and from the west coast of North America out to 176° west longitude. Preliminary analysis of the movements of fourteen fish, 12 of which were at liberty for close to or beyond 1 year, demonstrates that 6 albacore remained in the Southern California Bight or in waters to the southeast along Baja California throughout the time at liberty. Five albacore ranged into waters midway between southern California and Hawaii during the winter months, but returned and were recaptured near the tagging locations. Two fish made broader movements into waters north of Hawaii beyond 150° W, before returning to Pacific Northwest waters where they were recaptured. Refinements to the light-based location estimates are currently being made using composite SST data from satellite imagery. Albacore occupy a broad vertical and thermal niche. All fish exhibited a diurnal pattern of repetitive deep diving to below the thermocline during the day, while remaining closer to the surface at night. Dives routinely exceeded 200 m, and one fish reached a maximum depth of 1150 m. Surface temperatures encountered by tagged fish throughout the tracks ranged from 14° C to 23° C, whereas temperatures while swimming at depth were as low as 7-8° C. The broad movements observed from these 16 fish demonstrate the wide-ranging nature of north Pacific albacore residing off the North American west coast during their juvenile years. Future recoveries will help elicit the extent of their migratory movements and how juvenile albacore from the eastern Pacific recruit to fisheries in the western Pacific.

MOVEMENTS OF BIGEYE AND YELLOWFIN TUNAS IN THE EASTERN PACIFIC OCEAN, ASCERTAINED FROM ARCHIVAL TAGS

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Preliminary results are presented on the movements of bigeye tuna tagged and released with archival tags in the equatorial eastern Pacific Ocean during 2002 through 2005, and yellowfin tuna tagged and released with archival tags off Baja California, Mexico during 2002 and 2003. Analyses of the movement patterns are based on 25 bigeye at liberty from 162 to 575d (238.8 d average) and 20 yellowfin at liberty from 154 to 1161 d (294.4 d average). The geolocation data recovered from archival tags was processed using previously developed algorithms matching sea-surface temperatures from the tags with sea-surface temperatures from satellites to adjust latitude positions and allow for estimation of positions near the times of the equinoxes. Movement paths for fish with the greatest times at liberty and for other representative fish of each species are presented, along with home range analyses.

MOVEMENTS AND FOCAL AREAS OF TWO LAMNID SHARK SPECIES IN THE EASTERN PACIFIC

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As a component of the Tagging of Pacific Pelagics Program, we tracked mature white sharks and salmon sharks in the eastern north Pacific, and in both species documented annual migrations over ocean-basin scales from eutrophic coastal foraging locations to pelagic regions. Male and female white sharks (n = 20) tracked with PAT tags undertook an east-west migration from nearshore California waters to an offshore region between Hawaii and Baja, 1900 km from the tagging location. While in nearshore California waters in the autumn and winter, temperatures ranged from 9.8 to 14.2°C and depths ranged from the surface to 76 m. While in the offshore focal region in the subtropical gyre during spring and summer, white sharks encountered waters ranging from 5.4 to 26.2°C and used a broad range of depths from the surface to over 980 m. Female salmon sharks (n = 76) tagged with SPOT, PAT, SPLASH and SMRU tags undertook migrations from southern Alaska into a broad region of the subtropical eastern Pacific spanning Hawaii to Baja. The timing of the migration was variable, with southern movements beginning during July through March. Animals overwintering in subarctic waters spent 98 ± 4 % of their time in waters cooler than 8°C. During their southern migrations, salmon sharks experienced temperatures up to 24°C but often remained in cooler waters below the mixed layer. In multi-year tracks, 11 out of 13 salmon sharks migrated to similar regions in consecutive years, with seven animals visiting the subtropical gyre and four the California Current System; two animals visited both regions in consecutive years.

TRANS-PACIFIC MIGRATIONS OF PACIFIC BLUEFIN TUNA

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Electronic tagging of Pacific Bluefin Tuna (*Thunnus orientalis*) has revealed details of east to west basin scale migratory movements in the Pacific Ocean. Archival tags log ambient pressure, temperature and light levels, and peritoneal temperature, data that can be used to provide both daily positional information and fine temporal scale behavioral and environmental information. Pacific Bluefin tuna are spawned in the western Pacific Ocean near Japan. Archival tagging of fish in year classes two through five in the eastern Pacific has shown that all year classes move to the western Pacific. Archival tag records (n=7) have indicated that the timing of exit from the eastern Pacific (east of 130° W) ranges from early winter (Dec) to late spring (May). Entrance to western residence areas (west of 150° E) occurs in mid summer. Basin scale migrations are characterized by periods of transit and aggregation. Transit routes occur along a narrow band of latitudes (34.2° N +- 1.84 SD) and sea surface temperatures (14.1° C +- 1.45 SD) through oligotrophic waters east of 180° W. Areas with dynamic oceanographic features, such as the fronts and eddies that are associated with the Emperor Seamount chain (170 °E) and the Shatsky Rise (155° E), encountered along the east-west migratory route, provide putative forage grounds for animals that have left the eastern Pacific in early winter. Individual migratory routes and behaviors are the result of the interaction of physiological constraints and the availability of appropriate oceanographic conditions.

PRELIMINARY TESTING OF A PROTOTYPE POPUP SATELLITE ARCHIVAL TAG

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Over the past four years a new concept for a popup satellite archival tag has evolved from schematics to working prototype. The tag differs from existing designs in that it has increased sensor capability, an exchangeable power supply and an instantaneous means of separation from the animal. The very first field trials were recently conducted in Costa Rica under controlled conditions (moorings) as well as fish deployments. Three out of five deployments were a complete success. A mechanical, O-ring related, problem was identified that led to the failure of two tags. Tags were allowed to transmit to orbiting ARGOS satellites, but when possible they were recovered and data downloaded directly. Further testing continues as of this writing and full results will be presented at the Tuna Conference.

PROCESSING AND DISPLAYING OF POP-UP SATELLITE ARCHIVAL TAGS (PSAT) DATA WITH *EASy* GEOGRAPHICAL INFORMATION SYSTEM

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The PSAT Tracker algorithm[1] is the most recent, fully automated and GIS-integrated tool for correcting and analyzing tracks of organisms carrying pop-up archival tags. The algorithm is seamlessly integrated into **EAS**y (Environmental Analysis System), a geographic information system (GIS) that is specifically designed for oceanographic applications.

Pop-up archival tags are widely used, and are attached to species that are either too small or do not remain at the sea surface for a sufficient length of time to allow location via satellite telemetry. The tags contain a clock and sensors for light intensity, temperature, and depth. Estimates of the latitude and longitude can be calculated from manufacturers' light-based algorithms, based upon the timing and duration of sunrise and sunset. Because latitude estimates are prone to considerable degrees of error, particularly around the equinoxes, we have implemented an algorithm that improves the accuracy of geo-location by searching the field of pixels of the time series of remotely-sensed sea surface temperature (SST) imagery with the time series of SST recorded by the tag to obtain a best match. The results of this algorithm compared favorably to the estimates of latitude calculated with the light-based algorithms and allowed for estimation of fish positions during times of the year when the light-based algorithms failed. The PSAT Tracker also implements Kernel home range estimation methods that produce contours of species habitat utilization from tagging data. The algorithm has passed several rigorous tests, and is routinely used by the Pfleger Institute of Environmental Studies, and currently tested with collaborators in IATTC, and NOAA Fisheries Centers in La Jolla and Miami.

[1]Domeier, M. L., D. Kiefer, N. Nasby-Lucas, A. Wagschal and F. O'Brien. 2005. Tracking Pacific bluefin tuna *(Thunnus thynnis orientalis)* in the northeastern Pacific with an automated algorithm that estimates latitude by matching sea-surface-temperature data from satellites with temperature data from tags on fish. Fish. Bull. 103:292-306.

FROM LIGHT MEASUREMENTS TO MOST PROBABLE TRACK

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Reconstructing the most probable track of an archival tagged individual is often done as a two step process 1) Obtain raw geolocations from the tag manufacturer or from their software. 2) Use the `kftrack' package or some other modeling approach to estimate a plausible track from the raw geolocations. This two step approach is however not optimal, as information is lost between the steps, and there is no feedback from the second step to the first step. Furthermore, it is frustrating to see patterns that can only be explained as artifacts of hidden details in a proprietary geolocation algorithm.

This talk is a progress report on the efforts to create a transparent, statistically sound model to reconstruct the most probable track.

A state space model is presented that combines the two steps. The model uses the light measurements from the tag to estimate the most probable track, without estimating isolated daily geolocations. The model performance is evaluated by mooring data and compared to raw geolocations and to the results from the two step approach. The model is promising, as it is able to provide very accurate tracks for tags where the other methods have failed. Older tag versions are however still problematic.

PARAMETER ESTIMATION PROCEDURE IN THE MODEL OF PELAGIC ECOSYSTEM SPATIAL DYNAMICS WITH APPLICATION TO PACIFIC SKIPJACK

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The environmental population dynamic model (SEAPODYM) describing biological system forage – large pelagic predators (tunas) is considered. The predictions of the model are the numerical solutions of advection-diffusion-reaction equations, representing the spatio-temporal variability of several forage populations and predator's age classes. The environmental characteristics (currents, temperature, dissolved oxygen) as well as ocean primary production predicted by physical-biogeochemical models are explicitly used as physical forcing playing the major role in dynamics of marine species. The determination of functional links between environmental indices and fish population biology and their parameterization which would allow us to achieve the best fit to data and therefore to make reliable prognosis of biomass, distributions and catches are the most important tasks.

The useful computer tool based on the adjoint technique has been developed. Adjoint method allows us to apply maximum likelihood approach for parameter estimation by minimizing the residuals between predictions and observations. Likelihood function can include catch or CPUE indices reported by different fisheries and, since the model is age-structured, length frequencies data. The first parameter estimation procedure is being applied for Pacific skipjack population. There is the fairly small number of parameters which govern the predator population dynamics in Seapodym model. We're estimating diffusion and advection rates, parameters of habitat indices, natural mortality and survival, catchabilities and coefficients of selectivity functions.

The set of experiments have shown that the current model structure and numerical values of parameters defining skipjack population dynamics can be improved significantly providing much better fit to the data. The results will be presented and discussed.

THE INFLUENCE OF THE ENVIRONMENT ON HORIZONTAL AND VERTICAL BIGEYE TUNA MOVEMENTS INVESTIGATED BY ANALYSIS OF ARCHIVAL TAG RECORDS AND ECOSYSTEM MODEL OUTPUTS

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The influence of the environment on horizontal and vertical bigeye tuna (*Thunnus obesus*) movements was investigated by analysis of archival tag records (from the Coral Sea 1999-2002, Papua New Guinea, New Caledonia and Tonga waters 2002-2005) and SEAPODYM ecosystem model outputs. Horizontal movements were studied on a 10-day scale and showed a high degree of residency in NW Coral Sea and around New Caledonia, a clear migration/dispersion pattern by a few individuals in the Coral Sea (eastward in December, westward in July). The latitudes estimated for each individual were improved by comparison of temperature data recorded by the tags with temperature data extracted from ocean model outputs corresponding to the geolocation areas. Tag-recorded horizontal movements were used to validate the parameterisation of 'bigeye habitat' in SEAPODYM (based on temperature and estimated forage biomass). Vertical movements exhibited two major seasonal behaviours that were significantly related to environment: a classic W-shaped feeding behaviour observed all year round, in which the dive depth during the day was related to the estimated deep forage abundance; a feeding and reproductive behaviour observed from August to November, in which tunas would target seasonal forage biomass concentrations, especially in warmer surface waters during the day. The precision of geolocation estimates (especially for PSAT data) and the gap in space-time scales between tag records and model outputs remain critical. The results will be used for the parameterisation of bigeye habitat in SEAPODYM and constitute a first stage towards the definition of a rule-based IBM of bigeye tuna movements in relation to their environment.

FOR AN ENLIGHTENED TUNA,
THE GREATEST JOURNEY BEGINS WITH A SINGLE STEP:
MODELING TUNA NAVIGATION AND MOVEMENT

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Tuna either carry a very accurate map of the world, GPS, and access to the latest satellite data or there must be another way they get about. And what do they want? Do they have long term dreams, hopes, and desires or do they react in the instant. Do they exist in a state of nirvana, in the permanent now, leading to cessation of all entanglement and attachment in life, or do they mull over the consequences of their actions in terms of the bigger picture of their long term ambitions. We propose nirvana and the gradient of magnetic field intensity.

The goal of this project is to model the movements of tunas from the simplest rules, from first principles and from an immediate decision reference frame. The suggested simple model for general movements of animals, applied to tuna, is a random walk consisting of only direction and determination to continue in the same direction at each step. Changing these variables in response to local environment can cause model tuna to congregate or disperse, and further simple rules for response to encountering land, other tuna, or ocean fronts, etc., can cause a suite of possible emergent patterns of movement and distribution. This basic modeling technique is explored by its application to schooling theory and navigation of tunas over large distances. The aim is a biologically plausible model tuna which can be introduced into ecosystem models in large numbers, but the approach might also help study the way tuna have evolved to most efficiently search and exploit their environment. Benefits in the approach include; inbuilt simulation of the natural variation among groups, and straightforward use of data from tagging and other behavioral studies to parameterize the model tuna. In essence the approach allows one to bypass the conference question of "What do large pelagics want?" and rather ask "What is the fish's next move in the face of this specific cue?" and then normal computing power allows the result of many iterations to be visualized. The work follows on from other self organization studies in biological systems which have had success in explaining how simple individual behavioral rules for ants, bees, birds, humans and fish lead to remarkable complex organized spatial patterns of groups.

It is a work in progress and the results are more visual and philosophical rather than numerical at present.

THE FORTUNES OF FISHES AND FISHERS: THE POLITICAL ECONOMY OF INNOVATION IN ATLANTIC RESOURCE MANAGEMENT

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Evincing rivalness and open access, highly migratory species are the epitome of global common pool resources and there has been much pessimism regarding the ability of national governments to cooperatively manage these important fishes at sustainable levels. Actually, regional fisheries organizations have failed to maintain many stocks at maximum sustainable yield but, by adopting new management measures, they have succeeded in rebuilding some populations. To explain these innovations, I hypothesize that, for any given stock of fish, the policy preferences of decision-makers, reified as states, can be derived from the economic vulnerability of their commercial fleets under increasing international competition. In this model, vulnerability is defined as a combination of the costs of production (competitiveness) and the opportunity costs of switching to alternative sources of revenue (flexibility) for the domestic fleet targeting a stock, relative to other national fleets in the fishery. As a stock is depleted under open access, economic recession is felt in vulnerable states, providing their policy-makers with incentives to push for new management measures, including establishing catch limits that are in line with scientific advice, allotting national quotas, and developing international monitoring and enforcement mechanisms. Both preferred measures and willingness to pay are expected to differ cross-sectionally based on economic vulnerability and temporally depending on the level of depletion.

Six in-depth case studies from the International Commission for the Conservation of Atlantic Tunas were compiled to test this vulnerability response model. States generally behaved as predicted based on their economic vulnerability. A clear pattern was observed, including the increasing use of transfers from more to less vulnerable states to ensure cooperation as commercially valuable stocks declined. Secondary expectations were also developed to investigate the impact of vulnerability response on management outcomes. This analysis confirmed one of the most important ramifications of the hypotheses, which is that, if effective management occurs at all, it will not be to maintain stocks at sustainable levels but rather to rebuild depleted stocks. Furthermore, successful rebuilding plans were only adopted in cases where a certain balance existed between more and less vulnerable countries. More vulnerable countries must have enough power to create consensus on effective measures, but without competitive pressure from the fleets of less vulnerable countries the costs of effective regulation will continue to outweigh the benefits. Further work is needed, on this model and others that also focus on changes in behavior that take place in response to the experienced, rather than expected, costs of overexploitation. Exploration of such causal mechanisms can illuminate the circumstances under which negative cycles of resource use are self-limiting and when they are not.

SPATIAL MODELING OF THE TRADEOFF BETWEEN SEA TURTLE TAKE REDUCTIONS AND ECONOMIC RETURNS TO THE HAWAII LONGLINE FISHERY

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One research priority of the Hawaii-based longline fishery is the integration of economic and biological models, so as to provide timely scientific advice for fisheries management. The objective of this study is to construct a bio-economic modeling of multiple time-area closures in the Hawaii longline fishery, in particular, to improve understanding of the effects of closures on sea turtle takes. A framework was developed to incorporate features of a biological model of sea turtle takes built by Kobayashi and Polovina (K-P) for economic analysis of the Hawaii longline fishery. Based on available cost-earning survey data, this research applied a regression model to identify the significant variables which contribute to variable costs of longline fishing. Along with trip types (targeting swordfish or tuna), number of sets, and length of vessels, distances to ports of each set significantly affect variable costs. To evaluate the trade-off between sea turtle reductions and economic returns, a cost function was built into the model to measure the changes of net revenue and profit to the fisheries under different policy options. Also, this study refined the K-P model by designing flexible and multiple time-area closure scenarios to allow the model to assess closures that are combinations of different areas (by one degree of latitude and/or longitude) and seasons (1 to 12 months) by specific trip types. Instead of relying on a single combination of time and area closure, such improvement of the modeling will offer more realistic longline fishery management scenarios.

MONITORING TRENDS IN U.S. ATLANTIC BLUEFIN TUNA LANDINGS AND ATLANTIC AND PACIFIC BLUEFIN TUNA TRADE

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Atlantic bluefin tuna (*Thunnus thynnus*) has been a prized commodity for export from New England fisheries to Japanese sushi markets, in recent years on the order of 750 metric tons and $7.5 million annually. The value of the U.S. fishery over the past two decades has been great; however, U.S. bluefin tuna landings and value have very recently declined. The height of the commercial fishery has shifted from traditional New England fisheries in the summer and fall to winter fisheries off the mid to South Atlantic states. These recent changes are under investigation both domestically and internationally regarding their implications for stock assessments and potential consequences for future management. In addition, trade data show that import/export patterns have also shifted, which may reflect domestic shifts and changes in international fisheries and markets.

This paper will review changes in amount and distribution of domestic Atlantic landings, and size distribution of landed bluefin tuna. Trends in U.S. bluefin tuna trade, including Atlantic and Pacific (*Thunnus orientalis*) species will be presented, based on domestic implementation of the International Commission for the Conservation of Atlantic Tunas (ICCAT)'s bluefin tuna statistical document program. A brief review of newly established national trade monitoring programs for southern bluefin tuna (*Thunnus maccoyii*), bigeye tuna (*Thunnus obesus*), and swordfish (*Xiphias gladius*), in accordance and cooperation with the Inter-American Tropical Tuna Commission, ICCAT, Indian Ocean Tuna Commission, and Commission for the Conservation of Southern Bluefin Tuna, will also be presented.

PANEL SESSION:

FLEET CAPACITY AND THE ECONOMICS OF TUNA FISHERIES

*Panel***:**   Mr. Brian Hallman (Senior Policy Advisor, IATTC)
Dr. Rebecca Lent (Director, NMFS Office of International Affairs)
Dr. Charles Karnella (International Fisheries Administrator, NMFS Pacific Islands
   Regional Office)
Dr. Dale Squires (Economist and Senior Scientist, NMFS SWFSC)
Dr. Joe Terry (Economist, NMFS Office of Science and Technology)

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The panel will discuss the management of fishing capacity, with an emphasis on the individual and collective efforts of RFMOs. The panel is composed of fisheries professionals with expertise in the research and management activities of the Inter-American Tropical Tuna Commission, the International Commission for the Conservation of Atlantic Tunas, the Western and Central Pacific Fisheries Commission, and the U.S. The session will begin with brief presentations on the following: (1) the FAO Methodological Workshop on the Management of Tuna Fishing Capacity; (2) NMFS' efforts to initiate regular assessments of overcapacity in federally-managed commercial fisheries; and (3) the successes, failures, innovations, challenges and future plans of individual RFMOs concerning the management of fishing capacity. Following the presentations, there will be an open discussion moderated by Dr. Terry. That discussion is intended to take advantage of the expertise of the Tuna Conference participants in order to both identify research efforts and management actions that would improve the management of fishing capacity and address methods for initiating such efforts and actions.

FOOD AND FEEDING HABITS OF THE BLUE SHARK, *Prionace glauca*, CAUGHT OFF ENSENADA, BAJA CALIFORNIA, MEXICO

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An artisanal fishery for pelagic sharks occurs off the western coast of Baja California, where blue shark is the primary target species. As part of a blue shark fisheries biology study, to describe this shark species feeding habits, during April 1995 to May 1997 we collected 893 blue shark stomachs contents onboard artisanal "pangas" (vessels with less than 10 m in length), that were based in Ensenada. Most of the sharks (n=614, 68.7%) had food in their stomachs. Cephalopods occurred in more stomachs (55.5%) than crustaceans (30%) or teleosts (21%). However, diet was numerically dominated by the pelagic red crab *Pleuroncodes planipes*, accounting for 41% of all preys. Also, we found remains of other vertebrates in 2.91% of the stomachs contents, including some from elasmobranchs, seabirds and marine mammals; in addition, in 3.25% of the stomachs we found trash originated from human activities, which might be a sign of the intense maritime traffic in the area. Significant differences were found in the diet between six shark size classes, where larger size sharks feed on larger size squids. Besides the description of feeding habits of the blue shark in the area, this study also allowed us to understand the species presence in the area for some of the preys, especially for the squid species.

DIET DIFFERENCES AMONG 3 SPECIES OF PELAGIC SHARKS INHABITING THE CALIFORNIA CURRENT: THE SHORTFIN MAKO (*Isurus oxyrinchus*), BLUE (*Prionace glauca*), AND THRESHER (*Alopias vulpinus*) SHARKS

Antonella Preti, Susan E. Smith, Darlene A. Ramon and Suzanne Kohin

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The California Current ecosystem is a unique transition ecosystem between subtropical and subarctic water masses with a seasonal coastal upwelling phenomenon. The effects of the physical oceanographic processes within the ecosystem are strong interannual oscillations in productivity and a rich species diversity. There are several species of pelagic sharks which inhabit the California Current, the most abundant of which are the shortfin mako (*Isurus oxyrinchus*), blue (*Prionace glauca*) and thresher (*Alopias vulpinus*) sharks. All three species are captured in the pelagic drift gillnet fishery operating off the California and Oregon coasts. In order to determine whether the 3 species feed on common prey in their overlapping habitats, we examined the feeding habits of sharks sampled from the pelagic drift gillnet fishery between 2002 and 2005.

Contents of 115 shortfin mako, 97 blue and 89 thresher shark stomachs sampled by fishery observers during the period August 2002 - January 2005 were analyzed and compared. Most of the sharks (78-89%) were taken in the Southern California Bight south of Point Conception. The geometric index of importance, GII (Assis, 1996), was chosen to rank prey items and to graphically represent the relative measures of prey quantity.

The mako sharks sampled ranged from 72 to 211 cm fork length (FL). Of 115 mako shark stomachs examined, 81 contained prey representing 23 taxa. Jumbo squid (*Dosidicus gigas*) (GII=63.3) and Pacific saury (*Cololabis saira*) (GII=28.1) were the two most important prey items. The blue sharks sampled ranged from 76 to 182 cm FL. Of 97 blue shark stomachs examined, 67 contained prey representing 24 taxa. Octopus of the *Argonauta* spp. (GII=51.2) and squid of the *Gonatus* spp. (GII=40.7) were the most important prey items. The thresher sharks sampled ranged from 96 to 228 cm FL. Of 89 thresher shark stomachs examined, 55 contained prey representing 18 taxa. Pacific sardine (*Sardinops sagax*) (GII=66.4) and northern anchovy (*Engraulis mordax*) (GII=44.9) were the two most important prey items.

Comparing the first 12 prey items ranked by GII for each species, it was apparent that the diet of each species was distinct. Mako sharks fed on a combination of different taxa of teleosts and cephalopods, blue sharks fed primarily on different cephalopod species, while threshers consumed mostly teleosts, especially coastal pelagic species, and very little squid. Within each species, some interannual differences in the main prey items consumed were observed. However, whether those differences were correlated with changes in potential prey availability or prevailing oceanographic conditions warrants further analysis given that the prevailing oceanographic conditions of the 3 years of the study were similar and considered "average".

PREDATION BY JUVENILE ALBACORE IN THE CALIFORNIA CURRENT SYSTEM AND IMPACTS ON GROWTH

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Juvenile albacore are landed in the California Current System (CCS) from June until October, and recent tagging data suggest at least some remain in the CCS year-round. Past diet studies indicate they are opportunistic and voracious predators. This study aims to quantify albacore diet habits in the CCS through a new gut content study and analysis of a spatially-explicit bioenergetics model. Albacore diet habits appear to be dictated by the type of prey available in different parts of the current. My re-analysis of gut content data from the late 1960s shows clear spatial patterns in prey relative abundance in albacore diet. The central CCS is considered a transition zone, and correspondingly, albacore gut contents reflect a more diverse prey field than in the northern or southern parts of the current. Moreover, different species are eaten in different proportions depending on the time of season and location of the predator in the current. An on-going new gut content study will quantify current diet habits and investigate whether changes in albacore predation from past studies are apparent. The prey energy densities [Joules/gram of prey] of various species consumed by albacore vary significantly. A bioenergetics model relating albacore consumption rates to growth shows a non-linear relationship between prey energy density and consumption rates. If the prey field available to albacore changes significantly, e.g., from primarily small pelagic fishes to primarily squid and large crustaceans, albacore would need to invest more energy in predation to maintain a stable population biomass. The bioenergetics model is used to simulate scenarios of changing relative abundance of prey items and the result for albacore growth. Furthermore, the model and diet data are used to calculate the biomass of different prey species removed annually from the CCS. Although migration routes, in particular known spawning grounds, for albacore are still somewhat uncertain, several studies suggest that juveniles occupy the upwelling regions of the CCS or the Kuroshio Current. Adults complete trans-Pacific migrations to spawning grounds in the central North Pacific, an area of very low productivity. Given that 80% of total growth is completed before albacore become reproductively mature at 5 to 6 years of age, their growth and hence diet habits during this part of their life cycle may be critical to overall population size. High energy prey fields in the CCS may therefore be a driving factor in albacore migration routes.

FEEDING HABITS OF THE LONGNOSE LANCETFISH (*Alepisaurus ferox*) IN THE WESTERN INDIAN OCEAN

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This presentation is based on two recent analyses on the feeding habits of longnose lancetfish (*Alepisaurus ferox* Lowe, 1833) collected during research longline cruises carried out in 1986-1987 and in 2001-2003 in the western Indian Ocean. Three different areas were prospected: a high sea area between the EEZs of Kenya and Seychelles, the EEZ of Mauritius (Saya-de-Malha Bank-Ahalega Islands area) and the Seychelles EEZ. A total of 158 stomachs (108 non-empty stomachs) were collected during the 1986-1987 period, and 150 stomachs (139 non-empty) during the 2001-2003 period.

The pelagic crab *Charybdis smithii* (Portunidae) was the principal food component of lancetfish during the boreal winter season (winter monsoon), both in the northwest high-sea area of Seychelles (during the 1980s) and in the Seychelles EEZ (in the early 2000s). This prey species contributed 58 to 80% by reconstituted weight to the winter diet. Previous studies indicate that this pelagic crab is a frequent species of the pelagic community of the northwest Indian Ocean in winter.

In this area Crustacea represented 81 to 97% of the IRI in winter, and 60% in the summer. A strong seasonal pattern was apparent, with *C. smithii* predominating in the winter and the stomatopod *Natosquilla investigatoris* in the summer. This observed switch probably reflect variations in the prey availability linked to the currents that occur in this part of the western Indian Ocean. Furthermore, huge numbers of stomatopod in the lancetfish diet reflect long-term variability in the composition of the pelagic community, as recurrent demographic outburst of this species have been previously reported in the Indian Ocean in 1933, 1944, 1965-1967, and early 1970-s. But this species was absent in the stomachs of tunas and lancetfish during the 1980-1999 time period.

Data from the Mauritius EEZ showed a spatial effect in the food composition of lancetfish. Crustaceans were minor component of the diet in this area and lancetfish switch to fish prey (86% by reconstituted weight) with a high level of cannibalism (35% by reconstituted weight).

Size-specific variability in the food composition of small (FL < 100 cm) and large (FL ≥ 100 cm) lancetfish were also evidenced. Large lancetfish were able to catch incidentally large and even fast-swimming fish, had higher level of cannibalism and might apparently migrate to the ocean surface.

Using the longnose lancetfish as a biological sampler of the micro nekton organisms, our results emphasize the role of pelagic crustaceans in the trophic chain of the western part of the Indian Ocean. The prey diversity in the stomach contents is indeed constrained by local prey availability and foraging behaviour. Our results provide important evidence that lancetfish adopt opportunistic foraging behaviour, though there is spatial difference in diet composition, with lancetfish selecting non-conspecific prey such as crustaceans when they are available and abundant in the environment.

GENETIC STOCK STRUCTURE AND INFERRED MIGRATORY PATTERNS OF SKIPJACK TUNA (*Katsuwonus pelamis*) AND YELLOWFIN TUNA (*Thunnus albacares*) STOCKS IN SRI LANKAN WATERS

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Tuna are the major marine fishery in Sri Lanka and Skipjack Tuna (SJT) and Yellow Fin Tuna (YFT) form the most important component species with the Tuna catch increasing rapidly each year in Sri Lanka and generally in the Indian Ocean. To date however, no genetic studies have been done to assess wild stock structure in Sri Lankan waters for management purposes. The current study is the first to document the extent of wild Tuna genetic resources in Sri Lanka.

Samples of both SJT and YFT were collected over a period of 4 years from 9 major fishing grounds around Sri Lanka in the Indian ocean referred to as West, Southwest, South, Southeast, East, Northeast, Northwest and also from the Maldives and Laccadive Islands. Sample locality (GPS), body length and sex data were recorded.

mtDNA and nDNA variation was examined for ~350 individuals of each species to document genetic diversity within and among sampled sites and hence to determine stock structure and to infer migratory behaviour for both species. ATPase-COIII region sequences of the mitochondrial genome were amplified and genetic variation determined using TGGE (Temperature Gradient Gel Electrophoresis). Haplotypes were determined from banding patterns and each unique haplotype was sequenced. Microsatellite markers were developed for both species via DNA cloning and nDNA variation was examined for each species at 3 Tetra- and Tri-nucleotide microsatellite loci.

40 and 15 unique mtDNA haplotypes were found in SJT and YFT samples, respectively. Analyses of mitochondrial ATPase-COIII region sequences and microsatellite genotypes revealed significant genetic variation in SJT among all sites. Some significant differentiation was also observed among sites in the more pelagic YFT and this will be discussed.

CONCEPTUAL MIGRATORY MODEL OF MONTEREY SPANISH MACKEREL (*Scomberomorus concolor*) IN THE GULF OF CALIFORNIA

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Monterey Spanish mackerel (*Scomberomorus concolor*) is an endemic species of the Gulf of California and develops reproductive and feeding seasonal migrations. Based on data from population structure (length and age) and gonadic maturation index, during 2000 to 2003, a migratory conceptual model about this species is proposed. During the study period we didn't record catches of the Monterey Spanish mackerel beyond the south of Guaymas, which is located in the central part of the Gulf. In order to describe the monthly movements of the fish, the data were arranged in two groups. A group was denominated zone 1 (feeding) that included the data recorded from Guaymas to the Isla Tiburon. The second group of data was denominated zone 2 (spawning), including the data from San Felipe, the Gulf of Santa Clara, and Port Libertad. In general, zone 1 was characterized by fishes of small length (350 ± 57 mm fork length FL, 2.9 years old) and the gonads in developing stage (stage 2). In zone 2, the averages of length and age were 385 ± 62 mm FL and 3.5 years old respectively, higher values than observed in zone 1. In addition, in the zone 2 the gonad maturation changed from stage 2 to mature stage (stage 3) in April, and in May spawning was detected (stage 4), while in the zone 1 the gonads always showed the developing stage. In the middle of autumn, Monterey Spanish mackerel move southward close to the coast toward feeding grounds. A northward and offshore migration toward spawning grounds occurs in the end of spring and beginning of summer. This migration pattern is discussed around the food availability and changes in the sea surface temperature.

SENSITIVITY ANALYSES FOR TUNA STOCK ASSESSMENTS

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Stock assessments for Pacific stocks of yellowfin and bigeye, and south Pacific albacore, are routinely carried out using age-structured catch-at-length models fitted using maximum likelihood, such as A-SCALA, MULTIFAN-CL, and Stock Synthesis 2. Assessments using these methods are also under development for north Pacific albacore and Pacific bluefin. The estimates derived from these models are used to provide management advice. I examine the sensitivity of these estimates to some biological parameters, including expected asymptotic length (L infinity) and sex ratio at length, and to alternative modeling approaches.

mtDNA VARIABILITY OF EASTERN PACIFIC DOLPHINFISH
Coryphaena hippurus

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In Mexico the dolphinfish (*Coryphaena hippurus*), is by law reserved for sport fishing within 50 miles of the coastline, although there is significant catch along the Pacific coast by artisanal fisheries. The eventual opening of the resource for commercial exploitation makes necessary to obtain information about population dynamics to define management strategies, which should be based on the previous definition of the population structure in the fishing area. Dolphinfish samples were collected over four consecutive years from four locations in the eastern central Pacific to evaluate the genetic variation in a 751 bp segment of the mitochondrial NADH subunit 1 (ND1) to test for the presence of genetic population structure. Sequence analyses revealed no significant differences among collections from the same location in the different years sampled nor among locations spatially separated. Mismatch distributions, estimations of population expansion parameters, and neutrality tests revealed significant fluctuations in population size in coincidence with past glacial and interglacial periods during the late Pleistocene. The low levels of nucleotide diversities and shallow coalescence of mtDNA genealogies observed are discussed in light of their association with past demographic fluctuations and the prevention of the accumulation of deep lineages delaying the emergence of a population divergence process.

EVALUATING THE IMPORTANCE OF OCEANOGRAPHIC, BIOLOGICAL AND FISHERY CONDITIONS IN RELATION WITH EASTERN PACIFIC YELLOWFIN TUNA, *Thunnus albacares*, RECRUITMENT

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Typically a stock-recruitment relationship is considered in assessment of fish stocks. In the case of the yellowfin tuna stock in the eastern Pacific Ocean no relationship has been found, suggesting that other variables might be more relevant in shaping recruitment. In the past it has been shown that high recruitment follows an "El Niño" phenomenon with several years time lag. In this work we consider seasonal data of sea surface temperature from several areas, the sum of 1x1 degree areas with temperature above 24o, ENSO index, catch from several gears-type of fish schools, discards and spawners biomass by age in a self organizing map to classify yellowfin tuna recruitment levels.

FEEDING HABITS OF PACIFIC BLUEFIN TUNA OFF THE WESTERN COAST OF BAJA CALIFORNIA, MEXICO

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Studies have determined that a single population of bluefin tuna (BFT) has been found in the Pacific Ocean and that this species spawns only in the western Pacific, south of Japan. This species, of a greater size than other tuna species, migrates across the Pacific Ocean eventually arriving at the coast of the Baja California peninsula in June to September. Previous studies have related the changes in the migrating proportion with the high abundance of *Sardinops melanostica*, a species on which the BFT in the western Pacific prey. Also there is a greater abundance of BFT in the northeastern Pacific in years in which the sardine (*Sardinops caeruleus*) has been more abundant. To determine if this sardine species is an important prey for the BFT, we wanted to determine the tuna's feeding habits. A total of 81 organisms were sampled (100 to 140 cm fork-length), which were captured by the Mexican purse-seine fleet that operated along the western coast of Baja California Sur during summer 2004. Quantitative analyses of the prey found in the stomach content were made using numerical, gravimetric and frequency of occurrence methods, to obtain the index of relative importance (IRI). To determine the breadth of the trophic niche the Levin's index was used and to determine a possible dietary overlap between sexes we used the Morisita-Horn index. Fifty percent of the analyzed stomachs were empty, which were in organisms > 130 cm. In the smaller organisms there were a total of 15 different prey organisms, with the most important, according to the index of relative importance (IRI), jumbo squid *Dosidicus gigas* (%IRI = 77%), mackerel *Scomber japonicus* (IRI = 10%), and the crabs *Pleuroncodes planipes* and *Portunus xantusii* (IRI = 2.5%). These organisms had a relatively low trophic niche breadth (Levin = 0.25), considering them as selective predators. By using the index of Morista-Horn, we determined that the diet between sexes is slightly different (Cλ = 0.5), in which the males consumed *S. japonicus* with a high frequency and number, whereas the females did not consume this prey. *Sardinops caeruleus* was not recorded as one of the prey species.

CANNIBALISM WITHIN LONGNOSE LANCETFISH (*Alepisaurus ferox*) POPULATION IN THE WESTERN INDIAN OCEAN

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This poster gives additional information to the oral presentation entitled "Feeding habits of the longnose lancetfish (*Alepisaurus ferox* Lowe, 1833) in the western Indian Ocean" (Romanov et al., this Conference). Here we investigate the spatial variability of the cannibalism level of longnose lancetfish. Cannibalism is a widespread phenomenon among fishes depending on species-specific behaviour, food availability, population abundance (density-dependent relationships), and many other non-accountable factors. The predation by lancetfish is often described as being an opportunistic process (i.e. non-selective) constrained by local prey availability and by its feeding speed during an attack of prey. Our study shows that cannibalism is negatively related with abundance of easy accessible slow swimming preys (such as the pelagic crab *Charybdis smithii* during the boreal winter season) and with the total abundance of prey. The cannibalism level (and apparently the food competition) increases in the waters where the pelagic crab was absent, the prey density was lower and prey such as fish, hyperiids, and polychaets were abundant. Our results suggest that lancetfish adopt opportunistic foraging behaviour, selecting non-conspecific abundant prey such as crustaceans when available, and switching to non-selective feeding with high-level of cannibalism in poor waters.

CLIOTOP — CLimate Impacts on Oceanic TOp Predators

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CLIOTOP is a regional project implemented under the international research program GLOBEC, a component of the International Geosphere-Biosphere Programme (IGBP). CLIOTOP is devoted to the study of oceanic top predators within their ecosystems and is based on a global comparative approach, i.e. among regions, oceans and species. It requires a substantive international collaborative effort. The project aims at identifying, characterizing and modeling the key processes involved in the dynamics of oceanic pelagic ecosystems in a context of both climate variability and change and intensive fishing of top predators. The goal is to improve knowledge and to develop a reliable predictive capacity for single species and ecosystem dynamics at short, medium and long term scales.

CLIOTOP is based on the idea that the variety of climatic and oceanographic conditions in the three oceans (Atlantic, Indian and Pacific) provides a unique opportunity for large-scale comparative analysis of open ocean ecosystem function. The work of CLIOTOP is partitioned among five working groups: WG 1 – Early Life History; WG 2 – Physiology, Behaviour and Distribution; WG 3 - Trophic Pathways in Open Ocean Ecosystems; WG 4 - Synthesis and Modeling; WG 5: Socio-Economic Aspects and Management Strategies. A compete account of the CLIOTOP vision and the goals of each working group are presented in the Science Plan available on the World Wide Web.

[*] Presented on behalf of the CLIOTOP Steering Committee: M. Shiham Adam, Heidi Dewar, Alistair Hobday , Patrick Lehodey, Molly Lutcavage, Olivier Maury, Kathleen Miller, Raghu Murtugudde, John Sibert , Sung Kwon Soh, Yuji Uozumi, Henry Weimerskirch

ELECTRONIC TAGGING DATA REPOSITORY

https://www.soest.hawaii.edu/tag-data/

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The ETDR is a facility for exchange of data derived from electronic tags. The increasing trend of multiple authorship is an important hallmark of a developing new culture of science where more is gained by sharing information than by locking it away dark filing cabinets. The repository provides information about data – metadata – in a way that satisfies well-developed, open standards. It also assists "data rescue" by providing a means of archiving and documenting data in jeopardy of being lost forever. The repository resides on a dedicated secure server. Access to meta-data and data can be strictly controlled to individual users according to requirements of the data owners. Guidelines for ethical use have been established. The repository currently houses data from over 700 archival tags, PSATs and acoustic tags.

MERCURY LEVELS IN THE COMMON THRESHER AND SHORTFIN MAKO FROM SOUTHERN CALIFORNIA

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Along the southern California coast, large numbers of the common thresher, *Alopias vulpinus* and shortfin mako, *Isurus oxyrinchus* are caught by both commercial and sport fisheries. These sharks are mostly utilized for human consumption. Being apex predators, both common thresher and shortfin mako are susceptible to bioaccumulate high levels of mercury (Hg) in their tissues. Ontogenetic increases are common in shark species while sex-based differences are known in some billfishes.

To determine their mercury levels, common thresher and shortfin mako were sampled from the coast of southern California from the west coast drift gillnet fishery, NMFS shark surveys and sport-fishing tournaments during 2004-2005. In total, 38 common threshers and 33 shortfin makos were analyzed for total Hg in white muscle. In addition, 11 common threshers and 2 shortfin makos were analyzed for total Hg in liver. All of the liver samples had no detectable levels of Hg.

Common thresher sizes ranged from 63 to 241 cm fork length. Common thresher muscle total Hg levels ranged from 0 to 0.704 ppm, wet wt. A two sample t-test did not find a significant difference in total Hg levels between the sexes (t = 0.981, df = 34.4, p = 0.33). Therefore, sexes were combined for the regression. The Pearson test found a significant regression between fork length and ln total Hg, (r^2 = .156, p = 0.014).

Shortfin mako sizes ranged from 75 to 330 cm fork length. Shortfin mako muscle total Hg levels ranged from 0.152 to 2.90 ppm, wet wt. A two sample t-test did not find a significant difference in total Hg levels between the sexes (t = 1.561, df = 31, p = 0.13). Therefore, sexes were combined for the regression. The Pearson test found a significant regression between fork length and ln total Hg (r^2 = .769, p < 0.001).

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