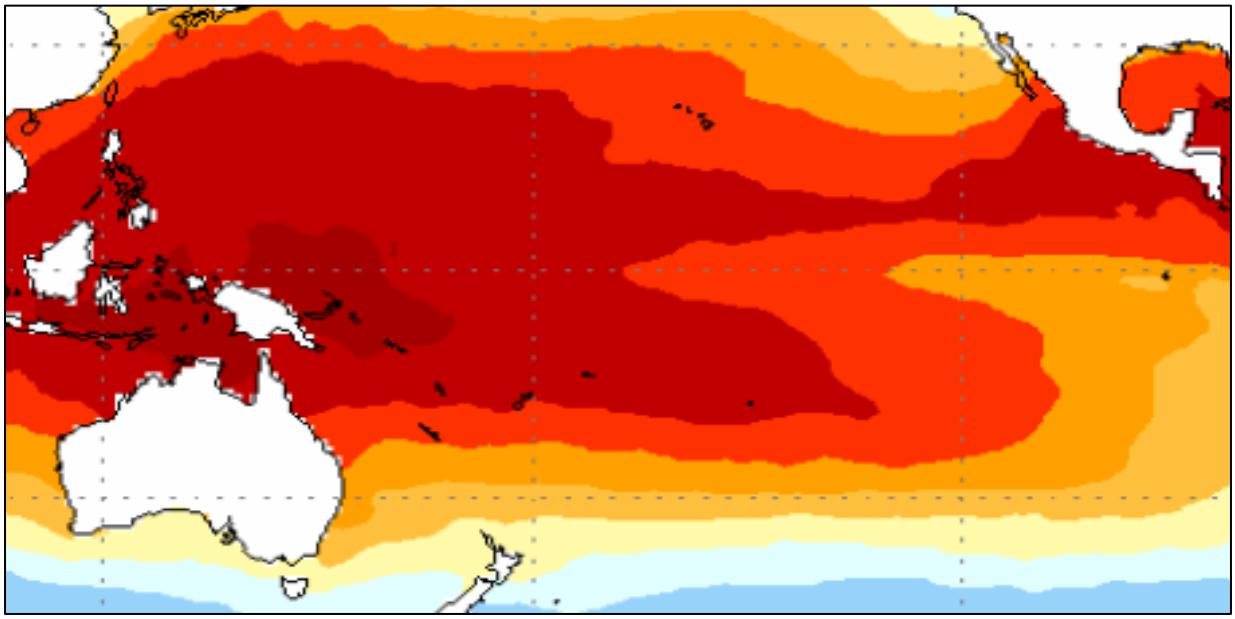
Proceedings of the 56th International Tuna Conference
Lake Arrowhead, California, May 23-26 2005

Where's the Fish?



Simon Hoyle and Michael Hinton, Co-chairs
Sponsored by the Inter-American Tropical Tuna Commission and the
Southwest Fisheries Science Center NMFS

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

PREFACE

Welcome to the 56th Tuna Conference. This international conference occurs in an informal environment in which scientists from diverse fields can exchange concepts and foster collaboration for future research. This year's theme is "Where's the fish?", a very general theme that summarises the various reasons we are here. We thank all presenters (both paper and poster) for their contributions.

The *Caboz Memorial Scholarship* was awarded to Mathieu Doray for his research on "The Distribution And The Dynamics Of Large Pelagic Fish Aggregations Around Moored Fads In Martinique (Lesser Antilles) And Their Contribution To Local Fisheries". *Tuna Conference Scholarships* were awarded to Ramzi Mirshak for 'Towards Mapping Thermocline Depth In The Equatorial Pacific With Satellite Altimetry'; Walter Golet for 'Analysis Of Shape And Fat Content In The Gulf Of Maine Bluefin Tuna (*Thunnus thynnus*)'; John Logan for 'Analysis Of Forage Preferences And Movement Patterns Of Atlantic Bluefin Tuna (*Thunnus thynnus*) Using Carbon And Nitrogen Stable Isotopes'; and John Richert for 'Spatio-Temporal Variability In The Trophic Ecology Of Large Pelagic Fishes Of The Southern Gulf Of California'. The Tuna Conference is very pleased to support their participation and their research interests, and we hope they will find the conference a valuable experience. We thank Wildlife Computers for their donation, which was added to the scholarship fund.

We also gratefully acknowledge donations to the Tuna Conference by Monterey Bay Aquarium, the Federation of Japan Tuna Fisheries Cooperative Association, the American Tunaboat Association, the US Tuna Foundation, and Prime Time Seafood. Our Tuna Conference experience will definitely be enhanced by their generosity.

Chairing the tuna conference is an initiation rite for new staff at the IATTC and NMFS, *i.e.* 'a formalized, ceremonial rite of passage that may involve secret or private procedures and/or painful and difficult trials…'. This year the initiation process (for Simon) has been undermined through the efforts of many people, whose experience and support have made organizing the conference run smoothly. We particularly thank JoyDeLee Marrow for her extraordinary assistance in planning this year's event. She kept track of all the people, the money, and the important deadlines. We thank Ed Everett for helping to organize transport and many other vital tasks (*i.e.*, making sure there is enough beer), Millie De Los Reyes for help with the banking, Randall Rasmussen for updating the web site, Don Petersen for the tuna pickup, and Kim Holland and his team of sashimi cutters. Bill Bayliff, Gary Sakagawa, and Jeanne Wexler provided prompt and useful reviews as members of the Scholarship Committee. We also thank a number of other former chairs and administrators for their very useful advice. The efforts of the session moderators, Richard Brill, Kerstin Fritsches, Molly Lutcavage, Nanette Malsol, Robert Olson, Don Petersen, and John Sibert, are also appreciated.

The abstracts contained in these Proceedings were edited solely for formatting. All abstracts appear in the order in which they are scheduled in the program. If readers would like further information about these talks or to cite any information or ideas contained in the Proceedings, they should contact the author(s) for the appropriate citation.

Have a productive conference.
Simon Hoyle and Michael Hinton, Co-chairs

NOTES

AGENDA

Monday, 23 May 2005

12:30 – 14:00 Registration

14:00 Conference Begins – Welcome and Introduction

Session 1: Tagging & Movement (Moderator: Molly Lutcavage)

14:10 PROGRESS IN DEVELOPING "ECOLOGY TAGS" FOR LARGE PELAGIC FISHES – Kim Holland, Carl Meyer, Yannis Papastamatio, and Laurent Dagorn

14:32 IMPROVING LIGHT-BASED GEOLOCATION BY INCLUDING SEA SURFACE TEMPERATURE – Anders Nielsen, Keith A. Bigelow, Michael K. Musyl, and John R. Sibert*

14:50 REFINING LIGHT-BASED POP-UP ARCHIVAL TAG TRACKS USING THE KFSST PACKAGE – Evan A. Howell, Anders Nielsen, and Jeffrey J. Polovina

15:07 ANALYSIS OF SMOOTHED SEA SURFACE TEMPERATURE FIELDS TO IMPROVE KALMAN FILTERED ESTIMATES OF ATLANTIC BLUEFIN TUNA (*THUNNUS THYNNUS*) LOCATIONS – Ben Galuardi, Anders Nielsen, and Molly Lutcavage

15:25 Coffee break

15:47 WHERE'S THE TURTLE? A MOVEMENT MODEL OF LOGGERHEAD SEA TURTLES (*CARETTA CARETTA*) IN THE NORTH PACIFIC OCEAN – Donald R. Kobayashi and Jeffrey J. Polovina

16:10 PRELIMINARY RESULTS FROM SWFSC/AFRF NORTH PACIFIC ALBACORE ARCHIVAL TAGGING PROJECT – John Childers, Suzanne Kohin, Paul Crone, and John LaGrange

16:32 MOVEMENT, BEHAVIOR, AND HABITAT OF YELLOWFIN TUNA IN THE EASTERN PACIFIC OCEAN, AS ASCERTAINED FROM ARCHIVAL TAGGING DATA – Kurt Schaefer, Daniel Fuller, and Barbara Block

16:55 Announcements

17:00 Registration and check-in continued

17:30 Welcome gathering in Tavern (continued after dinner)

18:30 Dinner
Socializing in the Tavern.

*presenter if not senior author

20:00 Monday night movie: BIGEYE TAGGING CRUISE 2003, ABOVE AND BELOW THE WATERLINE – Kurt Schaefer and Dan Fuller

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Tuesday, 24 May 2005

8:00 Breakfast

Session 2: Modeling & Oceanography (Moderator: John Sibert)

9:00 RECENT RESULTS AND INTERROGATIONS ABOUT THE DYNAMICS OF ATLANTIC BLUEFIN TUNA POPULATION – François Royer and Jean-Marc Fromentin

9:22 COLERAINE MODEL ASSESSMENT OF NORTH PACIFIC ALBACORE TUNA – Max Stocker, Simon Hoyle, Shelton Harley, and Mark Maunder

9:45 MODELING TUNA POPULATION MOVEMENT USING ADR APPROACH ON MIXED-RESOLUTION SPATIAL SCALE – Inna Senina, John Sibert, and Patrick Lehodey

10:07 WHY ARE THERE STILL LARGE PELAGIC PREDATORS IN THE OCEANS?: EVIDENCE OF SEVERE HYPER-DEPLETION IN LONGLINE CATCH-PER-EFFORT – Robert Ahrens and Carl Walters

10:30 Coffee Break

10:50 ANCHORED RESEARCH BUOYS: POTENTIAL OPPORTUNITY FOR ESTIMATING RELATIVE ABUNDANCE OF TUNAS? – Shelton Harley and Mark Maunder

11:12 AMERICAN SAMOA ALBACORE TUNA HABITAT AND THE OCEANOGRAPHIC CHARACTERIZATION OF THE AMERICAN SAMOA FISHING GROUNDS – Réka Domokos, Donald Hawn, Jeffrey Polovina, and Michael Seki

11:35 TOWARDS MAPPING THERMOCLINE DEPTH IN THE EQUATORIAL PACIFIC WITH SATELLITE ALTIMETRY – Ramzi Mirshak

12:00 Lunch

Session 3: FADs (Moderator: Richard Brill)

13:10 OBSERVING TUNA AND THEIR PREY COMMUNITY AROUND DRIFTING FADS USING A MULTI-FREQUENCY ECHOSOUNDER – Gala

Moreno, Erwan Josse, Patrice Brehmer, and Leif Nottestad

13:32 BEHAVIOR OF TUNAS AROUND DRIFTING FADS: THE FISHERMEN'S POINT OF VIEW – G. Moreno, L. Dagorn, and G. Sancho*

13:55 WHY DO DOLPHINFISH (*CORYPHAENA HIPPURUS*) ASSOCIATE TO FLOATING OBJECTS? – Marc Taquet, Jean-Claude Gaertner, and Laurent Dagorn

14:17 THE DISTRIBUTION AND THE DYNAMICS OF LARGE PELAGIC FISH AGGREGATIONS AROUND MOORED FADS IN MARTINIQUE (LESSER ANTILLES) AND THEIR CONTRIBUTION TO LOCAL FISHERIES – Mathieu Doray

14:40 Coffee break

15:00 HOW LONG DO FISH STAY AROUND DRIFTING FADS? – L. Dagorn , C. Girard , M. Taquet , G. Sancho , D. Itano , R. Aumeeruddy , C. Peignon , G. Moreno , E. Josse , P. Brehmer, and K. Holland

15:22 ANCHORED FADS AS MONITORING STATIONS – David Itano, Kim Holland, Laurent Dagorn, and Dean Grubbs

15:45 TROPHIC ECOLOGY OF YOUNG-OF-YEAR YELLOWFIN TUNA IN HAWAI'I – Dean Grubbs, Kim Holland, and David Itano

16:30 Poster session (see list of posters) and 'Sushi Party' in the Tavern
Party sponsored by Japan Tuna Fisheries Cooperative Association, the US Tuna Foundation, the American Tunaboat Association, and Prime Time Seafood, Inc.

18:30 Dinner

List of Posters

END OF THE LINE: USING INSTRUMENTED LONGLINE TO STUDY VERTICAL HABITAT OF PELAGIC FISHES – Donald Hawn and Michael Seki

LIFESIZE ATLANTIC BLUEFIN PAINTING – Susan Slayter King

LET'S TALK ABOUT SEX: THE DEVELOPMENT OF SEX-SPECIFIC MOLECULAR MARKERS FOR THREE SPECIES OF BILLFISH: BLACK MARLIN (*Makaira indica*), BLUE MARLIN (*Makaira nigricans*) AND STRIPED MARLIN (*Tetrapturus audax*) – Catherine Purcell and Suzanne Edmands

A NOVEL APPROACH FOR IMPROVING SHARK BYCATCH SPECIES IDENTIFICATIONS BY OBSERVERS AT SEA – Marlon H. Roman, Nick Vogel, Robert Olson and Cleridy Lennert

*presenter if not senior author

RELATIONSHIP BETWEEN YELLOWFIN AND SKIPJACK TUNA FREE SCHOOL DISTRIBUTION AND OCEANOGRAPHIC FEATURES IN THE GULF OF GUINEE AND INDIAN OCEAN – Igor Sancristobal and Yolanda Sagarminaga

ELECTRONIC TAGGING DATA REPOSITORY: http://shibi.soest.hawaii.edu:8080/knb – John Sibert and Johnoel Ancheta

MULTI-SPECIES AGGREGATIONS AROUND DRIFTING FADS: THE UNDERWATER VIEW – Marc Taquet, Riaz Aumeeruddy, David Itano, Gorka Sancho, Bertrand. Wendling, Laurent Dagorn, Christophe Peignon

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Wednesday, 25 May 2005

8:00 Breakfast

Session 4: Ecology (Moderator: Nanette Malsol)

9:00 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

9:22 FEEDING ECOLOGY OF NERITIC TUNAS IN TROPICAL NORTHERN AUSTRALIA: PRAWN PREDATORS IN THE NORTHERN PRAWN FISHERY – Shane Griffiths, Gary Fry, Fiona Manson, and Richard Pillans

9:45 TROPHIC RELATIONS AMONG PELAGIC FISHES IN THE TUNA PURSE-SEINE FISHERY OF THE EASTERN PACIFIC OCEAN – Noemí Bocanegra-Castillo, Felipe Galván-Magaña, and Robert J. Olson

10:07 TROPHIC STRUCTURE IN THE PELAGIC EASTERN TROPICAL PACIFIC OCEAN: PROGRESS BASED ON STABLE ISOTOPES AND DIETS – Robert Olson, Brittany Graham, Felipe Galván-Magaña, Brian Popp, Valérie Allain, and Brian Fry

10:30 Coffee Break

Session 5: Biological Studies (Moderator: Robert Olson)

10:50 MOLECULAR INDICATORS OF CAPTURE RELATED STRESS IN PELAGIC SHARKS CAPTURED BY COMMERCIAL AND SPORTFISHING GEAR – Diego Bernal

11:12 TEMPERATURE AND OXYGEN REQUIREMENTS FOR SURVIVAL OF FIRST-FEEDING YELLOWFIN TUNA (*THUNNUS ALBACARES*) LARVAE

AND LABORATORY GROWTH OF THE LARVAL AND EARLY JUVENILE STAGES OF YELLOWFIN TUNA – Jeanne Wexler, Daniel Margulies, Vernon Scholey, Jenny Suter, and Sharon Hunt

11:35 VISUAL CAPABILITIES IN TUNA AND BILLFISHES – FROM ANATOMY TO BEHAVIOUR – Kerstin A Fritsches

12:00 Lunch

Session 6: Billfishes and bycatch (Moderator: Don Petersen)

13:10 MOVEMENTS OF PACIFIC BLUE MARLIN RECORDED USING PSATs – Mike Musyl, Chris Moyes, John Sibert, Anders Nielsen, Andrew West, Lianne McNaughton, and Richard Brill*

13:32 WHERE THE BILLFISHES WERE (AND WERE NOT) – William A. Walsh

13:55 SEASONAL AND DIEL MOVEMENTS OF BLUE MARLIN IN THE GULF OF MEXICO – Richard T. Kraus and Jay R. Rooker

14:17 SURVIVAL OF WHITE MARLIN (*TETRAPTURUS ALBIDUS*) RELEASED FROM COMMERCIAL PELAGIC LONGLINE GEAR IN THE WESTERN NORTH ATLANTIC – David W. Kerstetter and John E. Graves*

14:40 Coffee break

15:00 INCIDENTAL MORTALITY OF BLACK MARLIN (*MAKAIRA INDICA*) CAUGHT ON ROD AND REEL: DO WE HAVE A PROBLEM? – Michael Domeier

15:22 LONGLINE FISHING EXPERIMENTS ON REDUCING SEA TURTLE BYCATCH – Christofer H. Boggs

15:45 DISTRIBUTION OF DOLPHINFISH CATCHES IN THE EASTERN PACIFIC OCEAN: SEASONAL AND INTER-ANNUAL VARIABILITY – Sofía Ortega-García, Rubén Rodríguez-Sánchez, Juan Guillermo Vaca Rodríguez, and Heriberto Santana-Hernández

18:30 Dinner – Tuna conference BBQ
Party sponsored by Monterey Bay Aquarium.

Socializing in the Tavern and campfire at the Amphitheatre

*presenter if not senior author

Thursday, 26 May 2005

8:00 Breakfast

Session 7: Bluefin (Moderator: Kerstin Fritsches)

9:00 ANALYSIS OF SHAPE AND FAT CONTENT IN THE GULF OF MAINE BLUEFIN TUNA (*THUNNUS THYNNUS*) – Walter Golet, Molly Lutcavage, Andy Cooper, and Bob Campbell

9:22 EVIDENCE OF TRANS-OCEANIC MOVEMENT OF ATLANTIC BLUEFIN TUNA FROM CHEMICAL SIGNATURES IN OTOLITHS – Jay Rooker and David Secor

9:45 ANALYSIS OF FORAGE PREFERENCES AND MOVEMENT PATTERNS OF ATLANTIC BLUEFIN TUNA (*THUNNUS THYNNUS*) USING CARBON AND NITROGEN STABLE ISOTOPES – John Logan and Molly Lutcavage

10:07 REPRODUCTIVE STATUS AND CONDITION OF ATLANTIC BLUEFIN TUNA IN THE GULF OF MAINE, 2000-2002 – Jennifer Goldstein, Scott Heppell, Solange Brault and Molly Lutcavage

10:30 Coffee break

10:45 MOVEMENT PATTERNS AND POPULATION STRUCTURE OF ATLANTIC BLUEFIN TUNA (*THUNNUS THYNNUS*) AS REVEALED BY ELECTRONIC TAGS – A. Walli, B.A. Block, S.L.H. Teo, A. Boustany; K. Weng; H. Dewar, C. Farwell, and T. Williams

11:07 TRACKING OF PACIFIC BLUEFIN TUNA WITH ARCHIVAL TAGS – C. Farwell, A. Boustany, R. Matteson, M. Castleton, T. Kitigawa, and B.A. Block

11:30 Business meeting

12:00 Lunch

13:00 End of Conference – Check Out

Paper Abstracts

(In order of presentation)

Tagging & Movement

PROGRESS IN DEVELOPING "ECOLOGY TAGS" FOR LARGE PELAGIC FISHES

Kim Holland[1], Carl Meyer[1], Yannis Papastamatio[1] and Laurent Dagorn[2]

[1] Hawaii Institute of Marine Biology, University of Hawaii
[2] IRD, Seychelles

Hawaii Institute of Marine Biology
P.O. Box 1346
Coconut Island, Kaneohe, HI, USA

In an attempt to improve our ability to interpret pelagic fish behavior (e.g., diving behavior, diel shifts in habitat selection, association with FADs), we are evaluating various types of data loggers that might give insight into finer scale events such as feeding bouts and ingestion events. We are also evaluating tags that might allow us to determine physiological status (e.g., hunger level) and whether or not the animal is in a school of conspecifics or associated with structures such as FADs. Four types of data logger are currently being tested with captive sharks – stomach pH sensor, stomach motility sensor, three-dimensional accelerometer and a "bioacoustic probe". This latter device records ambient sound. Our group was the first to deploy this tag by intraperitoneal insertion and it yielded promising data. In the event that these tags prove productive and reliable, we anticipate working with the private sector to turn them into active transmitters rather than passive data loggers. Examples of data from each type of tag will be presented.

IMPROVING LIGHT-BASED GEOLOCATION BY INCLUDING SEA SURFACE TEMPERATURE

Anders Nielsen[1], Keith A. Bigelow[2], Michael K. Musyl[1] and John R. Sibert[1♦]

[1] Pelagic Fisheries Research Program, JIMAR
University of Hawai'i at Manoa
[2] NOAA/Pacific Islands Fisheries Science Center

An approach to integrate sea surface temperature (SST) measurements into estimates of geolocations calculated by changes in ambient light level from data downloaded from pop-up satellite archival tags (PSAT) is presented. The model is an extension of an approach based on Kalman filter estimation in a state-space model. The approach uses longitude and latitude estimated from light, and SST. The extra information on SST is included in a consistent manner within the milieu of the Kalman filter. The technique was evaluated by attaching PSATs directly on thermistor-equipped GPS drifter buoys. Sea surface temperatures measured in the PSATs and drifter buoy were statistically compared to SSTs determined from satellites. The method is applied to two tracks derived from PSAT tagged blue sharks (Prionace glauca) in the central Pacific Ocean. The inclusion of SST in the model produced substantially more probable tracks with lower prediction variance than those estimated from light level data alone.

♦ Presenting

REFINING LIGHT-BASED POP-UP ARCHIVAL TAG TRACKS USING THE KFSST PACKAGE

Evan A. Howell[1], Anders Nielsen[2], and Jeffrey J. Polovina[1]

[1] Pacific Islands Fisheries Science Center
[2] Pelagic Fisheries Research Project, JIMAR, University of Hawaii

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Pop-up satellite tags have been used to track animals and attempt to decipher their environmental preferences. While vertical profiles of depth and temperature data are high-quality, there are well known limitations in the accuracy of computing the geographic positions of deep-diving pelagic animals using the current light-based system. One possible solution to this problem is to incorporate sea surface temperature (SST) measurements into a state-space Kalman Filter model. In this study we used pop-up archival tag vertical and horizontal data from 8 bigeye tuna which had over 40 days at liberty. Geographic tracks were computed using the software provided with the archival tags. These raw data were then run through the SST based Kalman Filter (KFSST) to produce geographic tracks using the light-based longitude measurements and SST-based latitude measurements. These results are compared to the raw light-based tracks and most probable tracks produced by the standard light-based Kalman Filter (KFTrack) package. This approach provided improvements in tracks where sufficient temperature gradients were present. To account for thermal homogeneity around the Hawaiian Archipelago and periods when insufficient SST values could be computed from the archival tag data, subsurface temperature fields were used in place of SST. The tracks computed with this method were then compared with the ones previously computed from the KFTrack and KFSST Kalman Filter approaches.

ANALYSIS OF SMOOTHED SEA SURFACE TEMPERATURE FIELDS TO IMPROVE KALMAN FILTERED ESTIMATES OF ATLANTIC BLUEFIN TUNA (*Thunnus thynnus*) LOCATIONS

Ben Galuardi[1], Anders Nielsen[2], Molly Lutcavage[1]

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[2] Danish Institute for Fisheries Research and the Royal Veterinary and Agricultural University

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Pop-up archival satellite tags (PSAT), which record light levels, ambient temperature and depth, offer a unique way to study large pelagic species over the course of their migrations. In 2002, PSATs (PTT-100, Microwave Telemetry, Inc) were applied to 67 Atlantic bluefin tuna (*Thunnus thynnus*). These tags returned estimates of daily geolocation along the fish's migration path for as long as 11 months. Here we examine methods of optimizing the bluefin geolocation estimates with additional information. Geolocation by light level alone is inaccurate but estimates can be improved through the application of a state-space Kalman filter. The Kalman filter is a maximum likelihood estimator which can include SST's recorded by the tags as an input parameter and can also assess the match to SST satellite imagery. Smoothed sea surface temperature (SST) imagery used in conjunction with the Kalman filter has the potential to produce more accurate PSAT geolocation estimates. This technique is especially useful for fish tracked near land and in oceanic regions with distinct thermal gradients such as boundary currents. Smoothing satellite SST temporally and spatially fills in data gaps from cloud obstruction and limited swath coverage inherent to these products. Obtaining a single tag SST corresponding to a single geolocation requires an average of all SST readings that day. This necessitates matching to a smoothed rather than discrete field. We will determine the optimal degree of spatial and temporal smoothing that best represents available environmental information in the Northwest Atlantic. Obtaining better spatial information on the distribution of highly migratory species tracked with PSAT tags is important for accurate portrayal of fish behavior, and has the potential to help fishery managers make more informed decisions.

WHERE'S THE TURTLE? A MOVEMENT MODEL OF LOGGERHEAD SEA TURTLES (*Caretta caretta*) IN THE NORTH PACIFIC OCEAN

Donald R. Kobayashi and Jeffrey J. Polovina

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A movement model of juvenile loggerhead sea turtle (*Caretta caretta*) transpacific migration is developed and tuned with 120 tracks of ARGOS satellite tag data. The model mimics the eastward swimming of small juveniles as they start from areas around Japan. The turtles transit through the Kuroshio Extension Bifurcation Region and areas north of the Hawaiian archipelago, and eventually reach the west coast of North America. The turtles return westward along a similar route. Individuals are able to complete the entire circuit in approximately five to seven years using the modeled swimming speeds and diffusivities. Several approaches will be discussed including the use of generalized additive models and Kalman Filter techniques to estimate swimming parameters. Model performance will be discussed, as well as utility of the model to assist in fishery management issues such as mapping potential interaction zones over time and space.

PRELIMINARY RESULTS FROM SWFSC/AFRF NORTH PACIFIC ALBACORE ARCHIVAL TAGGING PROJECT

John Childers[1], Suzanne Kohin[1], Paul Crone[1], and John LaGrange[2]

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[2] American Fisherman's Research Foundation

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A five year archival tagging project was initiated in 2001 to detail the migration routes of juvenile North Pacific albacore (3 to 5 year old fish) and to determine environmental preferences of the migrating fish throughout their migration cycle. The project goal is to deploy 500 tags by the end of 2005 (tagging approximately 100 fish in each year). Funding problems limited the number of releases to 20 tags in the first two years. However, 234 archival tags have been deployed to date, of which 11 have been recovered. Tagging efforts have been concentrated in 2 geographic areas with 136 tags deployed off the coast of southern California and northern Baja California, while the remaining 98 tags were deployed off Oregon and Washington. Times at liberty ranged from 62 days to 349 days. Ten of the tags were recovered in 2004 between mid-July and September. Eight of the 11 tags recovered revealed that the fish remained near or within the EEZs (exclusive economic zones) of the U.S. and Mexico off Southern California and Baja California. Three fish, which were all released in the same area within 2 days, traveled offshore to an area near 135°W longitude and 26°N latitude, moving at the same time of year. Most fish demonstrated a common diurnal pattern of repetitive deep diving (to 250 meters) during the day while remaining near the surface at night. Refinements to the latitude estimates are being made using composite SST data from satellite imagery and a Kalman filter routine. Successful feeding events are evidenced by post-prandial metabolic and body temperature elevations as has been seen for other heterothermic tunas. The last two years of the project have been very successful. The data recovered from the archival tags will help provide details of the North Pacific albacore stock structure and habitat use patterns which are essential to improving stock assessments. We expect to deploy 120 tags in 2005 off the coasts of Oregon and Washington.

MOVEMENT, BEHAVIOR, AND HABITAT OF YELLOWFIN TUNA IN THE EASTERN PACIFIC OCEAN, AS ASCERTAINED FROM ARCHIVAL TAGGING DATA

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

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[2] Tuna Research and Conservation Center

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Yellowfin tuna were captured by rod and reel off Baja California, Mexico, tagged, and released during 2002, 2003, and 2004 with 25, 43, and 115 LOTEK LTD 2310 archival tags, respectively. Preliminary results, based on data from 34 archival tag recoveries from deployments in 2002 and 2003 are presented. Times at liberty ranged from 9 to 560 days, with 17 fish at liberty for more than 180 days. Location estimates from the archival tag data sets for the fish at liberty for more than 10 months show seasonal movements to the south and then to the north correlated with shifts in the sea-surface temperatures off Baja California. The depth data illustrate previously-undocumented bounce-diving behavior throughout the day to depths commonly in excess of 250 m, apparently due to foraging behavior following movements offshore away from coastal areas and topographical features. Yellowfin habitat is evaluated from the depth, temperature, and light observations recorded by the tags.

This research is supported by the Tagging of Pacific Pelagics (TOPP) program, which is being conducted within the framework of the Census of Marine Life (COML). TOPP is a program using electronic tagging technology to study the movements of large open-ocean animals, and the oceanographic factors influencing their behavior.

Modeling and Oceanography

RECENT RESULTS AND INTERROGATIONS ABOUT THE DYNAMICS OF ATLANTIC BLUEFIN TUNA POPULATION

François Royer[1,2] and Jean-Marc Fromentin[1]

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The long term fluctuations in Atlantic bluefin tuna population, as derived by historical catch time series from the Mediterranean coastal traps (1634-1960), are investigated with various non-linear and linear signal processing tools. Following the exploratory analysis conducted by previous authors, the frequency structure of these time series is further detailed and decomposed in a stepwise manner.

Phase space embedding was first performed on the original data, uncovering a significant amount of recurring patterns: test against surrogate data of varying properties allowed to conclude about the existence of some hidden determinism and non-linearity in the observed dynamics. The high frequency structure (*i.e.* up to a period of 3 years) was then detailed using standard time series analysis tools, such as the Partial Rate Correlation Function (PRCF). All time series showed significant and negative direct and delayed density-dependence. As Bartlett's significance criterion proved to be size-dependent, Empirical Orthogonal Functions were applied as a form of meta-analysis to extract a synthetic time series, thus preserving the whole frequency spectrum of the dynamics. The synthetic PRCF strongly confirmed the original order-2 density-dependent pattern. The classic explanations for such patterns are reviewed (*e.g.* intercohort or assymetric predatory-prey interactions), and an alternative hypothesis involving non-yearly spawning due to varying condition factors is proposed. Finally, the low-frequency component of this dataset is linked to a reconstructed climate index, the Total Solar Irradiance, which shows a closely matching dominant period, with a weakly different phase behaviour. While the statistical significance of such long term association can hardly be assessed, some hypotheses involving direct and indirect responses of the oceanic ecosystem to climate may be formulated and remain to be tested.

The practical impacts of these results are discussed, in the light of recent findings from large-scale tagging programs and actual knowledge about bluefin tuna ecology and oceanography.

COLERAINE MODEL ASSESSMENT OF NORTH PACIFIC ALBACORE TUNA

Max Stocker[1], Simon Hoyle[2], Shelton Harley[3], and Mark Maunder[2]

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A statistical age-structured population dynamics model was used to assess the North Pacific albacore stock. The assessment was conducted with the generalized age structured model package Coleraine (Hilborn et al., 2003). The Coleraine model can simultaneously be fitted to a multitude of data including catch-at-age, size-at-age, and multiple indices of abundance. The model estimates parameters using maximum likelihood theory in a first phase and a Bayesian approach in a second phase. The start year of the model was 1952, the fisheries were separated into two groups namely the surface fishery (troll, pole and line, purse seine, gill net and sport) and the longline fishery, selectivity for these two groups of fisheries was modeled to vary by age, and recruitment followed a Beverton-Holt spawning biomass-recruitment relationship. Three commercial fishery CPUE indices were fitted to mid-season vulnerable biomass using selectivity-at-age. Biological parameters (e.g., growth, natural mortality, maturity schedule) used in the Coleraine model analysis were the same as those used for the albacore assessments conducted during the 19th North Pacific Albacore Workshop. There are two distinct steps in model fitting (1) obtain the best possible fit to the data by minimizing the global objective function, and (2) apply Bayesian integration to obtain estimates of the marginal posterior distribution of parameters of interest. The model was projected into the future using constant catches of 80,000 t, 100,000 t, and 120,000 t. The MCMC technique is used to generate samples from the joint posterior probability distributions. The estimated spawning biomass trajectory for North Pacific albacore shows a steady decline from the high level at the start of the time series in 1952 to the lowest level in the early 1990s. The estimated spawning stock biomass has increased considerably from the early 1990s to the present. Posterior mean (and mode) estimates of North Pacific albacore spawning biomass as well as the 90% Bayesian confidence intervals (credible regions) are presented. Histograms of the marginal posterior distribution of the ratio of the estimated spawning biomass in 2008 (future stock size) to the estimated spawning stock size in 2004 (current stock size) for three scenarios (annual landings 80,000 t, 100,000 t, 120,000 t) are presented.

MODELING TUNA POPULATION MOVEMENT USING ADR APPROACH ON MIXED-RESOLUTION SPATIAL SCALE

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Spatial environmental population dynamic model (SEAPODYM) for simulating spatial structure of tuna species based on advection-diffusion-reaction equations was implemented with mixed-resolution grid. Non-regularity of the grid is circumscribed by analytical functions, which transfer either one-dimensionally stretched or two-dimensionally stretched grid coordinates into regular ones. It allows us to introduce variable resolution into numerical scheme by using only derivatives of stretching functions. Within this approach the number of nodes as well as the cost for numerical computations remains the same.

Several simulations with mixed-resolution grids were performed to test how finer grid resolution in areas of interest can improve the model catch predictions for population of skipjack. The hypothesis that coarse 1 degree resolution in SEAPODYM results in insufficient predictions of catches in Kuroshio region was tested.

In the presentation the comparison of the simulation results produced on regular and mixed-resolution grid with the same model parameterizations will be shown.

WHY ARE THERE STILL LARGE PELAGIC PREDATORS IN THE OCEANS?: EVIDENCE OF SEVERE HYPER-DEPLETION IN LONGLINE CATCH-PER-EFFORT.

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Industrial catch-per-effort (cpue) data are used as an indicator of population abundance and, contrary to strong cautions of potential biases, have in one assessment been the only data source from which inferences are made. Recent controversy surrounding the status of large predatory pelagic communities has resulted from varying interpretations of the Japanese longline cpue data. Contrary to many stock assessments on the major tuna species, ratio and fished-area-only cpue estimators for specific regions of the world oceans indicate that biomass has declined to 10% of pre-industrialized fishing levels, with large declines occurring in the first few years of fishing. We have re-examined the Japanese longline 5°x5° global data set, correcting for errors that result from utilizing ratio cpue estimators, to see if such spatially corrected cpue data provide a more reliable indicator of population abundance. Although spatially corrected cpue time series indicate depletion more in line with current stock assessments, there is evidence of severe hyper-depletion even in the corrected data. For several species, estimates of recruitment (to size classes fished by longlining) based on catch and cpue would indicate linear stock recruitment relationships. Such relationships are contrary to current assessments and are expected under declining catchability (q) over time. When recruitment is assumed stable (utilizing compensation observed over most species) q is calculated to decline rapidly over the initial years of the fishery. Other, more complex assessments utilizing recruitment and abundance estimates from catch composition data also estimate declining q even after the period of early cpue decline. Apparent fishing mortality rates (F) required to produce the initial declines in cpue with 20-30% of the maximum effort observed later, imply substantially higher F in later periods if q is assumed constant. Such high fishing mortality rates are inconsistent with current estimates from stock assessment, and with size composition of catches; yield per recruit analysis indicates that such Fs would have resulted in greater declines in mean weights than observed in the catch. Such observations can be explained by hyper-depletion in the cpue data and further investigation into the early spatial distribution of fishing effort is required to determine if effort was initially targeted at localized spatial aggregations or alternately if longline effort initially removed more active and susceptible components of the population.

ANCHORED RESEARCH BUOYS: POTENTIAL OPPORTUNITY FOR ESTIMATING RELATIVE ABUNDANCE OF TUNAS?

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One of the biggest weaknesses in tuna stock assessments is the lack of meaningful abundance indices. While longline catch-per-unit-of-effort (CPUE) data, appropriately standardized, provide information on relative abundance of large tunas, information about relative abundance of small tunas is either absent or inadequate, leading to uncertainty in current stock status and short-term projections. It is difficult to derive reliable indices of abundance from purse-seine CPUE data because of the highly-aggregated behavior of the tuna and non-random searching behavior of purse-seine fisheries. These difficulties are magnified with the new technology associated with the use of fish aggregating devices (FADs).

Here, we discuss the anchored research buoy array that is distributed across the Pacific Ocean as part of the Tropical Atmospheric Ocean (TAO) project and how it interacts with tuna and tuna fisheries in the tropical eastern Pacific Ocean. We describe the types of fishery and oceanographic data that are available from this research program, and the IATTC data bases. We discuss the future directions in modeling and data collection that could allow the estimation of abundance indices from these data.

AMERICAN SAMOA ALBACORE TUNA HABITAT AND THE OCEANOGRAPHIC CHARACTERIZATION OF THE AMERICAN SAMOA FISHING GROUNDS

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To study the American Samoa albacore habitat and fishing grounds, a variety of data types were utilized: longline catch logs from the American Samoa fisheries fleet, ambient temperature and depth recorded by PAT tags attached to albacore, 38kHz and 120kHz acoustic backscatter and CTD profiles from shipboard measurements, and sea surface height from satellite altimetry. The American Samoa fishing grounds is a dynamic region with strong mesoscale eddy activity that show temporal variability on the scale < 1 week. In addition, high horizontal shear towards the northern half of the American Samoa EEZ during March and April between the eastward flowing South Equatorial Counter Current (SECC) and the westward flowing South Equatorial Current — with a signature of high sea surface height in the northern half of the EEZ relative to that of the southern half — results in instability, contributing further to eddies and meanders during the peak months of March and April. Longline albacore catch tend to be located at the eddy boundaries. Albacore catch per effort show intra-annual variability with high catch per effort during May through August relative to catch per effort from September through April. Further, during the May-August 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. Albacore spend most of their time between 150 − 250 m depth, corresponding to 25 − 21°C, with depths (temperatures) between 150−300 m (25−18°C) during the day and 0−200 m (30 − 24°C) during the night. The depth of 150 − 250 m corresponds to relatively high biomass — estimated from acoustic backscatter — as well as to strong temperature and salinity gradients. While temperature and salinity are relatively uniform from north to south throughout the EEZ, concentration of subsurface dissolved oxygen is lower while concentrations of chloropigments are higher toward the northern end.

TOWARDS MAPPING THERMOCLINE DEPTH IN THE EQUATORIAL PACIFIC WITH SATELLITE ALTIMETRY

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A fundamental problem in modeling any ocean ecosystem is the dynamic nature of the ocean itself. For example, bigeye tuna (*Thunnus obesus*) are believed to prefer the colder water below the thermocline. Historically, thermocline depth is derived from *in situ* data which are expensive to obtain and give sparse coverage at best. Using remote sensing, on the other hand, gives consistent spatial and temporal coverage but only measures the state of the sea surface. As much as 97% of thermocline depth variance occurs on time scales captured by contemporary remote sensing altimetry methods. Hence, if the thermocline can be mapped by satellite altimetry, it would provide rich spatial and temporal coverage. In this study, we exploit the concept of isostasy to infer thermocline depth from satellite altimetry. Using ten-year time series of both temperature profile data from the Tropical Atmosphere Ocean (TAO) project and TOPEX/Poseidon altimetry data, a relationship between remotely sensed sea-surface height and *in situ* measurements of thermocline depth across the entire domain of the TAO mooring array is found. Examining relationships at and between individual mooring stations shows variability in the relationship across the domain.

FADs

OBSERVING TUNA AND THEIR PREY COMMUNITY AROUND DRIFTING FADS USING A MULTI-FREQUENCY ECHOSOUNDER

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Drifting FADs (Fish Aggregating Devices) are extensively used in purse seine fisheries; more than 70% of tuna catches in the Indian Ocean are taken around drifting FADs. Although this usage of FADs by tuna fisheries has been well known by the scientific community for years, very few studies have characterized these fish aggregations. Hydroacoustics represent a powerful tool to study the composition and behaviour of such fish aggregations. During FADIO cruises (Fish Aggregating Devices as Instrumented Observatories of pelagic ecosystems, a research project funded by the European Community), acoustic data were collected in the western Indian Ocean from fish aggregations around drifting FADs, and on local sound scattering layers (SSL). The tuna aggregations and their prey environment were studied using a Simrad EK60 echosounder with three frequencies: 38, 70 and 120 kHz. Advances in multi-frequency analysis allow echo-classification and an accurate characterization of the biotic environment, which shows the potential of multi-frequency treatment analyses to study such aggregations in large pelagic environments. Results show that tuna aggregations around those FADs can be very dynamic over short time periods, in terms of school structure, vertical displacement and density. Relationships with local prey environments (SSL) are discussed.

BEHAVIOR OF TUNAS AROUND DRIFTING FADS: THE FISHERMEN'S POINT OF VIEW

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Drifting Fish Aggregation Devices (FADs) in the open ocean are difficult to access in order to study associated tuna aggregations. Recent efforts to study tuna behaviour and develop new technologies to observe pelagic ecosystems as part of the FADIO[1] Project, funded by the European Union, further confirmed the difficulty of directly studying the behavior of tuna associated with drifting FADs in the open ocean. A collaborative approach to this problem was to obtain relevant field data from those who most regularly visit drifting FADs and observe the behaviour of tuna around them; the skippers of tuna purse seine fishing boats. Spanish and French purse seiners have been exploiting and seeding drifting FADs in the Western Indian Ocean for the past 20 years, with limited scientific observer data available. The experiential-based knowledge of their skippers is a valuable source of data which has been largely untapped, but that can compliment scientific knowledge on tuna movements and behaviour obtained through other methods (acoustics, divers, tagging). More than 30 personal interviews of Spanish and French skippers were completed. It should be noted that skippers demonstrated a high degree of collaboration and enthusiasm during the interviews. Overall the surveys focused on tuna behaviour and fishing strategies on drifting FADs , and produced valuable information spanning twenty years, with almost daily observations on drifting FADs. Data from this empirical source of knowledge will be presented, discussed and compared to information on tuna behaviours collected through other methods. Preliminary analyses have yielded valuable information on drifting FAD colonization and decolonization rates, tuna school dynamics, and the role of environmental conditions in aggregation processes around FADs.

[1] Fish Aggregation Devices as Instrumented Observatories of pelagic ecosystems (http://www.fadio.ird.fr/)

WHY DO DOLPHINFISH (*Coryphaena hippurus*) ASSOCIATE TO FLOATING OBJECTS?

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Although different hypotheses have been advanced to explain why fish associate with floating objects (with main focus on tunas), none of them could be proven so far. It is possible that all associated species do not associate for the same reasons. Although it is admitted that tunas do not generally feed on prey associated to Fish Aggregating Devices (FADs), one assumption for dolphinfish is that if they are so frequently found associated to FADs, it might be because they mainly feed on associated prey. Moreover, if we want to understand the possible effects of FADs on the pelagic ecosystem, we must determine what the different species do while around FADs.

A stomach content analysis has been conducted on dolphinfish captured around drifting objects in the Indian Ocean in order to study why this species is so frequently found around FADs. In parallel to this diet study, precise inventories of species associated to FADs (within the first 50 meters) have been done through scientific dives, in order to determine which prey species are associated to FADs. It appears that prey associated to floating objects only represent 27% (in weight) and 14% (in number of individuals) of the diet of adult dolphinfish captured around drifting FADs. The majority of the diet comes from species that are not found associated to floating objects, such as flying fish and organisms from the Deep Scattering Layer (DSL). Therefore, the frequent excursions off FADs, as determined from acoustic tagging, could correspond to foraging behavior. We postulate that FADs could serve as a feeding reserve for dolphinfish, where they would feed only when other prey are not available. Whether dolphinfish associate to FADs because of this reserve ("better a bad meal than no meal"), or because FADs could be indicators of the richness of the area (indicator-log hypothesis), is discussed.

THE DISTRIBUTION AND THE DYNAMICS OF LARGE PELAGIC FISH AGGREGATIONS AROUND MOORED FADS IN MARTINIQUE (LESSER ANTILLES) AND THEIR CONTRIBUTION TO LOCAL FISHERIES

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In response to the rapid expansion of FAD-based fisheries in Martinique and Guadeloupe islands (French West Indies), the DAUPHIN research program was initiated by IFREMER to study large pelagic fish aggregated around moored FADs and their contribution to the local fishery.

From April 2003 to April 2004, monthly sea surveys (each of 60 h duration) were conducted around 2 moored FADs in Martinique. The use of a scientific echo-sounder combined with an underwater camera and classical fishing methods allowed determination of overall biomass and species composition as well as fine scale temporal analysis of the behavior and spatial geography of the assemblage. This paper presents the first results of ongoing data processing.

Large diel variations of the fish distribution were observed around the moored FADs. At daytime, 4 types of fish aggregations were observed: i) a large sub-surface (30 -100 m) aggregation of small tunas ii) aggregations of very small tuna very close to the surface iii) a surface wreckfish aggregation iv) sub-surface scattered large predators (mainly blue marlin, *Makaira nigricans*). Tuna aggregations assembled close to the moored FADs 2 h before sunrise during nearly all the surveys. The daily biomass of the aggregation peaked in the morning or around noon. The large sub-surface aggregation (220m long and 70m high in average) was situated within the mixed layer and accounted for nearly all the large pelagic fish biomass aggregated around the moored FADs during the daytime. This aggregation was distributed within 400m from the FAD buoy, was generally up-current, and appeared to be primarily comprised of 50cm FL blackfin tunas (*Thunnus atlanticus*), sometimes mixed with yellowfin (*Thunnus albacares*) and skipjack (*Katsuwonus pelamis*) tunas of at least the same size. The average estimated biomass of the aggregation was 45 MT. The sub-surface tuna aggregation spread away in the afternoon and had nearly disappeared at sunset. At night time, a smaller sub-surface tuna aggregation was generally observed near the moored FAD, whereas unidentified scattered fishes were detected from 10 to 500m depth. Dramatic day to day variations of the maximum daily biomass were commonly observed, as well as seasonal variations.

The local artisanal fishery appeared to exploit a very small part of the resources aggregated around the moored FADs. Local fishermen mainly targeted the large scattered predators while using very small tunas as living bait. Their fishing gears seemed not to be suitable to exploit the sub-surface tuna aggregations even though these aggregations represented the vast majority of the pelagic biomass around the moored FADs.

HOW LONG DO FISH STAY AROUND DRIFTING FADS?

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Drifting Fish Aggregating Devices (FADs) play a major role in tuna fisheries worldwide, as more than fifty per cent of the world catch of tropical tunas come from FAD aggregations. One of the key scientific issues related to the use of FADs in fisheries is to determine the impacts of FADs on the spatial dynamics of tunas and associated species. Determining how long different species remain around FADs is one of the priorities of this research.

FADIO (Fish Aggregating Devices as Instrumented Observatories of pelagic ecosystems) is a European Union funded research project with active participation and collaboration from European and U.S. research institutions and the commercial fishing industry (www.fadio.ird.fr). The primary objective of the project is the development of appropriate monitoring and observational tools to study fish behavior and abundance around FADs. To study the residence times of fish around drifting FADs, the present available tools are acoustic tags sending signals to automated listening stations (Vemco VR2 – www.vemco.com) that must be recovered to collect stored data. Because these receivers must stay in the water for a long time, and FADs can drift to areas difficult to reach, new listening stations capable of transmitting data via satellites were identified as a priority by the project.

Collaboration between VEMCO and FADIO has led to the development and testing of a new generation of listening stations: the ARGOS-VR3. These allow us to download data from ARGOS satellites at the lab or onboard the research vessel without returning to the instrumented FAD.

Tunas (yellowfin, skipjack and bigeye) and other associated species, such as dolphinfish (*Coryphaena hippurus*), wahoo (*Acanthocybium solandri*), silky shark (*Carcharhinus falciformis*) and oceanic triggerfish (*Canthidermis maculatus*) have been uniquely identified with acoustic tags (some of them with depth sensors) around drifting FADs in the Western Indian Ocean. Fish of different species tagged at the same time around the same FAD provide very valuable information on the dynamics of these multi-species fish aggregations. Initial results of time residency, temporal patterns and swimming depths of FAD associated species are shown.

ANCHORED FADS AS MONITORING STATIONS

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Anchored fish aggregation devices (AFADs) surrounding the island of Oahu have been instrumented with sonic receivers since August 2002 in support of PFRP studies on yellowfin (*Thunnus albacares*) and bigeye (*T. obesus*) tunas found in association with AFADs. Two years of monitoring have produced size and species specific data on arrival times, residence times and movement patterns of tuna within an island associated network of anchored FADs.

The data retrieval and maintenance of an active listening station array is logistically difficult, but can easily accommodate simultaneous studies on a variety of species. In order to capitalize on this opportunity and address some ecological aspects of FAD aggregation, we have expanded the scope of our research by deploying depth sensing sonic transmitters in yellowfin tuna. These studies use our existing listening station array; providing fishery independent data on the vertical behavior and depth stratification of two year classes of yellowfin tuna within the same anchored FAD aggregations. Stomach contents from both size classes of tuna captured during tagging operations are also being analyzed to examine feeding activity of tuna from mixed FAD aggregations.

Through collaboration with the Pfleger Institute of Environmental Research and the Western Pacific Fishery Management Council, striped marlin (*Tetrapturus audax*) are being double tagged with internal sonic tags and external pop-up archival transmitting (PAT) tags. It is hoped that a combination of tag technologies may provide both fine scale movement and residence patterns of a billfish species on AFADs and a broader look at the distribution and movement patterns of striped marlin that seasonally transit the Hawaiian Islands. The residence times and movement patterns of yellowfin in relation to AFADs and preliminary results of related studies will be discussed.

TROPHIC ECOLOGY OF YOUNG-OF-YEAR YELLOWFIN TUNA IN HAWAI'I

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The trophic ecology of yellowfin tuna (*Thunnus albacares*) has been described by numerous researchers in many regions of the Atlantic, Pacific, and Indian Oceans. With few exceptions, these studies concluded that these are opportunistic predators that feed on diverse forage bases, though only a few families of epipelagic teleosts and crustaceans often compose the majority of the diet. Most of these studies only included adult tunas, however. Very little data have been published on the feeding and ecology of young-of-year tunas, in part due to an overall lack of information concerning the distribution of the early life stages throughout much of the species' range.

The Hawaii Institute of Marine Biology, in cooperation with the State of Hawai'i's Division of Aquatic Resources, monitors and maintains 55 anchored FADS around the main Hawaiian Islands. Young-of-year yellowfin tuna aggregate to these FADs in large numbers throughout much of the year. Between October 2002 and October 2004, we collected and analyzed the stomach contents of nearly 1,000 young-of-year yellowfin tuna (19.0 - 50.0 cm fork length) from 12 different anchored FADs around the island of Oahu. Overall prey diversity was very high and primarily included micro-nektonic animals associated with the upper mixed layer, rather than organisms associated with the FADs. In total, 74 families of prey were identified, including 34 families of fishes, 30 families of crustaceans, and 9 families of molluscs. The larvae of seven families of stomatopod and decapod crustaceans were dominant in the diet, though the importance of small epipelagic fishes and the pelagic larvae and juveniles of reef-associated fishes increased ontogenetically. These data will be discussed in detail and related to ongoing projects concerning movements and distribution patterns of juvenile and adult yellowfin tuna associated with FADs in Hawaii.

Ecology

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. Preliminary results and potential implications of this ongoing study will be discussed.

FEEDING ECOLOGY OF NERITIC TUNAS IN TROPICAL NORTHERN AUSTRALIA: PRAWN PREDATORS IN THE NORTHERN PRAWN FISHERY

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Ecosystem-based fisheries management is becoming increasingly popular for Australian fisheries, such as the Northern Prawn Fishery (NPF), to demonstrate ecological sustainability. Ecosystem models (e.g. ECOPATH/ECOSIM) used to quantify fishing impacts on an ecosystem or single target species require a good understanding of the species composition in the ecosystem and their trophic relationships. This knowledge is lacking for complex ecosystems of northern Australia.

The NPF is one of Australian's most valuable fisheries, and so managers are interested in quantifying the consumption rates of commercially important prawns and valuable squid byproduct by predators in order to better estimate natural mortality rates for stock assessment models. In earlier studies of prawn predation in the NPF undertaken by CSIRO, pelagic fishes were assumed not to be major prawn predators and not studied in detail. However, recent anecdotal accounts by fishers suggesting high prawn predation by pelagic fishes prompted a quantitative pilot dietary study of numerous pelagic fishes including longtail tuna (*Thunnus tonggol*), kawakawa (*Euthynnus affinis)*, frigate tuna (*Auxis thazard thazard*), bullet tuna (*Auxis rochei rochei*) and leaping bonito (*Cybiosarda elegans*).

We found marked differences in the diet breadth (B_a=0.002-0.056) and dietary overlap (R_o=0.263-0.915) among the five species, with competing species apparently partitioning prey resources by size. Overall, the five species consumed 116 prey taxa with most species mainly consuming small pelagic fishes (engraulids and clupeids) and small pelagic crustaceans (Brachyuran megalopa). Longtail tuna had the most diverse diet and widest niche breath (100 spp.; B_a=0.056), with the highest proportion of the diet (by dry weight) comprised of *Sardinella gibbosa*, *Nematalosa come* and *Stolephorus indicus*. In contrast, the smaller species (bullet tuna, leaping bonito and frigate tuna) had the least diverse diets and narrowest niche breadths (3-11 spp.; B_a=0.002-0.017), all consuming mainly *Stolephorus* spp. Interestingly, longtail and mackerel tuna also consumed many demersal prey items suggesting some degree of benthic-pelagic coupling in this tropical Australian ecosystem. Notably, commercially important penaeids such as *Penaeus merguiensis* and cephalopods (e.g. *Photololigo* spp.) comprised a reasonable percentage of the diet of longtail tuna (3% and 5%), which is the most prolific tuna in the region.

By estimating the biomass of longtail tuna from aerial surveys in the NPF during 1982-1984 (1.9 kg km^2), we estimate in excess of 500 tonnes yr^{-1} of commercially important penaeids may be consumed by longtail tuna alone on the NPF trawl grounds; equivalent to 12% of the average annual commercial catch. This study has shown that pelagic fish may have a substantial impact on demersal assemblages, including commercially important species in the NPF, and such impacts need to be considered in ecosystem models.

TROPHIC RELATIONS AMONG PELAGIC FISHES IN THE TUNA PURSE-SEINE FISHERY OF THE EASTERN PACIFIC OCEAN

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In pelagic open-ocean ecosystems, ecological relationships among large pelagic predators, and between them and animals at lower trophic levels, are not well understood. Given the need to evaluate the implications of fishing activities on the underlying ecosystems, it is essential to acquire a reliable understanding of the trophic structure of pelagic ecosystems.

The tuna purse-seine fishery in the eastern Pacific Ocean (EPO) uses three fishing modes: sets on tuna schools associated with dolphins, sets on schools associated with floating objects, and sets on unassociated tuna schools. The size composition of the target and incidental catches is different for each fishing method. In this study, samples of predators from 41 purse-seine sets were taken at sea by IATTC observers from Ecuador and Mexico and analyzed for diet composition. Dolphin sets provided 8 predator species, principally yellowfin tuna (*Thunnus albacares,* n=350 individuals) and skipjack tuna (*Katsuwonus pelamis*, n=148). Floating-object sets provided 29 fish species, including wahoo (*Acanthocybium solandri*, n=189), common dolphinfish (*Coryphaena hippurus*, n=154), skipjack (n=148), triggerfish (*Canthidermis maculates*, n=192), bigeye tuna (*Thunnus obesus*, n=156), rainbow runner (*Elagatis bipinnulata*, n=160), yellowfin tuna (n=149), bluestriped chub (*Sectator ocyurus*, n=120), Pacific amberjack (*Seriola rivoliana*, n=74), and silky shark (*Carcharhinus falciformis*, n=72).

The stomach contents from 1834 individuals of various taxa were analyzed by zone and by fishing method. The zone boundaries were taken from a previous diet study. Overlap indices and cluster analysis were used to determine which species share the same prey. The results indicate that large predators associated with dolphins, such as silky sharks, blue marlin (*Makaira nigricans*), shortbill spearfish (*Tetrapturus angustirostris*), common dolphinfish, yellowfin tuna, and skipjack feed mainly on cephalopods (*Dosidicus gigas* and *Argonauta cornutus*) in coastal regions. In offshore waters, however, the common prey of the above predators were fishes and crustaceans. In floating-object sets, the predators are small, and include common dolphinfish, Pacific tripletail (*Lobotes pacificus*), mackerel scad (*Decapterus macarellus*), wahoo, rainbow runner, sea chubs (*S. ocyurus, Kiphosus elegans*, *K. analogus*), filefish (*Aluterus monoceros*), and bigeye, yellowfin, and skipjack tunas. The cluster analysis distinguished four groups: Group 1) common and pompano dolphinfish, silky shark, wahoo, Pacific tripletail, rainbow runner, hammerhead sharks (*Sphyrna* spp.), barracuda (*Sphyraena* spp.), and blue marlin, which prey on fishes*;* Group 2) sea chubs, triggerfish, and filefish, which consume crustaceans*;* Group 3) skipjack, bigeye, and yellowfin tuna, which prey on squids, and Group 4) mackerel scad and filefish (*Aluterus scriptus*), which consume seaweed and invertebrates. Prey overlap occurred among a few species pairs, and the species pairs and shared prey taxa differed by region. However, despite high species diversity in the communities associated with floating objects, most predator species in the EPO appear to partition the resources and occupy specific trophic niches.

TROPHIC STRUCTURE IN THE PELAGIC EASTERN TROPICAL PACIFIC OCEAN: PROGRESS BASED ON STABLE ISOTOPES AND DIETS

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There is widespread concern that fisheries are altering the structure and function of marine ecosystems. Efforts internationally are being focused on elucidating the trophic structure of pelagic ecosystems, with the goal of evaluating the effects of fishing and climate variability on the underlying ecosystems. A three-year project, funded by the Pelagic Fisheries Research Program, University of Hawaii, is designed to define the trophic structure, establish an isotope-derived biogeography, and characterize large-scale tuna movements in the pelagic western, central, and eastern tropical Pacific Ocean. This presentation reviews a subset of the progress to date, highlighting stable isotope and diet data for common fauna of the pelagic eastern tropical Pacific.

Naturally-occurring stable isotope ratios in animal tissues have been used to reconstruct diets, to trace movements, and to track sources of carbon in the food web. Isotope ratios are expressed as $\delta^{13}C$ and $\delta^{15}N$, which are the normalized $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios of samples to standards, in parts per thousand (‰). Isotopic fractionation of C and N takes place during metabolic processes, with the lighter isotope of each pair differentially excreted relative to the heavier isotope. Nitrogen isotope ratios are often used to estimate trophic position because the $\delta^{15}N$ of a consumer is typically enriched by 3-4 ‰ relative to its diet.

Stomach, muscle, and liver samples are taken from a variety of predator species by observers on tuna fishing vessels, and particulate organic matter (POM), zooplankton, and prey organisms are collected on research cruises. Diet analysis is conducted on the stomach samples, and stable isotope analysis on the muscle and liver samples of the predators, and on the other components of the food web.

Specific predator-prey interactions are examined by coupling diet and isotope data for common predators and their principal prey. Three general patterns emerge: 1) For some predator-prey pairs, the diet and stable isotope data agree quite well. 2) In other cases, discrepancies between the two approaches appear, on average, but the discrepancies are resolved by adjusting for regional differences in the N isotope compositions, which we are documenting for the predators and prey. 3) In still other cases, there are discrepancies in the expected $\delta^{15}N$ enrichment from the prey to the predator. These discrepancies may imply that some components of the diet are typically not observed in the stomach contents, perhaps prey eaten at night or small prey that are digested quickly. We assert that stable isotopes, when coupled with diet analysis, provide a powerful tool for understanding the trophic dynamics of pelagic ecosystems and establishing isotope biogeographies for key ecosystem components is an essential ingredient.

MOLECULAR INDICATORS OF CAPTURE RELATED STRESS IN PELAGIC SHARKS CAPTURED BY COMMERCIAL AND SPORTFISHING GEAR

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The post-release survivorship of hooked fishes is a key assumption underlying many fishing practices and the reduction of bycatch of non-targeted fishes. However, little is understood about how cellular stress-threshold-indicator levels correlate with the post-release survivability. Although, most fishes can recover from acute bouts of exhaustive exercise, intense and repeated struggling during capture may lead to significant tissue damage and critical disruptions to homeostasis resulting in higher rates of long-term (>30 days) post-release mortality. This study quantified the presence of specific molecular indicators of cellular stress (i.e., *Hsp,* heat shock proteins 70 and 90) in the blood of sharks with different levels of swimming activity (i.e., the active short fin mako shark and the sluggish blue shark) in responses to capture with sport-fishing gear and commercial longline gear. Preliminary results for sport-caught sharks show an increase in the levels of *Hsps* as a function of angling time (i.e., struggle stress) in the mako shark and relatively smaller response in the blue shark. No apparent pattern has emerged for the longline caught specimens. When the levels of *Hsps* are compared between the two capture techniques, a higher stress response appears to be present in fishes caught with the commercial gear. Taken together, this preliminary study provides an initial assessment of molecular stress response in sharks and will serve as the foundation for future studies on the long-term molecular responses to capture related stress in fishes.

TEMPERATURE AND OXYGEN REQUIREMENTS FOR SURVIVAL OF FIRST-FEEDING YELLOWFIN TUNA (*Thunnus albacares*) LARVAE AND LABORATORY GROWTH OF THE LARVAL AND EARLY JUVENILE STAGES OF YELLOWFIN TUNA

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Recent experiments at the Achotines Laboratory in Panama were designed to determine the minimum and maximum lethal water temperatures and minimum dissolved oxygen requirement for first- feeding yellowfin larvae. These experiments were conducted to determine physical limitations to the distribution of yellowfin larvae in the ocean.

Fertilized eggs from the daily spawning of the yellowfin brood-stock at Achotines were collected and used for each temperature- and oxygen-controlled experiment. Results from the temperature experiments indicate that first feeding larvae are not capable of surviving at water temperatures ≤ 20ºC during the first day of feeding and at temperatures ≥34ºC after the first 2 days of feeding; however, they are capable of feeding and surviving at 21ºC and 32ºC for up to 3 days after first feeding. Results from the dissolved oxygen experiments indicate that during the first 8 hours of feeding yellowfin larvae are able to survive dissolved oxygen levels of > 2.20 mg/L (> 33.0% of oxygen saturation) at an average water temperature of 27.1 ºC (range 25.9-28.0 ºC) .

Measurement data from a series of experiments and rearing trials since 1997 were analyzed to examine possible factors affecting growth rates of yellowfin larvae and juveniles up to 45 days after hatching. The interactive effects of larval fish density, micro-turbulence, water temperature, and diet appear to influence the growth of yellowfin larvae up to 18 days after hatching just prior to juvenile transformation. Survival and growth during the early juvenile stage appears to be most strongly affected by diet and may be secondarily influenced by water temperature and fish density.

The fastest laboratory growth rates of yellowfin larvae were also compared with those of comparable-aged larvae collected in pelagic waters of the Panama Bight between 1990 and 1997. The laboratory growth rates were 12% lower than the slowest-growing group collected in the field; however, sizes at age of the laboratory fish approached those of the field-collected fish shortly after a piscivorous diet had been introduced. The discrepancy between laboratory and field growth rates and sizes at age prior to the introduction of a fish diet may be associated with suboptimal growth conditions in the laboratory.

VISUAL CAPABILITIES IN TUNA AND BILLFISHES – FROM ANATOMY TO BEHAVIOUR

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The open-ocean habitat of tuna and billfishes is one of the clearest aquatic habitats on earth, allowing light to penetrate much further horizontally and vertically than in coastal seawater or many freshwater habitats. The clear water allows the animals' visual sense to play a key role in many behaviours such as detection of prey and predators and prey capture; and the large eyes and well-developed visual centres indicate the importance of vision in these pelagic fish species. The remote habitat of tuna and billfishes renders the study of their visual system difficult, requiring a range of approaches to achieve our aim of understanding the visual capabilities of these blue water fishes.

In this ongoing comparative study we use optical, anatomical and physiological techniques to investigate areas such as the ability for colour vision, sensitivity to light, ability to detect fine detail as well as detection of motion. Animals are sampled in the central Pacific on research longline vessels of the National Marine Fisheries Service, as well as sourced from recreational fishermen in both Australia and the USA.

Throughout our investigation we find a strong correlation of preferred diving depths and visual capabilities in the tuna and billfishes studied. Both light intensity and the range of different wavelengths (colours) are reduced with increasing depth in the ocean, shaping the capabilities of the fishes inhabiting different depths. Deep divers such as the bigeye tuna or the swordfish have larger eyes, pupils and lenses than their shallow-diving relatives. Also, the dimensions, morphology and topography of the photoreceptors show adaptations to increase light capture, necessary in the dim-light habitat. The ability to detect fine detail (visual acuity) is similar in all species studied, irrespective of eye size. This suggests that the large eye size of deep divers is utilised to increase sensitivity to light rather than improve spatial resolution. Temporal resolution (a measure of motion detection) is lower in deep divers and a comparative study of species with different vertical niches shows a clear correlation with diving depth. Using a colony of small captive tuna (*Euthynnus affinis*) we now aim to complete the picture of these animals' visual capabilities by testing assumptions based on anatomy and physiology with research capturing actual visual behaviour.

Billfishes & Bycatch

MOVEMENTS OF PACIFIC BLUE MARLIN RECORDED USING PSATs

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We have deployed 39 popup satellite archival tags (PSATs) on Pacific blue marlin. The majority of fish were caught adjacent to the lee side (Kona Coast) of the Island of Hawaii by recreational fishers using both lures (84%) and live bait (16%). Three striped marlin and one black marlin have also been tagged. Approximately 80% of the PSATs reported data. On average PSATs remained attached for 76 days, although several tags remained on the fish until their programmed pop-off dates (i.e., for eight months). In total, we have data for blue marlin from 2140 days at liberty.

There was only one clear incidence of a post-release mortality. This occurred 82 days after release, and we conclude that it is very unlikely that the mortality was a result of the capture, release, and tagging events.

Our depth data agree with those previously obtained from marlins equipped with depth-sensitive acoustic telemetry tags. Even when observed for long periods and during extensive migrations, blue marlin in the Pacific can clearly be characterized as creatures of the upper uniform temperature layer. The fish spent approximately 70% of their time shallower than 50 m and only rarely descended below the thermocline. A few blue marlin exhibited a clear diurnal pattern in swimming depth, being shallower at night (generally above 10 m) than during the day. Overall, however, there were no clear differences in day and night depth distributions. The black and striped marlins showed roughly similar behaviors.

The general net movements of blue marlin were predominately eastward, and no fish moved significantly west of the main Hawaiian Islands following release. Likewise, only one fish moved further north than 30°N, and only three fish crossed the equator. One blue marlin reached the west coast of Central American and appeared to be returning westward when the PSAT jettisoned.

WHERE THE BILLFISHES WERE (AND WERE NOT)

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Ongoing studies of billfish (Istiophoridae) catch data reported in mandatory logbooks by the Hawaii-based longline fleet have documented and characterized misidentification problems with the five species known to be taken here (striped marlin, *Tetrapturus audax*; shortbill spearfish, *T. angustirostris*; blue marlin, *Makaira nigricans*; black marlin, *M. indica*; and sailfish, *Istiophorus platypterus*). These studies, conducted by fitting statistical models to observer data, applying the model coefficients to logbook data, and then checking the residuals from the application against commercial sales records, have revealed that the blue marlin catch estimate is inflated by approximately 30% while striped marlin and shortbill spearfish have been underreported by about 10%. Sailfish and black marlin catch estimates have been highly inflated (sailfish: *ca*. 75%; black marlin: *ca*. 95%). One consequence of these patterns of error in the logbook reports is that the apparent spatiotemporal distributions of these species also exhibit substantial inaccuracies. For example, the logbook data indicate that very high catch rates for blue marlin (≥10 per longline set) are sometimes attained in the autumn and winter months north of Hawaii, which is unexpected for this primarily tropical species. This presentation will compare and contrast the apparent distributions of these species derived from the logbook data to distributions revealed by logbook data that have been corrected by statistical analyses and verified against commercial sales records.

SEASONAL AND DIEL MOVEMENTS OF BLUE MARLIN IN THE GULF OF MEXICO

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In recent decades, the by-catch (total numbers) of blue marlin (*Makaira nigricans*) reported by the U.S. pelagic long-line fishery in the Gulf of Mexico has been equal to or exceeded catches in the northwestern Atlantic Ocean. Since this fishery may account for the majority of fishing mortality on this species, information on movements of blue marlin in the Gulf of Mexico is particularly important to understand the vulnerability of this species to pelagic long-lines. We developed a statistical model of blue marlin by-catch (total numbers) from data derived from U.S. pelagic long-line fishery from 1987 to 2003 to investigate inter-annual and seasonal trends. In the Gulf of Mexico, gradual declines in standardized catches since 1987 were coincident with gradual increases in the number of drop lines between floats and decreases in total area fished. In addition, we found significant 6 and 12 month sinusoids for blue marlin catches that showed a seasonal peak during July. To better understand movements during this summer peak in abundance in the Gulf of Mexico, we also deployed pop-up archival transmitting (PAT) tags on blue marlin (30 to 90 day deployments). Of the13 blue marlin tagged to date, 12 pop-off locations were within the Gulf of Mexico. Nominal travel speed (5 nm/day) was considerably less than what has been observed for blue marlin in the north Atlantic. Because annual effort (number of hooks set) has gradually increased and long-line fishing has become more concentrated into a smaller area, the shorter displacement distances of blue marlin in the Gulf of Mexico potentially increase the probability of capture during summer. Further, PAT data demonstrated that blue marlin in the Gulf of Mexico have vertical patterns of time-at-temperature and time-at-depth that are similar to previous studies, where these fish spend most of their time in the mixed layer and at temperatures around 26C. The tendency for these fish to spend most of their time in surface waters of the Gulf of Mexico supports the concept that deeper fishing long-line gear (e.g., with more drop lines between floats) that extends below the mixed layer will be less accessible to blue marlin. Thus, indices based upon pelagic long-line fishery catches may underestimate abundances in more recent years.

SURVIVAL OF WHITE MARLIN (*Tetrapturus albidus*) RELEASED FROM COMMERCIAL PELAGIC LONGLINE GEAR IN THE WESTERN NORTH ATLANTIC

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To estimate post-release survival of white marlin caught incidentally to regular commercial pelagic longline fishing operations targeting swordfish and tunas, short-duration pop-up satellite archival tags (PSATs) were deployed on captured animals for periods of 5 - 43 days. Twenty of 28 (71.4%) tags transmitted at the pre-programmed time, including one tag that became detached from the fish shortly after release and was omitted from subsequent analyses. Transmitted data from 17 of 19 tags were consistent with survival of those animals for the duration of the tag deployment. Estimates of post-release survival range from 63.0% (assuming that all non-reporting tags were mortalities) to 89.5% (excluding non-reporting tags from the analysis). The results of this study indicate that white marlin can survive the trauma resulting from interaction with pelagic longline gear, and suggest that current domestic and international management measures requiring the release of live white marlin from this fishery will reduce fishing mortality on the Atlantic-wide white marlin stock.

INCIDENTAL MORTALITY OF BLACK MARLIN (*Makaira indica*) CAUGHT ON ROD AND REEL: DO WE HAVE A PROBLEM?

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In an ongoing effort to describe the large scale movement patterns and habitat preferences for black marlin (*Makaira indica*), pop-up satellite archival tags (PSATs) were deployed on 55 adult black marlin in both the western and eastern Pacific. As this was not a mortality study, the health of each fish was assessed and only fish deemed likely to survive after release were tagged. A previous study on striped marlin (*Tetrapturus audax*) allowed for the development of criteria to aid in the determination of individual fish health alongside the vessel. These criteria, when applied to striped marlin, reduced the incidence of tagging fish that subsequently died to zero. Differences between the recreational striped marlin fishery and the recreational black marlin fishery do not allow for the same criteria to be precisely applied (specifically with respect to fight time); however, the same general principals were adhered to for this study. Despite the care in selecting healthy fish, a significant percentage of the fish died after release. Tag data revealed a cause of death in black marlin not previously recorded in striped marlin: shark predation. Twenty-five percent of tags that have reported (to date) have documented the mortality of the fish after release. Eighty-two percent of documented mortalities were consumed by sharks. Certainly the actual mortality rate incurred by the recreational fishery is higher than what has been recorded by this study. Care must be taken when interpreting these data since the overall impact on the black marlin population cannot be estimated without population assessments and knowledge of the total take of the recreational fishery. Since sharks cause a larger percentage of the mortality, large regional differences in post-release mortality would be expected.

LONGLINE FISHING EXPERIMENTS ON REDUCING SEA TURTLE BYCATCH

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The Pacific Islands Fisheries Science Center (PIFSC) and the Western Pacific Regional Fishery Management Council are engaged in promoting the introduction of more turtle-friendly longline fishing gear and live-release techniques in longline fisheries. Collaborating with Martin Hall at the Inter American Tropical Tuna Commission (IATTC), Kimberly Davis at the World Wildlife Fund (WWF), John Watson at the Southeast Fisheries Science Center, and Peter Dutton at the Southwest fisheries Science Center (SWFSC), these scientists are conducting gear testing and demonstration projects which are increasing the use of circle hooks and turtle dehookers. This new gear has effectively reduced sea turtle bycatch and injury in US longline fisheries in the Atlantic and Pacific Oceans, but greater benefits will come from widespread adoption by foreign fleets responsible for the majority of sea turtle bycatch.

Circle hooks have points that curve sharply inwards, unlike the tuna hooks or "J" hooks most used by the world's pelagic longline fisheries. Research by NOAA in Atlantic fisheries has shown that this inward curve mostly prevents the point from catching deep inside a turtle's throat, more often catching in the beak or jaw. A tagging study in Hawaii has indicated that deeply hooked turtles die more often after release than lightly hooked turtles, at least in the short term. NOAA researchers have also shown that large circle hooks catch fewer turtles than smaller hooks, and have demonstrated that dehookers can be effective tools for removing hooks from turtles and fish.

The status of several sea turtle populations is particularly grave in the Eastern Pacific, where fisheries based in Latin America have relatively high catch rates of sea turtles. The region has been identified as a prime location in which to test potential mitigation methods, and in Ecuador a project has been initiated that has successfully exchanged old hooks used by the fishermen with several sizes of circle hooks. NOAA, IATTC, and the WWF are all helping to expand this program and to initiate similar programs throughout Latin America and the world.

In September 2004, the PIFSC and the WPRFMC sponsored a workshop to plan a joint Japan-Hawaii Sea Turtle and Seabird Experiment with participants from Japan's National Research Institute of Far Seas Fisheries, the Japanese longline industry and fishery management authority, and the Hawaii Longline Association. This group met to discuss field experiments in 2005 and beyond. Hawaii is conducting a demonstration of the new gear in its newly re-opened swordfish longline fishery using large (size 18/0) circle hooks and fish bait to reduce turtle bycatch and injury. Japan is testing small and large circle hooks in comparison to tuna hooks in shallow-set longline fishing with two research vessels, continuing research that has been underway for several years. In April 2005, representatives from a dozen countries, international and regional organizations and many local interests attended a Technical Assistance Workshop in Honolulu on Sea Turtle Bycatch Reduction Experiments in Longline Fisheries. This was a follow-up to the FAO Technical Consultation on Sea Turtle Conservation and Fisheries held in Bankok in 2004, where the US delegation offered to help other nations to design and support programs for development and testing of turtle bycatch reducing technology. These two workshops reviewed all research on turtle bycatch reduction in longline fisheries to date and provided advice on experimental design and operation. In addition to many new projects in Latin America, new projects are being developed in Australia, Indonesia, Malaysia, Papua New Guinea, Philippines, Italy, Korea, Solomon Islands, Spain, and Vietnam.

DISTRIBUTION OF DOLPHINFISH CATCHES IN THE EASTERN PACIFIC OCEAN: SEASONAL AND INTER-ANNUAL VARIABILITY

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Dolphinfish (*Coryphaena spp.*) are distributed in tropical and subtropical waters. Their distribution is limited to around the 20°C isotherm in the Atlantic, Pacific and Indian Oceans. Ecologically they are a pelagic species that inhabit surface waters and usually congregate around floating objects. As a result they are captured as bycatch by the international tuna fleet that operates in the Eastern Pacific Ocean (EPO) using floating objects. The tuna catch associated with fish aggregating devices (FAD´S) has grown significantly in recent years, leading us to suggest that bycatch may be a useful indicator of dolphinfish spatial distribution and variability. An annual average of about 550,000 dolphinfish have been reported as discarded from tuna sets associated with floating objects. Bycatch of dolphinfish recorded by the international fleet that operated in the EPO during 1997 to 2003 was provided by the Inter-American Tropical Tuna Commission. The main analysis focused on the area 10°S-10°N and from the coast westward to high seas, which includes the well-known El Niño 3 area. Inter-annual variability in total catch showed the greatest catches in 1999 and the lowest in 2003. The catches in 1999 were concentrated in the north part of the study area while in 2003 they were widely dispersed;. no clear differences in the east-west direction were observed. Other years varied between these two opposite distributions, but in general the inter-annual distribution changes were apparently related to a geographical concentration during cold conditions and a geographical extension during warmer conditions.

ANALYSIS OF SHAPE AND FAT CONTENT IN THE GULF OF MAINE BLUEFIN TUNA (*Thunnus thynnus*)

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US landings of commercial sized (>60 kg) bluefin tuna in the Gulf of Maine have been relatively steady throughout the last 13 years. Fluctuations in average landings have been no greater than approximately 200 tons between any two years during this 13-year period. However, the apparent steady state of the fishery's CPUE indices of abundance is misleading, in part because recent seasons have been extended well into the fall in order to fill the quota. Previously, quota was often filled prior to the fall. This year despite an extended season well into November the Gulf of Maine bluefin fishery experienced its worst season and filled about a third of the U.S commercial quota.

It is a long standing belief that bluefin tuna travel to the Gulf of Maine to feed on an abundant and energy-rich forage base consisting primarily of mackerel and herring. This forage base provides bluefin with the necessary fat stores for extended migration and presumably, subsequent spawning in the spring of the year. With such a rich energy source it stands to reason that bluefin tuna will follow their forage base year after year to optimize this seasonal fattening window. Recent catch statistics of bluefin tuna in the Gulf of Maine suggest that there are substantially fewer adult bluefin present than in the mid and late 1990's. More importantly, fishermen and buyers report that the quality of bluefin landed in the Gulf of Maine has decreased along with landings.

One theory to explain poorer fish quality may be a reduction in the abundance and distribution of prey in the Gulf of Maine. A reduction in abundance or school density may reduce foraging efficiency and force bluefin to shift their distribution in search of better prey abundance. Less abundant and or more dispersed forage may be one explanation for the reduction in flesh quality for those fish remaining in the area.

The quality of bluefin tuna is determined by grading its freshness, shape, muscle color and fat/oil stores. Although grading is subjective, there is remarkable consistency in grading between buyers. Shape and fat content appear to be reasonable proxies for bluefin condition, and are not affected by gear type or trip length. To determine whether the quality of bluefin tuna has decreased in recent years, we analyzed a 14-year time series of market grades.

EVIDENCE OF TRANS-OCEANIC MOVEMENT OF ATLANTIC BLUEFIN TUNA FROM CHEMICAL SIGNATURES IN OTOLITHS

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Trace elements in otoliths of Atlantic bluefin tuna (*Thunnus thynnus*) have been used to delineate stocks; however, classification success for several year-classes has been moderate ranging between 60 and 80%. Here, we evaluate the utility of an alternative geochemical marker in otoliths, stable $\delta^{13}C$ and $\delta^{18}O$ isotopes, to discriminate yearling (age-1) *T. thynnus* from Mediterranean Sea and western Atlantic Ocean. Stable $\delta^{18}O$ values in whole otoliths of *T. thynnus* collected from eastern and western nurseries were significantly different in all years examined (1999-2003), with $\delta^{18}O$ values being more enriched in the Mediterranean than in the western Atlantic. In contrast, $\delta^{13}C$ values in otoliths were similar between nurseries in all years. Although significant interannual variation was observed for $\delta^{18}O$, cross-validated classification success from discriminant function analysis was still high (98%) when year classes were pooled by region. Stable isotope values of otolith cores (~ first year of life) from school/medium and giant category *T. thynnus* were assessed in a pilot study to determine whether these signatures overlapped with those found in yearlings. Stable $\delta^{18}O$ values in otolith cores of over 30% of the medium and giant *T. thynnus* collected in the U.S. recreational fishery ranged from -0.9 to -1.6, suggestive of Mediterranean origin. Results indicate that trans-Atlantic mixing (east to west movement) of *T. thynnus* is significant.

ANALYSIS OF FORAGE PREFERENCES AND MOVEMENT PATTERNS OF ATLANTIC BLUEFIN TUNA (*Thunnus thynnus*) USING CARBON AND NITROGEN STABLE ISOTOPES

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Tissue samples were collected from Atlantic bluefin tuna (*Thunnus thynnus*) to measure carbon and nitrogen stable isotope ratios as indicators of diet and trophic position and to assess the feasibility of using isotopes to trace large-scale movements. Stable isotopes act as natural markers, with organisms incorporating dietary isotopic signatures in fairly predictable patterns. Carbon, which typically fractionates less than one part per thousand between trophic levels, and nitrogen, which typically fractionates three to four parts per thousand, can be used to determine food web linkages and trophic position, respectively. If individual forage grounds have unique isotopic signatures, movement patterns may also be determined from stable isotope analysis. By measuring tissues with different turnover rates, forage preferences and movement can be measured over multiple time scales.

To build on a preliminary stable isotope study of bluefin diet preferences in New England feeding grounds, isotope samples were collected from forage grounds throughout the North Atlantic. Bluefin tissue samples and potential prey items were collected from forage grounds off Iceland, Canada, New England, North Carolina, Virginia, and the Gulf of Mexico in the western Atlantic and the Mediterranean Sea in the eastern Atlantic. White muscle tissue was collected from all fish sampled. When possible, liver, scale, and bone samples were also collected to provide isotopic data representative of different time scales. In cases in which bone tissue was available, individual vertebral growth rings were sampled. Since rings are deposited annually, analysis of individual rings allows feeding patterns to be measured over the life span of individual fish and may provide evidence of ontogenetic shifts in diet or movement. Juvenile bluefin tissues were sampled off Virginia while adults were collected from commercial landings in all other regions.

Stable isotope analyses among regions will build on past stomach content analyses and preliminary stable isotope studies to increase our understanding of the role of bluefin tuna as apex predators in pelagic ecosystems. By matching bluefin isotope values with specific prey items, dependence on different forage species in different regions throughout their range, and across years, can be quantified.

REPRODUCTIVE STATUS AND CONDITION OF ATLANTIC BLUEFIN TUNA IN THE GULF OF MAINE, 2000-2002

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The Gulf of Maine is an important seasonal foraging habitat for Atlantic bluefin tuna. Current management models assume that bluefin travel to the Gulf of Maine annually after spawning in the Gulf of Mexico in May and June, yet recent findings from pop-up and archival tagging programs suggest a much more complex scenario, including trans-Atlantic migrations, multi-month residency in the central north Atlantic, and years in which some tagged animals do not return to the western Atlantic at all. In light of these new findings, we examined the reproductive status and body condition of Gulf of Maine bluefin in order to define the energetic status bracketing their migration patterns outside the Gulf of Maine.

During the fishing seasons of 2000 - 2002, 257 bluefin tuna ranging in size from 185 - 291cm (CFL) and weights of 75 - 314kg were sampled as a part of an ongoing study of foraging energetics and fatty acid analysis of diet. Participating fishermen provided gonads, stomachs and a muscle samples, as well as capture location, length, and weight. Round weights were not recorded because most fishermen discard heads at sea, so dressed weights were recorded instead. Histological analysis identified six distinct reproductive stages for each sex.

Gonads were staged for 221 fish, 94 females, and 127 males. With a few exceptions, females fell into two stages, stage 1, indicating immaturity or complete resorbtion of atretic and mature follicles, and stage 6, showing signs of recent spawning activity/maturity. Males were found in all stages of gonadal development. Approximately 30% of bluefin landed in June and July of all three years showed signs of recent maturity, and by August, 100% of fish landed had completely reabsorbed their mature gametes and remained in stage 1 throughout September and October. Perigonadal fat reserves increased over the season, from a low in July to a high in September.

In attempting to develop condition indices for this population, difficulties were encountered with the accuracy of conversion factors for dressed lengths and weights to curved fork (CF) lengths and round weights. A regression of converted CF length on measured CF length uncovered a negative bias of converted values, underestimating true length by 7%. Because no round weights were taken to "ground truth" dressed weights, we chose to develop a condition index based on dressed weights and dressed lengths from measured data. A regression of dressed length on dressed weight indicates a power relationship has the best fit ($R^2 = 0.91$). From this regression, a condition index, W_r was developed after Anderson and Neumann (1996) by dividing the measured dressed weights by the expected regression values. Preliminary analysis indicates an initial decline in W_r from June to July, then a gradual increase through August, September and October. In a more complete study incorporating the NMFS landings database for size reference, a multivariate analysis will be performed to determine the effects of reproductive status on body condition.

MOVEMENT PATTERNS AND POPULATION STRUCTURE OF ATLANTIC BLUEFIN TUNA (*Thunnus thynnus*) AS REVEALED BY ELECTRONIC TAGS

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An electronic tagging program was initiated for Atlantic bluefin tuna (ABFT) in 1996 to assess large-scale movement patterns, population structure, breeding site fidelity, and behavior of western-tagged ABFT. Here we report on the electronic tagging of 772 Atlantic bluefin tuna in the western Atlantic Ocean. We deployed 499 implantable archival tags and 273 pop-up satellite (PAT) tags on bluefin tuna in the western Atlantic from 1998-2004. Eighty-six archival-tagged bluefin tuna have been recaptured; 54 in the west Atlantic, 9 in the east Atlantic, and 23 in the Mediterranean Sea. Individual tracks from 2 to 1,623 days have been obtained. Twelve PAT tagged fish were recaptured and 237 PAT tags transmitted data to Argos satellites after 2 to 251 days post-tagging. Geoposition data delineate two populations, one utilizing spawning grounds in the Gulf of Mexico and another from the Mediterranean Sea. Trans-Atlantic movements of western-tagged bluefin tuna reveal site fidelity to known spawning areas in the Mediterranean Sea. Bluefin that occupy western spawning grounds move to central and eastern Atlantic foraging grounds. Our results are consistent with two populations of bluefin tuna with distinct spawning areas that overlap on North Atlantic foraging grounds.

Archival tagged ABFT displayed four different age dependent migration patterns when released from a single location in offshore shelf waters of North Carolina, USA. Adolescent ABFT display western residency moving from winter aggregations in the offshore Carolina shelf and slope waters to summer aggregations in the Gulf of Maine. Mature fish, identified as western breeders, also moved between the winter aggregation in the Carolinas to the summer aggregation in the Gulf of Maine before and after visiting a distinctive region in the Gulf of Mexico. Mature fish, identified as eastern breeders, moved from winter locations in the Carolinas or Blake Plateau either to waters east of the Flemish Cap and further to the eastern Atlantic (multiple crossings were observed across ICCAT Management Boundary) or directly transatlantic to the Mediterranean Sea. These ontogenetic habitat shifts add to the complexity of international management. Most fish displayed seasonal aggregations in the same regions over successive years. Movement, diving behavior and oceanographic settings unique to respective regions of aggregations are discussed in context of future management applications and research directions will be presented.

TRACKING OF PACIFIC BLUEFIN TUNA WITH ARCHIVAL TAGS

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Between the years 2002 and 2005, we have deployed 256 Lotek LTD 2310 archival tags on Pacific bluefin tuna, *Thunnus orientalis*, in the eastern Pacific Ocean. Tagging took place off the coast of Baja California, Mexico and the Southern California Bight in the summers of 2002 to 2004 and the winter of 2005. Tagged fish were either caught on rod and reel from sportfishing boats or released from tuna farming pens along the coast of Mexico. Size of the fish ranged from 71 to 148 cm, CFL. To date, 95 (43% of 2002-2004 releases) fish have been recaptured and 78 of the archival tags have been returned providing over 23,000 cumulative days of tracking and behavioral data in "at large" fish as well as over 3,000 days of data on captive fish in holding pens. The tagging data are providing insights into the seasonal movements, habitat utilization and residency time of Pacific bluefin in the eastern Pacific. The southern California bight region, Baja peninsula and waters offshore of Central California are emerging as peak regions of residency. Pacific bluefin of this size class appear to move in a seasonal cycle, remaining off the coasts of Southern California and northern Baja in spring and summer and migrating to Northern California waters in fall and winter. Four fish have been recaptured off the coast of Japan demonstrating trans-Pacific migrations. The data are revealing migration corridors along the west coast of North America, hot spots of aggregation, and physical movements in relation to physical oceanographic patterns that are key to understanding how Pacific bluefin tunas use the open ocean environment. In addition to data on movement patterns, archival tags are providing information on the physiological ecology of Pacific bluefin tuna. Strong signals from the specific dynamic action of feeding events show when and where tuna are feeding, providing further insight into the biology of Pacific bluefin tuna.

Poster Abstracts

END OF THE LINE: USING INSTRUMENTED LONGLINE TO STUDY VERTICAL HABITAT OF PELAGIC FISHES

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To assist characterizing vertical habitat of tuna and other pelagic fish species, Time-Depth-Temperature Recorders (TDRs) and hook timers were instrumented onto pelagic longline gear fished on six commercial tuna longline vessels operating in waters east of the Main Hawaiian Islands and south of American Samoa during 2001-05. On a typical set, TDRs and hook timers were strategically placed on the last three or four baskets of the mainline to collect catch information. By using the baskets at the end the mainline we were able to sample those baskets which the baited hooks were at fishing depth the longest. A total of 62 sets consisting of 222 instrumented baskets were monitored during the course of the study period. Of the instrumented baskets, 794 TDRs profiles were collected and 72 animals caught on hook timers, including 18 bigeye (*Thunnus obesus*) and 23 monchong (*Taractichthys steindachneri*) dominating the species caught. The results of this study are presented.

LET'S TALK ABOUT SEX: THE DEVELOPMENT OF SEX-SPECIFIC MOLECULAR MARKERS FOR THREE SPECIES OF BILLFISH: BLACK MARLIN (*Makaira indica*), BLUE MARLIN (*Makaira nigricans*) AND STRIPED MARLIN (*Tetrapturus audax*).

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In this study, we are developing sex-specific molecular markers for three species of billfish: black marlin (Makaira indica), blue marlin (Makaira nigricans) and striped marlin (Tetrapturus audax). It can be very difficult to determine the sex of adult and larval billfish, as there are no obvious external sex-distinguishing characteristics. Typically, determination of sex can only be revealed through dissection and examination of gonadal tissue, and can remain inconclusive if the fish are not sexually mature. Biological assays for sex-determination have typically targeted sex hormones such as testosterone and estradiol, or other reproductive hormones such as vitellogenin. However, these assays can be problematic due to tissue quality, maturity of the fish, and seasonal variations in hormone levels. This study is aimed at developing genetic markers to determine the sex in these species. DNA-based molecular markers have the advantage of being able to utilize preserved tissue, or tissue that is too degraded for hormonal assays. Genetic markers would also not be dependent on the size or maturity of the specimen, or dependent on the season the sample is collected. We are using random amplified polymorphic DNA (RAPD) markers to screen the genomes of these three billfish. When consistent differences in banding patterns are found between males and females, the bands are isolated and sequenced to develop sequence characterized amplified regions (SCARs) to screen for identification of sex. Developing sex-specific markers is important in studying how various fishing techniques differentially target sexes, in revealing sex-specific migration patterns on tagged fish, and even in examining the sex-composition of larvae. We will present the goals of this project, our efforts to date, and a summary of our preliminary data.

A NOVEL APPROACH FOR IMPROVING SHARK BYCATCH SPECIES IDENTIFICATIONS BY OBSERVERS AT SEA

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Bycatches of sharks have been recorded by observers of the Inter-American Tropical Tuna Commission (IATTC) since 1993 as part of the IATTC's program to study the impacts of the tuna purse-seine fishery on the ecology of the eastern Pacific Ocean (EPO). Until recently, the shark bycatch was grouped into six categories: silky shark, oceanic whitetip shark, blacktip shark, hammerhead sharks, other identified sharks, and unidentified sharks. To better understand fishery effects on specific shark populations, it was necessary to increase the taxonomic resolution of the database, to improve observer training in species identification of, at least, the most common species, and to develop forms for collecting data that can be used to confirm or revise observers' at-sea identifications.

To achieve these goals, a new shark form was implemented in 2004. This form was designed to allow observers to record species-diagnostic characteristics on 12 species of sharks, as well as sex and length information. Morphologic characteristics of the species thought most likely to occur in the bycatch are illustrated in drawings, and observers are instructed to select the drawings depicting the characteristics that most closely match those of the animals in the bycatch. The shark form was designed such that this morphological information can be entered into a computer data base and easily analyzed with computer programs. Because the new shark form is not intended to be a species key, but rather a means of collecting species-diagnostic data for post-cruise evaluation of identifications, observers are also provided with a complete shark identification guide for the species commonly occurring in the bycatch. This guide was developed specifically for the EPO purse-seine fishery, and includes images showing the most distinctive characteristics, scientific names, common names, and names used by the fishermen of several countries, as well as the diagnostic differences for distinguishing similar species. The inclusion of names used by fishermen is critical because similarities between fishermen's names for several shark species and common names have led to misidentifications.

In this poster, we describe the new shark form and companion shark identification guide. We also outline a hierarchical algorithm for using the diagnostics characteristics collected on the new shark form to confirm or revise observers' at-sea identifications. We illustrate these procedures with data for two shark species, the silky shark (*Carcharhinus falciformis*) and the blacktip shark (*Carcharhinus limbatus*).

ELECTRONIC TAGGING DATA REPOSITORY – http://shibi.soest.hawaii.edu:8080/knb

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The repository is a facility for exchange of data derived from electronic tags. It is intended to encourage development of a new culture of science where more is gained by sharing information than by locking it away dark filing cabinets. The repository has purposes beyond simple exchange of data. It serves as means to provide 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.

A presentation at 2003 meeting of the Standing Committee on Tuna and Billfish attempted to show difference in bigeye tuna vertical distribution and behavior between the Eastern Pacific Ocean and the Coral Sea. The author noted in passing that the work was made more difficult because of problems encountered in accessing relevant archival tagging data. Several scientists from around the Pacific sent a request to the Pelagic Fisheries Research Program to use the auspices of the PFRP to host an electronic tagging data exchange facility.

This simple request evolved into a more complex project than originally envisaged. A talk by Bill Michener of Long Term Ecological Research Network (LTER) at the 2003 PFRP PI meeting demonstrated clearly that a simple password protected web page would not be of long-term value. It is equally important to document the data being shared. The repository therefore uses data sharing and documentation tools created by Knowledge Network for Biocomplexity. The KNB "focuses on research into informatics and biocomplexity, through the development of software products and by providing education, outreach and training".

RELATIONSHIP BETWEEN YELLOWFIN AND SKIPJACK TUNA FREE SCHOOL DISTRIBUTION AND OCEANOGRAPHIC FEATURES IN THE GULF OF GUINEE AND INDIAN OCEAN

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The tropical areas of Atlantic and Indian Ocean are known to be high fishing spots for longline and purse seiner vessels. The current research, undertakes Spanish purse seiner's free school captures data trying to explain Yellowfin and Skipjack tuna (*Thunnus albacares* and *Katsuwonus pelamis*) local distribution related to oceanographic features. Yellowfin tuna is the main target species in these free school fisheries and dominates the catch.

For this aim, 7 years of free school data captures have been put together along with Chlorophyll-a distribution, and sea surface temperature maps obtained from SeaWIFS and AVHRR radiometers data, and Sea Level Anomaly maps obtained from TOPEX/POSEIDON and ERS altimeters. Apart from the relationship of tuna distribution with the environmental parameters analysed, this study has provided comparative results between the two species and the two oceans.

MULTI-SPECIES AGGREGATIONS AROUND DRIFTING FADS: THE UNDERWATER VIEW

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As part of the FADIO project (Fish Aggregating Devices as Instrumented Observatories of pelagic ecosystems) studying the fish communities associated with drifting floating objects (FADs) in the Indian Ocean, we performed regular underwater visual surveys in order to estimate fish abundance and composition. The resulting data on the multi-species aggregations are complimentary to equivalent datasets recorded through the use of active acoustic methods and the analysis of commercial purse-seine catches.

Underwater observations were performed right upon arrival to a FAD, with observers quickly scanning the area from the surface while using snorkel. Species composition and abundance, plus size-range estimates were recorded by the observers. Secondary dives using SCUBA were used to observe fishes associated with the FADs but found in deep waters, beyond the visual range of surface observers. To test if any fishes were sensitive to the presence of divers, preliminary trials were carried out using an autonomous underwater camera..

The fauna lists recorded under drifting FADs were very similar. However, the abundance of some species varied greatly between individual FAD's, likely heavily influenced by the date of the last purse-seine set around the FAD. Dolphinfish (*Coryphaena hippurus*), wahoo (*Acanthocybium solandri*) rainbow runners (*Elagatis bipinnulata*) and silky sharks (*Carcharhinus falciformis*) were the large pelagic predatory species found associated with almost all the FADs studied, while other shark species were less common. All these species swam in and out sight, but regularly closely approached the observers. Tuna species (yellowfin, skipjack and bigeye) were almost never observed from the surface waters, with most observations made by SCUBA divers at 30-50 meters of depth. Other common species found around FAD's included *Canthidermis maculatus*, *Kyphosus* sp., *Decapterus* sp. and *Seriola rivoliana*.

Underwater observations provide very valuable information on fish communities and their behavior, plus are being used to better interpret active acoustic echoes from echosounders and dietary studies of predatory species associated with FADs.

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