# Symposium on Tagging and Tracking Marine Fish with Electronic Devices

Abstracts

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***Pelagic Fisheries Research Program,***
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# Lifestyles of the Giant Cuttlefish (Sepia apama)

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The giant cuttlefish *Sepia apama*, lives in the shallow temperate waters of South Australia. Few detailed studies have been undertaken into the biology, behaviour and reproduction of this cephalopod. With surgically attached acoustic transmitters cuttles were physiologically monitored on their native reef in Boston Bay, South Australia using a radio acoustic positioning telemetry system (RAPT). There were three applications: positioning, mantle jet pressure, and cuttlebone vacuum (buoyancy) which were monitored for up to 19 days. Reef fidelity was observed as the cuttles remained on and around their native reef during the monitoring period. Diurnal activity cycles were observed with emergence from their dens in morning and brief excursions during the evening. Cuttle behaviour was individualistic and resembles that of octopuses much more than squid. Emergence from dens appears to be just long enough for successful foraging and to be influenced by environmental factors possibly including predation. Energy expenditures will be extrapolated from lab ground-truthing combined with these daily activity records.

# Analysis of Swimming Behavior of a Free-Range Red Sea Bream using a Micro Data-Logger

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Swimming behavior of a free-range red sea bream was examined using micro data-loggers. The loggers were able to record activity parameters including surging and swaying acceleration, swimming speed, and depth. The adult red sea bream mounted with the logger was released in a experimental fishpond. Five swimming patterns were found for over two days. The types and their frequency were as follows; type1: dash and stop, 46.5%, type 2: dash, moderate swim, and stop, 23.3%, type 3: moderate swim, dash, and stop, 4.6%, type 4: moderate swim and stop, 2.3%, and others, 23.3%.

**Seasonal Residence, Movement, and Activity Patterns of Adult Tautog (*Tautoga onitis*) in Lower Chesapeake Bay**

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Seasonal residence, movement, and activity patterns of fishes are influenced by physiological (i.e., reproduction), biotic (i.e., food, habitat), and abiotic (i.e., temperature, photoperiod) factors. Physiological factors are assumed to affect a species similarly throughout its geographic distribution; however, changes in biotic and abiotic conditions may not affect a species similarly throughout its geographic distribution. Different responses to changes in biotic and abiotic conditions may result in different seasonal residence, movement, and activity patterns. Seasonal residence, movement, and activity patterns are documented for northern tautog (*Tautoga onitis*) populations, but have never been examined for southern tautog populations. Seasonal abundance and tag-recapture data suggest regional differences in seasonal residence, movement, and activity patterns for southern populations. This study used ultrasonic transmitters and automated acoustic receivers to document seasonal residence, movement, and activity patterns of adult tautog (n=33, 400-514 mm TL) in lower Chesapeake Bay. Tautog were caught using standard two-hook bottom rigs, tagged with ultrasonic transmitters (surgically implanted), and released at the same sites where captured less than two hours later. From 9 November 1998 to 13 October, tautog were monitored at four sites (two natural sites, two manmade sites) near Cape Charles, VA. Seventy percent (n=23) of all tautog remained at release sites and were never detected or recaptured away from release sites for the duration of transmitter battery life (up to 6 months). Tautog remaining resident near Cape Charles, VA, tolerated a wide range (5-27°C) of water temperatures. Rather than move to areas of warmer water in the winter and cooler water in the summer, as documented for northern populations, tautog released at sites near Cape Charles, VA, remained resident and decreased activity slightly in response to the thermal extremes. Tautog were diurnally active on 53-80% of days in this study. Nocturnal activity was greatest in winter and spring. Resident tautog were detected daily, except during the coldest water temperatures (5-7°C) in the winter and after abrupt (3°C) decreases in surface water temperature in the summer. Eighteen percent of tautog (n=6) were recaptured or detected at sites located 2.2-10.2 km away from where these fish were released. Tautog moved away from manmade sites only. No evidence of inshore-offshore movement was documented. Three tautog moved away from a single site, but returned to this site on several occasions. These three tautog primarily moved between this release site and an unmonitored site 2.2 km to the south. When these tautog were not located at the release site, attempts to locate them at the unmonitored site were always successful, suggesting high site affinity for both sites. Twelve percent (n=4) of tautog released were detected 24-106 days less (mean = 175 days) than resident tautog. These four tautog were never recaptured or detected elsewhere, thus, it could not be determined whether these fish moved or if transmitters failed. When these fish were assumed to have moved, percent movement of fish away from release sites was highly suggested ($R^2$=0.97) to be related to size ($m^2$) of release sites.

# Vertical Distribution of Tuna: Ultrasonic Tagging Versus Instrumented Longline Fishing

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Knowledge about vertical distribution of tuna is of great importance for analyzing pelagic longline CPUE. Sonic tags allow to record continuous movements of individual fish during a short period (one or a few days) and therefore represent an appropriate tool to study the vertical behavior of fish in their habitat. This technique, however, usually provides a very small sample size, in terms of number of individuals and variety of environmental conditions. Fishing experiments with longline equipped with time-depth recorders and hook-timers only give discrete data on the vertical distribution of fish, but concern a larger number of individuals, in different environmental conditions. Longline captures, however, do not only depend on the behavior of fish (movements, feeding motivation, attraction, etc.) but also on fishing effort, fishing technique, etc., and therefore represent an indirect observation of the movements of fish. The objective of this work is to compare very informative data on a few fish (sonic tagging experiments) to discrete data on more individuals (fishing experiments), that only provide instantaneous positions of fish in their habitat, in relation to fishing effort. We focus our study on the diurnal vertical distribution of one species (bigeye tuna, *Thunnus obesus*) in one area (French Polynesia). We discuss the utilization of these techniques (separately or simultaneously) and the most appropriate protocols for studying the vertical distribution of pelagic fish in their habitat.

**Depth, Thermal Preferences and Body Temperature of Pacific Bluefin Tuna from Acoustic and Pop-Up Satellite Archival Tracking**

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The Pacific bluefin tuna is a large, epipelagic, long-lived member of the tuna family. Compared to other bluefin species, comparatively little is known about this tuna's biology and seasonal migrations across the North Pacific. To augment our knowledge of the species and aid in our efforts to collect and maintain Pacific bluefin we tracked 8 fish in the Eastern Pacific with acoustic and pop-up satellite archival tags (PSATs). Five Pacific bluefin (13-49 kg) were tracked acoustically for up to 4 days in offshore waters of Southern California and Mexico. The bluefin spent the majority of their time in the top 20 meters of the water column in waters with sea surface temperatures of 16 to 22$^{o}$C. The oscillatory diving behavior of the bluefin was characterized by extended periods spent at the surface, as well as sunrise and sunset dives. An acoustic tag with an external thermistor probe was placed in the slow oxidative muscle of 3 bluefin. Thermal excess ranged from 6.2 to 8.6 $^{o}$C. We were able to compare this acoustic data with PSAT data transmitted from tags deployed on three fish (20-65 kg) for 4-52 days. Pressure, temperature and light were sampled at 1-2 minute intervals, summarized in 6-8 h bins and transmitted via satellite or recovered in an archival fashion by retrieving the tag. The bluefin spent most of their time in the mixed layer, but made occasional dives to over 300m. The PSAT data was similar to data from acoustic tracking, confirming the usefulness of this technique for collecting fisheries-independent information.

**Archival and Pop-Up Satellite Archival Tags Reveal New Information About Atlantic Bluefin Tuna Migrations, Biology and Oceanographic Preferences**

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The size, power and speed of Atlantic bluefin tuna *(Thunnus thynnus*) has made it a challenge to study their biology. Previous technology limitations have been overcome using archival and pop-off satellite archival tags, enabling studies of long-term movements, oceanographic preferences and behaviors. Archival tags provide estimates of geolocation, vertical movements, ambient and internal temperatures. The major advantage is the extensive detail of the archival record and the ability to extract daily geolocation and oceanographic profiles in addition to biological data. We have deployed 279 archival tags (during 1996, 1997 and 1999) in bluefin tuna in the western North Atlantic in fish up to 240 kg in size. To date, 21 archival-tagged fish have been reported as recaptured from both the western Atlantic and the Mediterranean. Detailed records up to 3.5 years in length have been obtained and some patterns have emerged. Archival tags indicate that bluefin tuna maintain a warm body temperature (23-30$^{o}$C) while experiencing a wide range of ambient temperatures (4-30$^{o}$C). Foraging events are evident in the record by reductions in peritoneal temperatures. Pressure records indicate bluefin prefer the surface 200m, dive at dusk and dawn, and make occasional dives to over 800m. Longitude estimates for bluefin tuna recovered in the western Atlantic indicate these fish remain in the west, both on and off the continental shelf. Although 3 tags have been reported from the Mediterranean, no instruments have been returned. Information on feeding and migration, combined with oceanographic data from the tags, reveals when and where bluefin tuna forage and how these behaviors are influenced by environmental conditions. Pop-up archival satellite tags that record depth, external temperature and light and at two minute intervals have also been deployed on bluefin tuna from the western North Atlantic. These tags bin the high resolution data into user set intervals which are then transmitted to the satellite. To date, 95% of the tags we deployed have transmitted data and position information. Patterns of vertical movements, ambient temperature and oceanographic profiles are comparable to data obtained from archival tags deployed in the same region.

**Use of Acoustic Tracking to Determine Home Range of a Coral-Reef Fish**

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Home range has been investigated in few coral-reef species: lemon shark (Morrissey and Gruber, 1993), and coral trout (Zeller, 1997). However, studies identifying the position of a reef fish over time, and home range studies on fishes in lakes and rivers are much more prevalent in the literature. The tropical marine environment provides unique challenges for investigations of home range. Acoustic telemetry with radio linked acoustic positioning buoys was utilized as a non-intrusive, remote monitoring technique to determine the home range size of Nassau grouper (*Epinephelus striatus*), a coral-reef fish. Transmitters with individual frequencies were surgically implanted into the abdomen of mature (>40cm) Nassau grouper. These cylindrical transmitters were pressure-sensitive, powered by a lithium battery, had a battery life of 60 days, and constituted less than 1% of the total fish weight. The internal transmitters emit a continuous signal of one acoustic pulse per second and provide opportunity for continuous surveillance. The study took place in The Exuma Cay Land and Sea Park located in the central Bahamas. This remote Park is comprised of islands oriented NW-SE along the edge of the Exuma Sound separated by inlets or tidal channels (which range from 200 m to > 2 km wide) with tidal currents around 2 knots. The challenge of working in a remote tropical locale and the logistical constraints of the tracking system will also be discussed.

**Behavior and Environmental Preference of Bluefin Tuna (Thunnus thynnus) off the Coast of North Carolina Inferred from Acoustic, Archival, and Pop-Up Satellite Tags**

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Atlantic bluefin tuna (*Thunnus thynnus*) have been congregating off the coastal waters of North Carolina for the past five years. Questions remain as to what attracts bluefin to this area in the winter months as well as whether the appearance of these fish is a recent phenomenon or one that was only recently noticed. The behavior of bluefin tuna has been studied off the coast of North Carolina since 1996 using acoustic, archival and pop-up satellite tracking. Data from acoustic and archival tags revealed that bluefin tuna in this area exhibit similar behavior patterns and environmental preferences. Bluefin remain over the mid to outer continental shelf, predominately in waters 30 - 80 meters deep. Temperature and oxygen concentrations varied little from surface to bottom. Bluefin showed a strong preference for the frontal boundary region between the warmer waters of the Gulf Stream (> 25 $^{o}$C SST) and the much colder near shore waters (<16 $^{o}$C SST). This narrow distribution around frontal zones combined with the lack of vertical stratification means that bluefin in this area were exposed to a very narrow temperature range (18 - 24 $^{o}$C). This area, time of year and temperature range coincide with a large spawning concentration of forage fish predominantly menhaden, croaker and spot. Histological sampling of the bluefin tuna gonads indicate that fish in this region are not spawning. It is proposed that the large numbers of bluefin that are residential along the coast of North Carolina in the winter months are feeding aggregations that are exploiting the abundant food resources that are present in this area during winter.

**New Muscle Biopsy for Sex Determination and Sexual Maturity in Large Pelagic Fishes**

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Through the use of new biotechnological techniques it is now possible to use molecular markers such as sex hormones and vitellogenin to determine sex and gonadal maturation in muscle samples from teleost fish. This type of data may play an important role in assessing migration patterns. The present study concerns the development of a muscle biopsy punch which can be used either in the field or at the market to obtain muscle biopsy samples from live or dead tuna or swordfish. These samples can then be assayed using standard ELISA methods developed in our laboratory for sex hormones and vitellogenin. Experiments in the laboratory have to date shown that as little as 100 mg of tissue are required for these determinations and the self-activating punch system can be adapted to fit on harpoons or used as a "stand alone" hand-held device. Further field trials are now planned to test this system in a full sampling programme. Financial support provided by EU grant CFP - BFTMED - 97/0029

# Horizontal and Vertical Movements of Bigeye Tuna (*Thunnus obesus*) Carrying Archival Tags

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To understand harvest impacts and interactions among fisheries for populations of tuna and billfish across the Pacific, information is needed on migration patterns and on how environmental factors influence distribution and catchability. Archival tags provide a powerful new tool for acquiring these data. The Honolulu Laboratory is, therefore, conducting an archival tagging project on bigeye tuna and swordfish in collaboration with the Pelagic Fisheries Research Program (Joint Institute for Marine and Atmospheric Research, University of Hawaii) and the Commonwealth Scientific & Industrial Research Organization of Australia.

Since April 1998, archival tags have been deployed on 63 bigeye tuna (fork length 50-133 cm) during research cruises aboard the NOAA Ship *Townsend Cromwell*. Fish were caught both near the leeward (Kona) coast of the Island of Hawaii, and over Cross Seamount (≈18° 42 N, ≈158° 17 W). Tags were implanted either into the dorsal musculature or the peritoneal cavity.

As of December 1999, four tagged fish have been recaptured and three archival tags have been returned. The fish from which archival tags have been returned had been at liberty for approximately three months, nine months, and nine days before recapture. Preliminary calculations of position showed the fish remained within a few hundred miles of the leeward coast of the Island of Hawaii, or almost immediately adjacent to Cross Seamount. As observed during studies of bigeye tuna carrying ultrasonic transmitters, the fish spent daylight hours at depth and returned to the surface at night. Bigeye tuna are, however, able to descend deeper (up to 735 m), into much colder water (down to approximately 5°C), and to withstand much lower oxygen levels (≈ 1 ml $l^{-1}$) then yellowfin tuna in the same areas. During daylight, bigeye tuna make regular upward excursions into the warm surface layer in order to maintain body temperature, which never went below approximately 17°C.

The minimum depths reached during the night were also found to be strongly correlated with moon phase; fish would ascend to shallower depths during the new moon. These observations confirmed and explained the correlation between catch rates of bigeye tuna on longline gear and moon phase previously observed.

**Orientation and Swimming Speed of Migrating Plaice from Acoustic Tracking and ADCP Measurements**

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Theoretical studies have shown that plaice can save a significant proportion of the metabolic cost of their annual spawning migrations through the use of selective tidal stream transport. Maximum gains (40% for adults, 90% for juveniles) are possible if the fish orientate precisely down-tide when in midwater, and also swim at their optimum speed. For large adult fish tidal stream transport is only economical when they actively swim down-tide relative to the current; juvenile plaice can, however, still gain a ten-fold increase in migration range without orientating.

We have been tracking large female plaice in order to investigate swimming speed and orientation of adult plaice during pre- and post-spawning migrations between the southern North Sea and eastern English Channel. We used 300 kHz transponding acoustic tags and sector scanning sonar to follow the fish and we determined the position of the research vessel by GPS. At the same time we measured the speed and direction of the tidal stream using a vessel-mounted broad band Acoustic Doppler Current Profiler (ADCP) transmitting at a frequency of 150 kHz. We have estimated the swimming speed and direction of the fish by vector subtraction, using data from 52 midwater excursions taken from the tracks of 10 fish that exhibited selective tidal stream transport.

Our results agree with theoretical predictions and show that adult fish generally head down-tide when in midwater. Although the degree of orientation is not sufficient to realise the maximum possible reduction in metabolic costs, mean headings are mostly within ± 20º of the mean direction of the tidal stream. The average down-tide swimming speed is approximately 0.6 body lengths $s^{-1}$. This value, which is close to the experimentally determined optimum swimming speed, confirms an earlier estimate based on whole-tide ground tracks and average tidal stream vectors derived from navigation charts, rather than direct measurements. We discuss our results in relation to the reconstruction of the geographical tracks of fish from pressure records obtained from data storage (archival) tags, and the sensory mechanisms involved in the migration of demersal fish in tidal seas.

**Effects of Intraperitoneal Implantation of Acoustic Transmitters on the Swimming Performance and Growth Rates of Juvenile Atlantic Cod, *Gadus morhua***

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As part of a three year study on the inshore habitat preferences of wild juvenile Atlantic cod, *Gadus morhua*, the short-term and long-term effects of intraperitoneal implantation of dummy acoustic transmitters (1.9 - 4.6% of the fishes' body weight) were investigated. Short term effects were examined by comparing critical swimming speeds 24 h post-surgery for implanted, sham-implanted and control treatments using a Blaska-style swim tube. Longer term effects were assessed through comparison of growth rates, mortality, and tag expulsion of cod, using the same three treatments, over a 220 d period. Differences in critical swimming speed between treatment groups was found to be non-significant between groups, suggesting that tagged juvenile cod are capable of similar physical performance to that of untagged cod soon (24 h) after surgery. During the long-term study period, there was no significant difference in growth between treatments, no increase in mortality associated with the tagging procedure, and no incidents of transmitter expulsion. This study suggests that intraperitoneal implantation of acoustic transmitters can be a valid technique to examine the behaviour of juvenile Atlantic cod in both short and long-term studies.

# Pop-Up Archival Tags: Prospects for Assessment of Tuna Dynamics from Micro- to Large-Scale

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This prospective paper examines the potential use of «ideal» pop-up archival tags, i.e. tags that give reliable and precise data on movements of tagged fish, independent of the fisheries, to study tuna dynamics from small- to large-scales. These «ideal» tags do not exist for the moment but it is necessary to explore some of the potential use of these tags in order to promote their development. Whereas sonic tags and conventional tags provide information on small- and large scale movements of fish, respectively, pop-up archival tags could represent the appropriate tool to fill the gap between those scales, i.e. between behavioral studies and stock assessment.

One important tactical objective of behavioral studies in fisheries sciences is to understand the 3-D movements of fish, with the ambitious strategic objective of being able to explain some meso- or large-scale movement and distribution from knowledge of small-scale behavior. Sonic tags give detailed information on very fine-scale movements of tagged fish that can be coupled with 3-D observations of the hydrological and biological environment. The main shortcoming of this kind of experiment is their relative short duration (less than one week) making it difficult to infer behavior on larger scales. Pop-up archival tags allow longer observations, and experiments should be designed to simultaneously observe the hydrological and biological environment. Specific protocols, employing multiple tagging techniques (sonic + pop-up) in conjunction with acoustic surveys are discussed.

Conventional tags are used to estimate population parameters (fishing mortality, natural mortality, growth, movements) of primary importance for stock assessment. However, the lack of information between points of release and recapture is a major limiting factor for an accurate assessment of transfer rates (diffusion and advection terms) at a meso scale, since it depends on the routes taken by the fish. In this perspective, the pop-up archival tags would provide highly valuable information. Their high cost requires an appropriate design of experiments, especially the number of tags to release according to specific issues.

By filling the gap between sonic and conventional tags, pop-up archival tags could greatly contribute to consider behavior in stock assessment. Some aspects of this challenge are discussed.

## Tagging Mediterranean Bluefin Tuna with Pop-Up Satellite-Detected Tags

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Fifty bluefin tuna, several of them giants, were tagged in 1998 and 1999, as part of an EC-funded project (TUNASAT) set up to investigate movements of tuna in the Mediterranean and eastern North Atlantic and evaluate the use of electronic pop-up tags. The fish were marked with tags programmed to detach themselves from the fish and float to the surface after intervals of 5 to 300 days. The 61 average hourly, or daily, sea temperatures recorded by each tag were recovered by radio telemetry using the Argos satellite system, which also determined the pop-up position. The tags were attached by nylon monofilament line to medical grade nylon darts (Floy Inc.) embedded in the dorsal muscles, or (in the case of three fish tagged in the Aegean Sea) inserted through the base of the dorsal fin rays. In 1998 the fish were caught in traditional tuna traps and tagged by divers using an underwater sport-fishing gun. Three fish were tagged at Stintino (northern Sardinia) in June and nine at Barbate (southern Spain) in late July. A further 23 fish were caught in the trap at Barbate in July 1999 and tagged by a diver using a hand-held harpoon. Fifteen line-caught fish were also tagged during 1999. Three fish, caught on hand lines, were tagged near Chalkidiki in the northern Aegean Sea in April; the fish were tagged in the water and the tags attached by hand. A further 12 fish were tagged in the sports fishery off Bonifacio (Corsica) in September and November 1999. These fish, which were caught on rod-and-line, were also tagged alongside the boat using a T-shaped tagging stick generously loaned by colleagues in the USA.

Six (50%) of the 1998 tags popped up successfully. Tags from Stintino popped up in the Tyrrhenian Sea (1 tag) and off the coast of North Africa (2 tags) after periods of 5-15 days at liberty. Two tags from Barbate popped up in the Atlantic near Madeira and the Cape Verde Islands after 60 and 177 days, respectively. Data from a third tag released at Barbate were returned from the Greenland Sea in March 1999, after the fish had been at liberty for 240 days. So far only 3 tags (19%) have popped up from the 1999 releases, although 16 were expected. One, which was tagged off Chalkidiki, popped up in the southern Aegean Sea after 30 days. Of the other two, one popped up off the coast of Morocco after 60 days, the other between Gibraltar and Madeira after 88 days. The first tags from the Corsican releases are not expected to pop-up until the end of December 1999; the last tag from the 1999 releases is due up in July 2000. Our pop-up rates are much lower than the rates of 85% and 95% recorded from two previous studies in the western North Atlantic, which used the same type of tag. The reasons for this marked discrepancy are not yet clear but we discuss a number of technical and biological possibilities.

**The First Deployment of Single-Point Pop-Off Satellite Tags on Bluefin Tuna and Marlin**

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A novel fisheries-independent tool, the pop-off satellite tag, was recently developed for studying the biology of pelagic fish. We piloted the use of this technology in February 1997, by tagging 37 Atlantic bluefin tuna (96-181 Kg) with short (3-14 day) and long-term (60-97 day) tags. Short-term tags archived ambient temperature hourly while long-term tags logged average daily values. Temperature both provided insight into thermal biology and was an important indicator of survivorship and premature release. In the short-term study, temperature records showed 100% survivorship. In the long-term study, 93% of the tags provided data. In a few cases, using temperature as a measure of whether the tag remained on the bluefin proved difficult. We also successfully deployed one 60-day tag on longline-caught, 40 kg, yellowfin tuna. We believe that tag placement is critical. Based on studies with captive tuna, we found the base of the second dorsal fin to be the ideal anchoring site, here contact with the body is minimized. In 1997, we also deployed twenty pop-up tags on marlin (70-390 kg) in the Atlantic and Pacific. We had a lower success rate (45%) with marlin but recorded some remarkable long-distance movements. Tag interaction with the fish could lead to instrument damage and mortality may be a factor. Interpreting temperature data was more difficult with marlin because of their preference for warm surface waters. While temperature is an important tool for examining whether tags remain on fish, caution must be exercised in data interpretation.

## A Pressure Induced Release Mechanism for Satellite Pop-Off Tags

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Pop-off satellite tags, although only a few years old, have already made significant contributions to pelagic fish research. One frustrating problem, however, has been the inability to determine the significance of a tag that does not report via satellite. Plausible explanations for a tag not reporting include: tag failure; a tagged dead (or live) animal sinking below the crush depth of the tag; premature shedding and subsequent loss; or the fish being caught and the tag not returned. The inability to distinguish between these has limited the ability to examine survivorship in existing studies or to design experiments to test mortality. We are developing a small, pressure induced release mechanism that will sever the connection between the tag and the anchor as the tag reaches its maximum depth rating, helping to eliminate mortality as a source of data loss. Development of a pressure based release mechanism used in conjunction with pop-off satellite tags will improve data interpretation and increase the breadth of questions that can be addressed using this technology.

**Habitat Utilization and Seasonal Migrations of Adult and Juvenile Jewfish, *Epinephelus itajara*, using Acoustic Telemetry**

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Jewfish, *Epinephelus itajara*, the largest grouper in the western North Atlantic, has been protected from all harvest in U.S. waters since 1990, after years of overexploitation at its spawning aggregations. We are currently assessing this species' recovery by monitoring the adult populations at offshore spawning aggregations and the juveniles at their nursery areas along mangrove shorelines. We have used externally-placed acoustic tags, coupled with large visual tags, on adults and have found much greater movement among aggregation sites than originally suspected. Juvenile jewfish, on the other hand, have more limited movement patterns. Some individuals have been recaptured up to seven times from the exact location. By using acoustic telemetry throughout the year, we have been able to describe juvenile jewfish habitat utilization under mangrove overhangs and in depressions in tidal passes. Although we were unable to catch jewfish in the winter using traditional trapping and angling methods, the internally-placed, acoustic tags demonstrated that the animals were present throughout the year and were quite sedentary in the winter months when the temperature declined. We are mid-way through an experiment using both visual tagging methods and acoustic telemetry to compare jewfish abundance and distribution in altered and unaltered habitats.

## Satellite Tracking of Whale Sharks

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Shark Research Institute

Results are presented from a series of satellite tags deployed on whale shark in the Indian Ocean and Caribbean Sea. Satellite tags were tethered to the sharks by darts of various designs. This study confirms that satellite tagging can be an effective tool in monitoring long and short term movements of whale sharks, but there exist significant problems with attachment of the tags to the host animals.

# An Evaluation of Pop-Up Satellite Tag Technology to Estimate Post-Release Survival of Blue Marlin (*Makaira nigricans*)

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About 90% of blue marlin taken by U.S. recreational fishermen are released after capture. The conservation impact of catch-and-release fishing for this species is not well understood as little is known about the survival of blue marlin following release. Results of acoustic tracking studies in which blue marlin were followed for up to several days after release suggest that mortality, when it occurs, usually happens within 48 hours of release. Pop-up satellite tags, which have been used to study movements of bluefin tuna and blue marlin over time periods of one to several months, provide a potential tool to study post-release survival of billfish over shorter time periods. To evaluate the feasibility of using pop-up satellite tag technology to estimate post-release survival we deployed nine pop-up satellite tags on blue marlin caught on recreational gear near two banks off the southwest coast of Bermuda. Tags were programmed to take and store direct water temperature measurements every two hours and release after five days. The first nine blue marlin made available to us were tagged. Estimated weights of the fish ranged from 150 to 425 pounds. Blue marlin were captured on rod and reel with trolled lures or skirted dead baits. Fight times ranged from fifteen to thirty-five minutes, and some individuals required resuscitation before release. Eight of nine tags reported after five days at liberty. Temperature records indicated that each fish was moving up and down in the water column over the course of the five day period. The eight individuals dispersed in all directions from Bermuda, with a mean net movement of approximately 90 nautical miles (range 40 to 134 nmi). These data demonstrate that at least eight of the nine tagged fish were alive for five days following capture and release, and clearly indicate that pop-up satellite tag technology is appropriate for estimating post-release survival of this highly migratory species.

**Basin Scale Migrations and Fine-Scale Movements of Juvenile Southern Bluefin Tuna Determined through Data Collected by Archival Tags**

John Gunn and Jason Hartog

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The development of archival (data storage) tags in the early 1990's allowed researchers studying the patterns and process of migration in oceanic pelagic fishes to overcome the significant gaps in our knowledge between the fine-scale data we'd collected using ultrasonic telemetry and coarse-scale data derived from conventional tag-and-recapture experiments. The technology has now been used successfully throughout the world on three species of bluefin tuna, and recently also on bigeye tuna. In all cases, the data collected have provided a quantum leap forward in our understanding of the biology and ecology of species.

Southern Bluefin Tuna (SBT) (*Thunnus maccoyii*) are distributed throughout the southern Atlantic, Indian and Southern Oceans and the Tasman Sea. Recent assessments estimate that the parental biomass of SBT is at historically low levels. Over the last two decades there has been significant contraction in the areas in which SBT are caught by high seas longline fleets. Depending on which assessment we adopt, the contraction in geographic distribution of catches is thought to be due either to a "real" contraction in the distribution of fish (resulting from drastic reduction in biomass), or to operational changes within the fishery. If the former is the case, then the chances of recovery of the stock are considered to be very low under current levels of exploitation, whereas if the latter is the case, the inference is that there is a large, currently unexploited (cryptic), biomass in non-fished areas which could support a stock recovery.

Conventional tagging experiments are uninformative in examining hypotheses regarding distribution and movement of fish outside fished areas. CSIRO has tagged over 100,000 SBT with dart tags since the early 1960's and from the many thousands of recaptures has developed a conceptual model of migration paths and distribution for the species. Since 1994 we have also used archival tags to examine the movements of juvenile SBT. The results from our first 80 archival tag recoveries have challenged the conceptual models based on conventional tag data. We have found that large-scale, cyclic migrations, associated with major changes in habitat and feeding behaviour, are common. The data from archival tags indicate that our previous understanding of migratory behaviour was significantly biased by the behaviour/co-operation of fishermen.

Archival tags have shown us the nature of variation in behaviour over daily, weekly, lunar and seasonal time periods. For example, diving patterns vary on lunar cycles when fish are in oceanic waters, but not when they are in coastal waters. Fish sun-bake in the upper 2 metres of the water column during summer afternoons, but in the winter prefer to spend most of the day at depth sin excess of 200 metres. At some times of the year fish

are restricted to depths above the thermocline, while at others this provides no barrier to movement. Although explanations for the variability are difficult to determine, we believe the majority are related to shifts in feeding behaviour.

The internal thermistor of the archival tag has allowed us to examine variation in visceral temperature. As Carey found for Atlantic bluefin in the 1970's, visceral temperature in SBT increases as digestion begins and remains above basal core temperature throughout the digestion process. Using thermodynamics models, we have been able to examine when, how often and where fish are feeding. These data show that fish frequently go for many days to a week or so without feeding; the longest period of "starvation" is 42 days. We are currently examining the relationship between the amount of heat produced and ration/calorific to determine whether we can also estimate the amount of food eaten over a given period.

The presentation will provide brief views through the various windows opened by archival tags and conclude with a look towards future developments in archival tag technology and associated science.

# How Much Does a Tuna Eat Each Day? Do Archival Tags Provide Us with a Means for Determining Daily Ration?

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Tunas are unusual among teleosts in that they are capable of maintaining core temperatures significantly above ambient. Although it is primarily believed that these elevated core temperatures promote an increased muscle efficiency, it has also been demonstrated that bluefin tuna warm their visceral during digestion. In the 1970's, Frank Carey and his associates found that visceral temperature in Atlantic Bluefin Tuna (*Thunnus thynnus*) increased as digestion began and remained above basal core temperature throughout the digestion process. Using the internal thermistor of an archival tag we have found a similar relationship in Southern Bluefin Tuna (*Thunnus maccoyii*).

We developed a thermodynamics model that provides a means of distinguishing between temperature variation related to changes in environmental temperature and that related to digestion. From there we have been able to examine when, how often and where fish are feeding. These data show that fish frequently go for many days to a week or so without feeding; the longest period of "starvation" is 42 days.

Having determined when a fish is feeding, we are now particularly interested in understanding the relationship between the amount of heat produced within the viscera and the ration or calorific value of the meal ingested. To estimate these relationships, we have begun a series of experiments on tuna being held in grow-out cages in South Australia. These fish are caught in purse seines, transferred into cages and for periods of 2-8 months fed to satiation each day in an attempt to fatten them for the very lucrative sashimi market in Japan. The cages provide an ideal setting for a range of biological and physiological experiments.

Over the last two months we have conducted two experiments, in summer and in winter, in which we examined the relationship between the amount of food eaten and the extent and nature of warming of the viscera. We implanted Vemco minilog temperature loggers into the visceral mass ventral to the caecum and the stomach.

Preliminary analyses of the experimental data suggest a very close linear relationship between heat production and ration in both summer and winter. Although the duration of visceral warming was similar in summer and winter for the same ration, we found very significant differences in the extent of warming, and the slope of the relationship between ration and total heat production.

We discuss the findings of the experiment in relation to the physiology and ecology of juvenile tuna.

**Use of a Remote Acoustic Telemetry System to Monitor Shark Movements in a Coastal Nursery Area**

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A series of 14 VR1 remote acoustic hydrophones (Vemco Ltd, Nova Scotia) were deployed within a coastal shark nursery area during the summer of 1999 to monitor the long-term movements of neonate *Carcharhinus limbatus*. Terra Ceia Bay, Florida, is a small bowl shaped bay with a muddy bottom and a mean depth of about 4 m. Hydrophones were deployed in Terra Ceia Bay in the middle of the water column with a float and anchor system used to maintain height and position. Hydrophone stations were deployed approximately 700 m apart and range tests confirmed an omnidirectional acoustic range of at least 500 m. Vemco V16 RCODE transmitters were surgically implanted into the abdomens of 18 *C. limbatus*. Sharks were tracked for periods of three to 159 days as they moved within the study site. Three sharks were also actively tracked to confirm movement patterns recorded by the remote hydrophone stations. Since remote acoustic technology provides data covering much greater time periods and lower spatial resolution than traditional acoustic tracking, novel approaches to data analysis needed to be developed. Some of these analyses are described. Observations were also made concerning movements into areas not monitored by hydrophone stations.

**Geolocation by Light Level, The Next Step: Latitude**

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Published methods of calculating location from light level involve selecting a threshold light level and determining the times at which recorded light levels cross this threshold during sunrise and sunset. This threshold level must be equated to an angle of the sun above the horizon (elevation), and standard astronomical equations can then be used to determine the location on the earth at which the recorded transitions could have occurred. A problem arises with this simple method in that there are a number of days near the spring and vernal equinoxes for which there is very little variation in day-length, and this results in a significant uncertainty in the latitude estimate. However, there is a significant variation in the shape of the light-level curves at dawn and dusk regardless of the day of the year. A method is presented in which the relationship between the elevation of the sun and measured light level (corrected to the seawater surface) is determined. This relationship is used to predict the light intensity through sunrise and sunset for any location on any day. The measured light level curve is then compared with predicted light level curves for the day in question and the best correlated curves give the best estimate of position. This process works well even through the equinoxes.

**Five Tags Applied to a Single Species in a Single Location: The Tiger Shark Experience**

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Between 1993 and 1999, five different types of tag have been used to study the movements and habitat usage patterns of tiger sharks. In all cases, the sharks were caught, tagged and released in the same coastal area (approx. 1.5 miles offshore of Honolulu Harbor in water 20 to 50 meters deep). Tags used were: 1) standard identification dart tags, 2) pressure sensitive sonic transmitters used for active tracking, 3) long-life acoustic pingers monitored by a data logger fixed on the ocean floor at the release site, and 4) archiving "CHAT" tags which sonically download stored data to the same fixed data logger site and 5. an archiving pop-up satellite tag.

The different tag types produced data which are congruent with each other and allow construction of a consistent hypothetical picture of the vertical and horizontal behavior and habitat utilization patterns of tiger sharks in the Hawaiian Islands. The relative value of the different tagging methods to the construction this overall picture will be discussed.

# A Summary of Norwegian Experiments with Tracking the Early Marine Migration of Atlantic Salmon (*Salmo salar*) Post-Smolts with Hydroacoustic Transmitters

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Results from tracking experiments in the early 80-ties in the Høgsfjord in SW Norway and from 1996 - 98 in the Trondheim fjord (mid- Norway) have been joined together to analyse details of the migratory behaviour during the first days of seaward migration of the Atlantic salmon post-smolts. In the first experiment we were able to monitor the vertical movements of some of the salmon post-smolts with miniature depth sensitive transmitters (SINTEF, Norway) attached to the fish. Later it was not possible to obtain depth sensitive tags small enough for post-smolts, and in these experiments we used miniature pingers (Vemco, Canada) and were able to track horizontal positions only. In these experiments 60 fish have been tracked for time periods varying from 1 - 80 hours (0.5 - 100 km tracks). The migratory behaviour of the fish is seen in relation to hydrographical and meteorological conditions observed in the fjords. The influence on post-smolt behaviour of different tag attachment methods used are discussed, and the importance of hydrocaoustic tagging for advancing post-smolt research is briefly discussed.

## Popup Satellite Tags: Their Evolution, So Far

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The technology of popup satellite tracked tags has advanced rapidly since our initial tests of the feasibility of such tags in the summer of 1996. The first free deployments of the original design single point popup tags in early 1997 proved very successful, 35 of the 37 tags deployed on Atlantic bluefin tuna reporting back after popping up successfully. Since then similar single point tags have been used around the world on marlin and sharks as well as tuna.

Since 1998 we have worked on the design of a true archival popup tag with light level geolocation. Several experimental tags were deployed in 1998 to gather fundamental light level data and test sensors in the real environment. In 1999 the design of our archival tag was completed. Since then a series of these tags have been deployed on bluefin tuna in the NE Atlantic, the first of these have already reported back fascinating insights into movements and behavior of these fish.

**Changing Plaices: Where and When to Go with the Flow**

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Fish populations inhabiting the European continental shelf are exposed to a wide range of tidal current speeds. In the northern and central North Sea, mean spring current speeds are around 0.2 $ms^{-1}$, but in the Southern Bight they can be greater than 0.5 $ms^{-1}$, and may exceed 1.2 $ms^{-1}$ in the Dover Strait. Tracking studies and mid-water trawling experiments during the seventies and eighties revealed that plaice, *Pleuronectes platessa* L., use the fast currents in the southern North Sea to transport between centrally located summer feeding grounds, and winter spawning areas in the Southern Bight and eastern English Channel. These results demonstrate that in areas of fast tidal currents plaice use the tidal streams efficiently for selective tidal stream transport (STST) and, furthermore, that this behaviour can minimise the energetic costs of migration.

More recently, our understanding of the use of STST by plaice in the Southern Bight has been extended using depth and temperature sensing electronic data storage tags (DST). Of 302 DST tagged plaice released between December 1993 and February 1997, 50 have been returned. Of the 50 returned DST, we were able to reconstruct ground-tracks for 33 fish. These tracks were reconstructed using a simple 2-dimensional computer simulation model of tidal stream movement, which translated the vertical movements of fish recorded by DST into horizontal movement by assuming a constant down-tide swimming speed of 0.6 BLs-1. By using temperature records and hydrographic data recorded by the DST, and by comparing track endpoints and capture positions, we were able to confirm the geographical accuracy of 22 of these tracks. Of the remaining 11 tracks, 10 were too short or contained insufficient additional information, however only 1 fish suggested behaviour different to down-tide swimming.

More recently we have tested the hypothesis that STST is an energy saving strategy. Between October 1997 and September 1999 we released 453 plaice equipped with DSTs in areas of contrasting tidal current speeds. Calculations of energy expenditure suggested that fish of a given size should only use STST when the current exceeds a critical minimum velocity. These experiments have already yielded in excess of 14 000 days of

behavioural data from 107 returned DST. We now have evidence that plaice in areas of low tidal flow behave very differently from southern North Sea fish. The movements of fish in areas of low tidal flow could not be accounted for by STST with down-tide swimming alone, suggesting instead that these fish were migrating by directed movement which is independent of the tidal currents. In these areas we have only been able to reconstruct ground-tracks using hydrostatic and temperature data. In this paper we compare the activity patterns and behaviour rhythms of plaice from different areas of the North Sea, and discuss these in terms of their adaptive significance.

**Modeling the Physiology, Behaviour and Spatial Dynamics of Tunas in Relation to Their Environment: A Mini-Review with Special Reference to the Role of Tagging in Model Derivation and Evaluation**

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A true understanding of fish behaviour and spatial population dynamics requires integrated study incorporating various approaches across traditional scientific disciplines. Modelling provides a means by which such a synthesis may be realised. The modelling approach adopted will depend on the purpose of the exercise. Statistical models describe the data and may have predictive power if relationships hold past measured values — theoretical models seek to represent the underlying processes of interaction between fish and environment and to then simulate behaviour in response to environmental variability and life history imperatives. Tagging and tracking of fish with electronic devices allows observations of free-living animals to be made. Such observations may be used to help derive models and also to test their predictions. This will only be possible if the right variables are measured and through collaboration between scientists involved in field, laboratory and computational ecology. Methods must be developed to simultaneously measure physiological variables such as heart rate and body temperature, and environmental variables such as water temperature, depth and ambient light, and to estimate local abundance of predators, prey and con-specifics. Modelling efforts may then proceed to integrate observations, illustrating the interconnectedness of fish and environment and highlighting gaps in present understanding that can be dealt with by further research.

# Finding the Smoking Gun: Where do Atlantic Salmon from the Inner Bay of Fundy go at Sea?

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Finding where post-smolt Atlantic salmon (*Salmo salar*) go at sea and when they can be found in those locations are crucial steps to ultimately identify the causes for the exceptionally high marine mortality of some salmon populations. Few salmon from rivers of the inner Bay of Fundy survive at sea, and they are under consideration for listing as "Endangered" in Canada. "Salar MAP", the Atlantic salmon Marine Acoustic-tagging Program, determined the feasibility of mapping the marine migration and distribution of Atlantic salmon from the inner Bay of Fundy, on the east coast of Canada, using strategically-deployed automated listening stations. Two groups of smolts (N=60) of similar genetic origin (Big Salmon River, New Brunswick) but with different juvenile history were tagged by surgically inserting coded sonic transmitters into their abdomen. The two groups of smolts were released near the mouth of the river at different times, 2 weeks apart, based on their readiness to enter salt water. Their initial movements away from the river were monitored using a network of submersible automated receivers deployed within a 5-mile radius of the river mouth. Subsequently, the passage of post-smolts from the inner to outer sectors of the Bay of Fundy was monitored for nearly 3 months using receivers deployed from shore to shore along a 25-mile line.

Automated monitors were effective in detecting the movements and depicting the behavior of tagged salmon during the initial stages of seaward migration. Over 80% of fish from the first group released and 100% of the second group were detected by at least one monitor, and the majority were detected by several monitors as they moved away from the coastal area and into the outer Bay of Fundy. Migratory behavior confirmed the successful adaptation of smolts to salt water and the survival of the majority of post-smolts beyond the first few weeks. The monitors were also very successful at logging the passage of post-smolts out of and, for some fish from the second group released (around 40%), back into the inner Bay of Fundy up to 2.5 months later during the first summer at sea. This behavior indicates that some salmon may not migrate very far during their time at sea. The technology developed for this study and the approach used should prove useful to determine the distribution of salmon throughout the Bay of Fundy, to find their winter habitat and, hopefully, the "smoking gun" responsible for their demise.

**Quantifying the Energetic Demands and Behavior of Juvenile Scalloped Hammerhead Sharks using Acoustic Telemetry Techniques**

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Metabolic and activity rates were determined from free-ranging juvenile scalloped hammerhead shark pups (*Sphyrna lewini*) in Kaneohe Bay, Oahu, Hawaii using a specially designed acoustic tailbeat transmitter. Previous laboratory experiments indicated that tailbeat frequency (TBF) and water temperature could be used as predictors of instantaneous swimming speed (U) and oxygen consumption rates. Five sharks tracked in the bay had an overall average (± SD) TBF of 70 ± 10 beats $min^{-1}$ and a U of 0.81 ± 0.1 bodylengths $sec^{-1}$, but swam significantly faster at night than during the day. These sharks also exhibited high average metabolic rates (MR) (23 ± 3.5 kcal $kg^{-1}$ $d^{-1}$) compared with other species of sharks previously studied. Sharks tracked during warmer summer months swam slightly faster and exhibited higher MR than one tracked in December. The high MR measured for sharks in the bay indicate that these sharks require a high daily ration. Low and/or negative growth rates of shark pups in the field and declining population size over the summer season suggests that a significant percentage of pups in Kaneohe Bay may starve due to their high MR requirements. The tailbeat transmitters offered an inexpensive effective tool for quantifying the behavior and energetics of these sharks in the field.

**They do Get Around: An Update on North Atlantic Bluefin Tuna Tagging Results in the NW Atlantic, 1990-2000**

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Intensive conventional tagging of giant North Atlantic bluefin tuna was conducted by Canadian scientists and fishermen in the Gulf of Maine from 1990 to 1992. With a 19% return rate overall, a broad picture of bluefin movements was observed, consistent with results of historical tagging studies (including strong seasonal homing tendency and a small amount of trans-Atlantic movement). In 1993, the New England Aquarium's direct assessment aerial survey program was undertaken to improve understanding of bluefin population biology. The fishery-linked spotter pilot surveys in the Gulf of Maine generated questions on spatial and temporal scales of school movement, behavior, and environmental associations. In 1996-97, working with tuna fishermen, we completed eleven hydroacoustic tracks (7- 48 hr) of giant bluefin in schools. Three consistent patterns of movement emerged from tracking: foraging with small daily displacements (e.g. < 20 km $d^{-1}$) and repetitive travel through the thermocline, long range movement (e.g. 40 -78 km $d^{-1}$) with travel primarily in the surface layer (<12 m), and daily, deep bounce dives at dusk and dawn. In 1997-98, in a collaborative study between the USA and Canada (scientists and fishermen), we deployed 51 single point pop-up satellite tags in New England and Canada, scheduled to jettison from the fish during their presumed spawning period (April - July) after 5 - 9 months. All successful tag releases (30) reported positions from the mid-Atlantic, each year 30% of the tagged bluefin were located east of the 45 degree W stock division line, and none were in known spawning areas when the tags jettisoned. These results put into question some of the basic assumptions about bluefin migration theory, in particular, where and when spawning occurs, and the range of NW Atlantic bluefin. In 1999, we successfully tested and deployed 21 fully archival pop-up satellite tags on giant bluefin, with attachment terms of up to 365 days, to identify full migration paths and possible spawning areas of the NW Atlantic fish.

## Modeling Population Movements from Individual Behaviour

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Fish, like many animals, move between different areas at different times in order to make optimal use of their environment. In most cases these movements are not random, but are structured in space and time.

Almost all fish species show ontogenetic and/or seasonal changes in habitat use. Juvenile fish often use habitats that are spatially different from those used by adults of the same species, while stocks of adults, particularly those of large and commercially important species, often undertake regular, seasonal migrations between spawning and feeding areas. These migrations often cover large distances and result in substantial seasonal changes in the distribution of fish stocks. Consequently, understanding the spatial and temporal scale of such population movements is critical to an effective fisheries management.

Our approach to the study of fish migration is to identify the basic biological (behaviour and physiology) and environmental (water currents, temperature etc.) processes which affect migrations, and to use this knowledge to develop predictive models of population movement. However, obtaining information about the behaviour of fish in the open sea is a difficult task; once a fish is released it disappears from view and cannot easily be followed.

Early studies involved ship-based sonar to track the movements and behaviour of individual fish over periods of a few days. More recently we have been using electronic data storage (archival) tags to monitor the movements and behaviour of many fish over extended time scales. We now have sufficient data to allow us to build behaviour-based models of population movement that will help to improve assessment methods and allow us to evaluate the management potential of special protected areas.

**The Challenges and Prospects of Very Shallow Water Marine Tracking: Hardwired to Hardshell**

Carl Meyer and Kim Holland

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Between 1993 and 1999, three acoustic tracking methods have been used to study the movements and habitat usage patterns of coral reef fish in two Hawaii 'no-fishing' marine reserves situated in different coastal habitats (sheltered patch reef and high energy fringing reef). Six species of food and game reef fish from three families have been tracked to date (*Caranx melampygus, Caranx ignobilis, Caranx sexfasciatus, Mulloides flavolineatus, Parupeneus porphyreus, Naso unicornis*).

Reef fish equipped with small acoustic transmitters were actively tracked using a 5 m Boston Whaler and 4 m kayak equipped with acoustic receivers, directional hydrophones, and GPS units. The tracking kayak provided access to extensive shallow areas of fringing reef habitat that were unnavigable by conventional boat but frequently visited by reef fish. The fidelity of transmitter-equipped fish to a daytime refuge habitat was monitored using an omnidirectional hydrophone hardwired to a datalogging system on land. All three systems provided unique data on reef fish behavior and the hardwired monitoring system demonstrated how array systems might in future be used to collect fish movement data at a fraction of the cost of current active tracking systems.

Reef fish tracked typically showed high site fidelity to well-defined home ranges and predictable diel patterns of habitat use, including separate diurnal and nocturnal habitats. Behavior patterns, home range size and habitat preferences varied considerably between species but showed relatively little intraspecific variation. Home ranges of most fish tracked in the patch reef environment were encompassed by the boundaries of the Coconut Island reserve. Preliminary tracking data from Waikiki suggest that while behavior patterns are broadly similar in the two habitats, some species (Goatfish and jacks) may range more widely in fringing reef habitats. The relevance of these findings to design and function of effective marine reserves is discussed.

# Tagging Experiment of Big Pelagic Fishes at the Espirutu Santo Seamount (During 1997-1998-1999) La Paz, B.C.S., Mexico

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Tagging is one of the most effective methods to study movements of any material objects. It is widely applied in practice of scientific researches in most diverse processes in micro and macro world. We recorded the occurrence of pelagic fishes at Espiritu Santo seamount during the 1997-1998 and 1999 El Niño by tagging individuals with coded acoustic beacons and detecting their presence with electronic listening devices. These research activities were carried out at all times of the year from small boats, but more intensively during four seasonal cruises research vessels. Two cruises were on board the R/V BIP II of the Centro de Investigaciones Biologicas del Noroeste (CIBNOR, SC.), one on board of the R/V Francisco de Ulloa of Centro de Investigacion Cientifica y de Educacion Superior de Ensenada, B.C. (CICESE), and another on board the R/V Sproul of Scripps Institution of Oceanography. During these cruises, we placed two moorings on their ends of the 1,200-m long underwater ridge of Espiritu Santo seamount. Each mooring consisted of a concrete block with line leading upwater to a rosette of subsurface buoys. Attached in the middle of each line was a fish-detecting monitor and temperature recorder. The first mooring was deployed on February 22nd and the second on August 17th. 1998. Twenty-three yellowfin tunas (*Thunnus albacares*) were tagged from Apr 11th to Sept 12th 1998. During the last 15 months, local water temperatures were above normal but less than earlier during of the Southern Oscillation. Results of this experiment show that some tagged tunas emigrated of the seamount from September 11th to October 13th, when the water temperature peaked at 30°C and began to drop. A fewer number of yellowfin tunas still remained at the site on Novembrer 2th 1999, when the temperature was 23° C and the monitors were last interrogated. Most other pelagic species of fishes were absent from the seamount during the ENSO event. Although yellowfin tuna were very abundant at the seamount during the summers of 1997-98, other species of pelagic fishes frequently observed in the past were less common. During these periods, temperatures were unusual due to the El Niño event.

**Ability of Electronic Archival Tags, Submerged at Varying Depths on a Stationary Mooring Line in the Pacific Ocean, to Provide Estimates of Geographical Position based on Light Intensity: How Good are They?**

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To test the ability of electronic archival storage tags to provide estimates of geographical position based on light intensity, six tags (three tags from two different vendors) were attached at 10 m depth intervals to a subsurface oceanographic mooring deployed on a 70 m bank in the central North Pacific Ocean (*ca*. 24.0$^{o}$N, 160.42$^{o}$ W) for the period August 29, 1998 until August 16, 1999. Upon retrieval, data from two of the tags (one from each vendor) could only partially be downloaded in one case and was not recoverable in the other. Longitude was estimated from a proprietary algorithm for 353 days. Due to the vernal and autumnal equinoxes, latitude could only be estimated for 317 days with the existing algorithms. The shallowest tag at a depth of 24 m recorded a noon light intensity about 13% higher than the deepest tag at 58m. Consequently, although longitude estimates for the tags were similar, the shallow tag at 24m had significantly smaller position errors (mean longitude error = 0.35 , *sd* = 0.41), than the deepest tag at 58m (mean longitude error = 0.64 , *sd* = 0.81 ). The tag at 24m also had significantly smaller position errors for latitude estimates (mean latitude error = 2.2 , *sd*=3.2 ) than the tag at 58m ( mean latitude error = 9.8 , *sd*=8.5). Ambient weather conditions and water clarity will obviously introduce errors into any geoposition algorithm based on light. Our data show position estimates were also greatly influenced by depth, and that appropriate correction factors must be developed to adjust for light attenuation. A logical extension of our findings is that deep dwelling fishes (or other marine organisms) that do not exhibit regular crepuscular diving behavior are unlikely to be suitable candidates for tracking by the current generation of archival tags. Lastly, although archival tags are suitable for studies to ascertain basin-scale movements, they do not appear well suited for mesoscale movement studies due to the magnitude of the observed position estimate errors. For studies of fine scale movements in relation to specific oceanographic conditions and forage densities, acoustic tagging remains the tool of choice.

**Some Results about the Tagging Experiment of Ocellate Puffer, *Takifugu rubripes*, Using an Archival Tag**

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To obtain new information about the behavior of ocellate puffer, archival tagging experiments were conducted in 1997 in the coastal water off Mie Prefecture, Japan. Eight wild ocellate puffers, 39-53cm in total length, were released with the tags installed in the body cavity. Four individuals were recaptured after an average of 202 days at sea. Based on the analyses of retrieved 2 tag data, some interesting findings were noted as follows:

1) In autumn, main swimming layers ranged from surface to 20m in depth, indicating some diving and rising. In winter, the fish stayed in the surface, shallower than 10m, with temporal diving. On the contrary, the maximum diving depth became deeper in winter, 40-90m. During the spawning season from late March to early April in 1998, swimming layers drastically changed and the fish remained on the bottom of the sea with frequent rising to subsurface layer.

2) The puffer fish is well known to practice a specific behavior to hide itself under bottom substratum, a burrowing behavior. The retrieved tag data gave relevant information on its time and depth of the behavior by identifying such recorded data as no change in depth and no reception of light during daytime. The duration of the burrowing is largely fluctuated from 2 minutes to 75 hours in autumn and 2 minutes to 41 hours in winter. Results also showed that ocellate puffer were under the burrowing behavior for 40-65% of the days analyzed. Diurnal regularity was not observed. The data further indicated that there were no relations between burrowing behaviors and the ambient temperature.

**Integrating Cross-Scale Movement Information From Tagging and Tracking Studies of North Atlantic Bluefin Tuna (*Thunnus thynnus*)**

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North Atlantic bluefin tuna exhibit continual movement, high rates of spatial re-distribution, and complex aggregation behavior that may be linked with changes in their three-dimensional environment. Our paper will analyze the spatial and temporal movements of giant bluefin tuna in the Gulf of Maine and northwestern Atlantic by integrating information derived from tagging and tracking studies. An improved understanding of bluefin tuna movements is key to evaluating depth and surfacing behavior, spatial mixing, residency, and the structure and size distribution of schools. Identification of patterns of bluefin aggregation and schooling dynamics is also crucial for elucidating how school structure and distribution is linked with changes in the bluefin tuna's prey distribution and habitat. Failure to address these questions will limit development of direct, fishery-independent population assessments.

## How Reef Squid Ride the Tide, as Revealed by RAPT

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Squid of the genus *Sepioteuthis* have full-length fins along their mantles, resemble cuttlefish (*Sepia)* and are called reef squid because schools are common, hanging over reef tops. Our earlier telemetry studies of jet pressures from the Azorean squid *Loligo forbesi* suggested that they used their ¾-length fins to reduce swimming costs by 'soaring' in tidal flows near seamounts. We used a Radio Acoustic Position and Telemetry system (RAPT) to continuously monitor the movements and power output of *Sepioteuthis australis* through tidal cycles around a rock reef 300m across, near the Lincoln Marine Science Centre in Port Lincoln, South Australia, to clarify and quantify this behavior. After release, tagged squid moved randomly until they joined a school. Simultaneously tagged squid did not necessarily wind up in the same school, but most showed similar movement patterns for several days orienting to tidal flows around the reef. The largest squid, carrying a jet pressure transmitter, demonstrated a mixed strategy of moving with the tide and holding against the tide, apparently minimizing swimming costs while maximizing opportunities to observe prey in currents. Although there were small variation in jet pressure with tidal phase, powerful jets associated with predator or prey interactions were rare.

**Aggregating Behavior of Yellowfin and Bigeye Tuna Tagged with Coded Ultrasonic Transmitters around FADs in Okinawa, Japan**

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Nine yellowfin tuna (*Thunnus albacares*, 48-99 cm FL) and three bigeye tuna (*Thunnus obesus*, 56-64 cm FL) were tagged with coded acoustic transmitters inserted into the abdominal cavity of the fish. We released the fish at two huge FADs (Nirai-1 and Nirai-8) off the south of Okinawa Island, Japan between 18 August and 15 October 1999. Automated acoustic receivers were attached to both Nirai FADs to detect pulses of each coded transmitter within a 500m range, and current meters and thermometers to monitor the environment. Eleven tuna stayed at the same Nirai they were released or visited another Nirai. The stays or visits ranged from three hours to 24 days (median = 12 days). Two yellowfin traveled between Nirai-1 and Nirai-8, 10 nautical miles apart from each other. One yellowfin released at Nirai-1 stayed there for about 12 hours before leaving there, then after 17 days, this fish appeared at Nirai-8 and stayed there for four days. Another yellowfin released at Nirai-8 stayed there for 15 days; after an eight day absence, this fish appeared at Nirai-1 and stayed there for two days. In the last half of October, the average current speed at Nirai-8 was more than one knot; still, four tuna stayed there during that time. For five yellowfin and one bigeye that stayed at Nirai over 48 hours, the frequency of detected pulses per hour was significantly higher in the nighttime than in the daytime. This may indicate that these tuna swam close to the FADs at night and extended their swimming range in the daytime. For two yellowfin, the frequency was lower in the nighttime than in the daytime.

**The Use of Archival Tags to Demonstrate Activity Profiles of Sea Going Arctic Charr (*Salvelinus alpinus*) in Norwegian Coastal Waters**

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Arctic charr (*Salvelinus alpinus* L.) are a diadromous fish which is fairly common in river systems in northern Norway. Migrating fish feed in seawater during the summer, and spend the winter in freshwater. Sea residence only lasts for a few weeks each year and fish increase their weight rapidly during this time. Life history investigations on the oceanic behavior would benefit from tracing migratory patterns of individual fish.

In the present study, small (16 g in air) archival tags which can store over 500,000 data samples to measure depth (0-100 m $\pm$ 0.2 m), water temperature (—4 to 23°C + 0.03 °C) were used to monitor detailed oceanic migration patterns of descending charr from the river Halselva, northern Norway. Out of five fish, three specimens were recaptured from two to four weeks after tagging. The archival tags provided new information of oceanic migration in Arctic charr. These analyses, were related to environmental factors to demonstrate activity profiles associated with salinity migrations.

# Short-Term Movements of Juvenile Sandbar Sharks, *Carcharhinus plumbeus*, on their Nursery Grounds in Delaware Bay

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Acoustic telemetry was used to investigate short-term movements of neonate and juvenile sandbar sharks, *Carcharhinus plumbeus*, on their nursery grounds in Delaware Bay during the summers of 1998 and 1999. Twenty-five sharks were tracked continuously for between 2.5-75 hours. The majority of the sharks caught and tracked on the Delaware side of the bay remained in this area for the entire duration of the tracks. These sharks predominantly limited their movements to within 3 km of shore and to water that was 2-5 m deep. Sharks tracked on the New Jersey side of the bay appeared to roam farther afield into deeper water and farther from shore, and occupied a larger activity space. Several sharks made longer offshore movements into the deepest section of the bay (37 m), and two sharks completely crossed the bay from Lewes, DE to Cape May, NJ and vice versa. In most cases tidal flow appeared to strongly influence the fine-scale movements of these sharks, and no diel patterns were observed. Since young sandbar sharks concentrate their movements within a restricted portion of the bay on the Delaware side, and utilize a larger activity space on the New Jersey side, the behavioral patterns should be taken into account by local agencies responsible for management of these populations.

**Possible Models for Combining Tracking Data with Conventional Tagging Data**

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Advection diffusion models have been used successfully to describe the time and place of recapture of tuna tagged with conventional dart tags. Such models are the continuous analogs a biased random walk. This paper demonstrates how biased random walks can be used to simulate large scale movements of tunas as recorded by archival tags in a way that captures all of the major characteristics of the tracks. The parameters of the biased random walk model are identical to the parameters of the advection diffusion model suggesting that a joint parameter estimation procedure might be feasible. Finally the potential application of the Kalman filter to the analysis of tracking data is discussed. This statistical model has the potential to increase the accuracy geo-position estimates from tracking devices as well as to estimate biased random walk parameters from tracking data.

**In situ Tagging and Automated Tracking of Deepwater Rockfishes**

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We developed techniques to use SCUBA to surgically implant sonic tags in fishes at depth to reduce barotrauma and temperature stress associated with bringing fish to the surface. In August and September of 1997 and 1998, we tagged 16 bocaccio (*Sebastes paucispinis*) and 6 greenspotted rockfish (*S. chlorostictus*) with VEMCO V16 series acoustic transmitters in Monterey Bay, CA. Each year, rockfish were captured at a depth of about 100 m, then reeled up to a depth of approximately 20 m. SCUBA divers descended to the depth of the captured fish, then anesthetized and surgically implanted acoustic transmitters in the rockfish. Tagged fish were released on the bottom at the location of catch. Several weeks after fish were tagged, we used the Delta submersible to place an array of VEMCO VR-20 recording receivers on the seafloor. The array of receivers enabled the tracking of horizontal and vertical fish movements for a three to four month period. In September 1998, we were able to re-locate three of the tagged fish by using a deepwater hydrophone on the submersible to navigate to the middle of schools that contained tagged fish. Tagged fish were tracked for more than three months and results indicate that the two species have different movement patterns. Greenspotted rockfish exhibited almost no vertical and only small horizontal movements whereas bocaccio demonstrated a wider variety of movements.

**Tracking Distribution and Migration Routes of Sea Trout (*Salmo trutta* L.), Arctic Char (*Salvelinus alpinus* L.) and Homing Atlantic Salmon (*Salmo salar* L.), in Icelandic Waters Using Information on Temperature and Salinity from Data Storage Tags and Integrated Information From Tidal Stream Data, Hydrographical Data and from Sea Surface Satellite Imagery**

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A data storage tags (DSTs) has been used to observe salmonid migration in Icelandic waters since May 1993. The tags recorded fish depth (pressure) and ambient temperature and salinity. The studies included sea (feeding) migration of sea trout (*Salmo trutta* L.) SE-Iceland (1995-1999) and of anadromous arctic char (*Salvelinus alpinus* L.) NW-Iceland (1997-1999) and homing migration of Atlantic salmon (*Salmo salar* L.) during 1993-1999. The observations were made onboard DSTs by mapping of behavioural and environmental information. Part of the data processing included delimiting how fish/species utilised different sea habitat, based on the salinity/temperature measurements (estuaries/shore migration and outer areas). In addition, the DSTs temperature data were in some studies on salmon and sea trout compared to corresponding sea surface data from NOAA AVHRR images, in order to delimit more precisely their distribution. Also vertical hydrographical information serves as comparative landmarks in relation to the vertical distribution of temperature and salinity.

The char (fork length = 36-55cm) started sea migration in manly in June and stayed during all their migration in the estuary area during their 7-10 weeks of sea migration, as also shown by the highly accurate experience of the tides. The char leaving the estuary habitat migrated along shores and then often stayed during some adaptation period in the estuaries before and after that off-estuary migration.

The sea trout (fork length = 32-72cm) observation showed that they migrated manly into sea in May and June, were they were in regular and often close contact with estuaries and near shore areas during the 4-10 weeks of feeding. Their migration behaviour partially reflected changes in tidal streams (spring/neap tide and ebb/flood tide). This shoreline axis in the sea migration of trout is still more obvious when taking also into consideration the high temperature recordings experienced by trout, because according to satellite measurements that sea temperature could only be found in narrow zone of 1-few kilometre's out from shore. That was also consistent to satellite photographs (30 x 30 m) of the coast of S-Iceland showing high influence of glacier rivers waters (little absorption of light) in this narrow zone along the SE shore. Comparison between DST data and satellite data on temperature also indicated that sea trout migrate partly eastward along the coast manly early migrants. These fishes seemed partly be feeding in narrow shear zone where the warm Atlantic water from the Gulf Stream met cold sea from the north,

approximately where this front was closest to shore, in range within tens of kilometres east of their home estuary. The salinity mapping verified this showing that majority of the sea trout visited very rapidly the less saline waters along shore. Comparison to wind and wave measurements showed that the fish stayed closer to shore when wind and waves were calm.

The homing salmon (fork length = 50-97 cm) observed were migrating quite close to the coast according to comparison of temperature data from satellites and from DSTs. This was confirmed by the DSTs salinity measurements reflecting experience of sea not fully saline and even brief migration into estuaries and even into rivers on the salmon way to their home. According to salinity recordings the salmon stayed more frequently near shore/estuaries during day than during night. SST images are valuable to compare to temperature recordings from migrants in order to locate them approximately. But their usefulness is manly dependent on the following: on the size of the area of interest (length of the migration); the cloud cover in the area of interest at a given time, and of course on the available temperature gradients in a given area together with the migration speed of the fish.

# Vertical Movements of Homing Atlantic Salmon (*Salmo salar* L.) in Coastal and Oceanic Waters

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The long and precise migrations of homing of Atlantic salmon (*Salmo salar* L.) have long been of special interest with respect to fish orientation and navigation mechanism. A migration studies on homing Atlantic salmon were carried out in Icelandic waters 1993 – 1999 to get detailed information on their migration behaviour with references to the environment experienced. The studies were based on observations of 142 salmon equipped with electronic tags that were recaptured from the 245 salmon that were tagged. Here we look at the vertical movements of the salmon during this spawning migration phase in sea, observing the response of the salmon to different environmental condition and using the patterns involved to get insight in the underlying mechanism, especially those involving orientation and navigation. The observations were based on mapping salmon behaviour during homing and the corresponding environmental conditions by use of data storage tags (DSTs). Additionally some information were received by means of double electronic tagging, using DSTs and ultrasonic transmitting tags. The DSTs were used during the migration to record pressure (fish depth), the corresponding ambient temperature and conductivity (salinity) and tilt (fish vertical heading).

The depth records showed the same main pattern in vertical movements in the coastal and oceanic waters. The salmon migrated mostly in the uppermost few meters, but most of them did also for short periods migrate through deeper layers, down to 153 m in coastal waters and down to 322 m in the ocean. During the preferred near-surface migration the salmon held very constant depth course manly within the uppermost 3 meters for intervals ranging from hours to days. The near-surface migration was disrupted by diving activity, which most frequently consisted of series of rapid excursions down from the surface layers (vertical speed up to 0,70m/sec). The salmon moved to considerable depth in the ocean and outer coastal area but most of the diving in coastal waters seemed to be targeted to the steep conditions gradient of the thermo- and haloclines layers that were approximately at 20-40m depth in the study area. In some of the studies there were significant diurnal pattern in the overall vertical movements of the salmon, though the difference were not large. The salmon preferred to stay in deeper layers during night and often made even deeper dives during the dusk hours. Diving activity of salmon were also triggered when they rapidly experienced large temperature changes during near-surface migration, that in one known instance where shown to be parallel to crossing area of complex currents. Also there were found examples where tides controlled vertical movements of salmon in near shore area, indicating tidal transport.

The main characters of the diving pattern of homing salmon, a series of very rapid dives, often targeted on steep gradients, indicates that these movements are made to scan the different layers involved, to receive (update) orientation information in order to navigate to the home estuary. In addition to these characteristics this assumption is made because available information from counterparts salmon in the area showed that non/low feeding of salmon could not stand for the overall diving activity. The diving at dusk hours indicates that such scanning behaviour is triggered by light condition. The light reference could also been needed directly along with the information received by moving trough different depth layers, in order to co-ordinate the orientation clues/cues to be able to migrate further and/or hold position. Such depth dependent orientation clues that can serve in conjunction with the navigation process of salmon can be of various sources, e.g. geomagnetic dip, odors and hydrographical gradients. The near-surface migration is preferred most of the migration time and it is therefore reasonable to assume that the salmon does receive important orientation clues from that part. The near-surface migration can for example reflect the use of sun compass for orientation. That suggestion is supported by the placement of homing salmon that are significantly closest to the surface at/near noon, and as revealed the excursion from that layer at dusk and dawn may also be linked to oriental reference of the sun. It might also be speculated whether the magnetic field generated by earth movements might be of some oriental use during these near-surface migration, because these magnetic potentials have the highest values in the surface layer whereof they are strongest at noon due to the position of the sun. When considering the role of near-surface migration it was shown to play important role in relation to salinity detection near shore, but such freshwater detection would parallel be expected to involve olfactory sensing of odors clues for orientation use.

**Sex Determination and Maturation Stage Estimation in Large Pelagic Fishes Using Steroids and Vitellogenin Levels. - An Experimental Field Approach**

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Measurements of the steroid hormones 17ß-Estradiol ($E_2$), Testosterone (T) and 11-Ketotestosterone (11-KT) and Vitellogenin levels in the plasma of Bluefin tuna (*Thunnus thynnus*) and Swordfish (*Xiphias gladius*) have revealed characteristic patterns for different sexes and reproductive maturity stages. These endocrinological characteristic have been confirmed by analysis of gonadal histology. High levels of $E_2$ and T are present in maturing females. High 11-KT concentrations are typical for mature males. In mature fish with increasing testosterone concentrations it is possible to determine sex from the ratio of [T] / [11-KT]. vitellogenin on the other hand is present only in female fish. The experimental field approach used to determine these parameters will be illustrated by a step by step description of such studies in the Bluefin Tuna and the Swordfish. The future role of a simple muscle biopsy to determine sex and sexual maturation for large pelagic fish tagging programmes will be emphasised. Financial support provided by EU grant CFP - BFTMED - 97/0029

# Choice of Coded Acoustic Transmitter Repeat Intervals Using a Simulator, with Comparison to Actual Detections Recorded from Multiple Transmitters in the Same Location

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Simple acoustic pingers have advanced to more complex ID coded transmitters which transmit infrequent code bursts. This type of coding extends the battery life, provides large numbers of unique ID codes, and provides a greater immunity to noise. The infrequent transmissions allow multiple transmitters on the same frequency, when one transmitter is silent there is room for another to transmit. The repeat interval for the code is usually a pseudo-random time interval so that codes from two transmissions which collide or overlap in time, will be distinct on their next transmissions. The choice of average code repeat interval is determined by the number of transmitters likely to be at the same monitor station at the same time, and the expected time for the transmitter to pass by the monitor. A simulator was written to predict the time required for detection of a user selectable number of transmitters given a user selectable code repeat interval. Simulator results are presented for typical migration studies. Simulator results are compared to actual recordings of multiple transmitters at fixed locations. Tables are presented as a guide in selection of code repeat intervals for future studies.

**Calibrating Caudal Pressure to Swimming Speed in European Sea Bass, *Dicentrarchus Labrax***

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We report the results of an experiment designed to verify the use of caudal peduncle differential pressure as a predictor of swimming speed in sea bass, both in the laboratory and in the field.

Six sea bass (0.180 – 0.226 kg) were instrumented with a miniature differential pressure sensor mounted on one side of the caudal peduncle. Differential pressure, tail beat frequency, tail beat amplitude and oxygen consumption ($MO_2$) were highly correlated to swimming speed of sea bass swum at 9 and 14BC. Integrated pressure ranged from 0 to 200 pascals for speeds up to 2.5 $Ls^{-1}$ while 'pressure difference' (maximum – minimum) ranged from 0 to 800 pascals. Burst swimming in the respirometer resulted in huge pressure 'bursts' of up to 3000 pascals 'pressure difference'.

We introduced sea bass (1.5 kg) with V-16 differential pressure transmitters, to a tidal marsh pond (19 x 11 x 1m ) and monitored their position and tail beat pressure each second for two weeks using a radio-acoustic buoy positioning system. Pressure was highly correlated to swimming speed calculated from positions, confirming that pressure as an indicator of caudal muscle power output can accurately predict activity patterns and swimming speeds of fish in nature. This technique uses a noninvasive sensor which can be coupled to ' real time' telemetry transmitters or data loggers for field measurements.

## Effects of Depth on Estimating Geoposition from Archival Tags

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Light-recording data storage tags potentially allow us to estimate the daily position of marine animals that remain continuously submerged. We conducted several earlier studies in which we deployed tags at fixed moorings in the North Pacific Ocean in order to test their geolocating capability. Data retrieved from the tags allowed us to derive estimation algorithms and to evaluate the accuracy of the position estimates obtained. The results were promising, suggesting an average positional error of ca. ±140 km (ca. 67 km in longitude and ca. 114 km in latitude; Welch and Eveson, 1999).

In our previous study, the tags were deployed at a uniform depth, which is not representative of a field study where tags would be attached to free-moving fish. In such a study, the issue of how light is attenuated with changes in depth becomes critical because it is necessary to correct the record of light variations for depth changes. We report here the results from a new experiment in which we again placed tags at three distinct depths on a fixed subsurface mooring. From the resulting data, we were able to estimate a relationship between light and depth, which we could then use to "correct" the light values to a constant depth.

Using data from the three depths, we generated a simulated variable-depth light record and applied our estimation algorithm to the depth-corrected values. This yielded an average error in longitude of 45 km and an average error in latitude of 51 km, a significantly better result than previously obtained. Reasons for the improvement could include modifications we made to our algorithms, changes made to the tags by the manufacturer, different environmental and meteorological conditions between experiments, and different mooring locations.

**Depth Behaviour and Position Estimates from Archival-Tagged School Sharks (*Galeorhinus galeus*) in Australia**

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Archival tags were used to study the movement and depth behaviour of school sharks (*Galeorhinus galeus*) in southern Australia. Thirty fish were released in October-November 1997 with externally attached tags, and another 16 in November 1998 with internal tags. To date there have been nine recaptures (30% recapture rate) from the 1997 releases, and four (25%) from the 1998 releases. Periods at liberty varied from 8 days to 18 months. Data from returned tags showed a relatively regular diel pattern of vertical movements with the sharks usually rising towards the surface at night and descending close to the bottom during the day. About 20 % of their time was spent in deep-water off the continental shelf when the diel vertical movements were up to 550 m in extent. Light data from the tags was used to estimate position when the sharks were at 100-150 m or less. Latitude estimates were refined from bathymetry information in conjunction with the maximum daily depth recorded by the tag, assuming the fish were on the bottom. None of the recaptured sharks showed extensive movements outside of the general area bounded by the release and recapture positions.

**Estimating the Time of Dawn and Dusk from Archival Tag Light Data: Methods Used in the Archival Tagging of School Shark (*Galeorhinus galeus*) in Australia**

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Current geo-location estimation from archival tag light data is based on determining the time of solar noon (for longitude) and the length of the day (for latitude). Solar noon can be estimated from the mid-point of the daily light curve using light levels indicative of dawn and dusk, but with no need to match the levels with a particular sun elevation. These indicative levels may simply be a light level (or a percentage of noon light, or a percentage of the difference between light at noon and at night) or alternatively be based on the time at which light levels are observed to change most rapidly. The time at which light changes most rapidly at the earth's surface is around the start and end of civil twilight (centre of sun 6º below the horizon), but under water it is delayed at dawn, and advanced at dusk, depending upon the depth and the sensitivity of the tag. The sun elevation chosen as the basis for calculation of day length should ideally be the time at which light is changing most rapidly at the particular depth. This results in the best estimates of sun elevation because large differences in light are associated with only small differences in elevation. Although the depths occupied by school shark often changed on a daily basis, for estimating positions for the entire deployment in a single pass, we chose a standard depth (typically the most common depth) and adjusted light levels to this depth using either a linear or exponential light vs. depth relationship derived for the particular type of tag.

**Are Tiger Sharks Pelagic or Coastal? Their Movement Patterns at Two Locations in Hawaii**

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During the summer, fledging seabirds, nesting green sea turtles and Hawaiian monk seals are abundant within the Northwestern Hawaiian Islands and represent potential prey for sharks. Tiger sharks are thought to move to these locations to take advantage of these prey and have been observed feeding on birds, turtles, and seals. Concern about the impact of shark predation on the population of endangered monk seals has prompted interest on the behavior of tiger sharks near seal haulout and pupping areas such as those at French Frigate Shoals (FFS). In a preliminary study on the movement patterns of tiger sharks at FFS, two sharks were fed transmitters and were tracked for multiple days near a small island where seals, turtles, and fledging birds are common. Movements of these sharks were often closely associated with shallow reefs and the sharks returned to the small island where tracking was initiated numerous times within a span of several days. The behaviors observed for sharks at FFS differed markedly from those of tiger sharks captured on longlines and tracked near Oahu in the main Hawaiian Islands. Nearly all of the sharks tracked near Oahu made directed offshore movements and traveled considerable distances after their release. These sharks remained far from shore and crossed water as deep as 600 m. Several of these sharks were recaptured or detected off Oahu near the original site of capture, but were reacquired after a period of weeks or months. Possible explanations for differences observed between the behavior of tiger sharks at FFS and off Oahu include variations in habitat, prey availability, method of transmitter attachment and human population.

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