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Archival Tagging of Atlantic Bluefin Tuna (*Thunnus thynnus thynnus*)

PAPER

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ABSTRACT

The size, power, and speed of tunas and other pelagic fishes (e.g. swordfish, marlins, sailfish) have made it a challenge to study their biology. These species are most often composed of large populations with broad geographic ranges and individuals are capable of traversing ocean basins in weeks or months. Data on dispersal patterns are hard to obtain because of the limited resolution of analytical tools available for studying pelagic fish. What is currently needed are technologies that can augment conventional tagging data sets to better define the geographic ranges and potential overlap of stocks. Archival, satellite and molecular technologies offer the fisheries research community the new techniques required to resolve the movement patterns and stock structure of highly migratory species.

We describe in this paper our use of archival tags on Atlantic bluefin tuna (Thunnus thynnus thynnus). Archival tags provide a record of thynnus ambient and internal body temperature, pressure, and light. From light intensity, augmented with data on sea surface temperature, it is possible to estimate latitude and longitude. In recent years, archival tags have dramatically increased the understanding of the biology of several species of fish. Use of the tags has the potential to address major questions concerning stock structure hypotheses of Atlantic bluefin tunas. We have developed the handling and surgical procedures necessary for internal placement of archival tags in medium and giant bluefin up to 234 kg. Additional studies to examine the survivorship and healing rate of archival tagged fish are being conducted using captive tuna populations in Monterey, California and acoustic and satellite technologies on wild fish.

INTRODUCTION

Atlantic bluefin tuna are highly prized by commercial and recreational fishers. The size, power, and speed of Atlantic bluefin has made it a challenge to study their biology. The unique thermoregulatory physiology of bluefin coupled with their large size enables this fish to migrate from polar seas to warm temperate waters in short durations of weeks or months (Carey and Lawson, 1973). We know surprisingly little about the movement patterns of Atlantic bluefin, where and when they breed, or how populations are structured. This lack of knowledge has accompanied the recent demise of Atlantic bluefin tuna stocks. The National Research Council (NRC, 1994) committee report on the status of this species noted that current research on the biology of this species was insufficient to address major biological questions relevant to the management of the fishery. A specific recommendation of the report was to use new tools, such as archival tags, as a means for resolving the stock structure. The International Commission for the Conservation of Atlantic Tunas (ICCAT) presently manages northwest Atlantic and northeast Atlantic-Mediterranean Sea bluefin tuna resources as two separate management units. One stock is recognized in the eastern Atlantic with a breeding area within the Mediterranean Sea and a second stock is presumed to exist in the western Atlantic ocean with a breeding ground in the Gulf of Mexico. The NRC review recommended that the two-stock hypothesis be reexamined (NRC, 1994). The greatest area of uncertainty identified in the report was the extent of bluefin movement within and between the eastern and western Atlantic, spawning site fidelity and the results such lifetime trans-oceanic movements have on the choice of a management strategy.

To understand the life history of bluefin tuna and to develop competent management strategies, temporal and spatial movement patterns in the oceans must be identified. Resolution of the stock structure questions of Atlantic bluefin tuna are critical to the management of the species. Data on dispersal patterns of pelagic fishes with large geographical ranges are difficult to obtain because of the limited resolution of analytical tools available for studying pelagic fish. Conventional tag and release data demonstrate that all size classes of bluefin have the propensity to make trans-Atlantic crossings (NRC, 1994). What is currently needed are technologies that can augment conventional data sets to better define the geographic boundaries of the stocks. Archival tagging offers the research community the technology required to unravel much about the movement and migration of highly migratory species.

PRIORITIES FOR AN ATLANTIC BLUEFIN TUNA ARCHIVAL TAGGING PROGRAM

A National Marine Fisheries Service (NMFS) sponsored workshop in Miami in 1995 (Restrepo, 1996) prioritized three studies aimed at addressing the stock uncertainties of Atlantic bluefin tuna. Recommendations included examining: (1) spawning area fidelity; (2) movement between east and west regions, and; (3) mixing proportions. The fundamental question for management regarding spawning area fidelity is to discern if and when mature bluefin tuna (large medium and giant bluefin) move across the Atlantic, do they reproduce in one area (e.g. Gulf of Mexico, Mediterranean) or in both places? Given that the major aim of managers should be to protect the reproductive potential in these management units, defining where and when Atlantic bluefin spawn is of critical importance. The Tagging Atlantic Bluefin (TAB) report maintained that spawning area fidelity could be demonstrated by the reappearance of mature fish in the same spawning area in consecutive years and that use of archival tags could address this question directly. In addition, the TAB report also stipulated that results from archival work addressing spawning area fidelity also would contribute to the overall knowledge of movement between areas. The TAB report was adopted by the 1995 ICCAT Standing Committee on Research and Statistics (SCRS) and their report also recommended that archival tag research be initiated as soon as possible to address biological attributes and movement problems of Atlantic bluefin tuna. In addition, the 1995 re-authorization of the Atlantic Tunas Conventions Act (ATCA; Anonymous 1995) includes provisions to identify and define the range of Atlantic bluefin tuna stocks and to conduct statistically designed cooperative tagging studies. Thus, the NRC report, U.S. conventions (ATCA), as well as international conventions (ICCAT) all recommend a high priority for addressing Atlantic bluefin tuna stock structure, movement, and management issues as soon as possible. The TAB report indicated that fifty archival tag recoveries (at least two years at large) should provide results that are reflective of Atlantic bluefin tuna stocks (Restrepo, 1996). Furthermore, the research plan indicated that the total number of archival tags needed in fish to reach this number of recaptures ranged from 150 to 3,000.

INITIATION OF AN ATLANTIC BLUEFIN ARCHIVAL TAGGING PROGRAM

A unique opportunity to conduct a large-scale, scientific study of medium (61–141 kg) and giant (141 kg or larger) bluefin tunas has emerged in the western North Atlantic off the coast of Cape Hatteras, North Carolina. Large aggregations of medium and giant bluefin tunas have been gathering during recent winters (1994–1997) for reasons as yet unknown. Warm Gulf Stream waters overlie the continental shelf at this location providing an area that is relatively warm (21–24°C) for winter western North Atlantic regions and a place where prey also congregate. Bluefin tuna found off of Cape Hatteras are remarkably aggressive toward taking a bait, making it relatively easy to catch these large fish on heavy tackle. Moreover, the current fishery operates during a period of commercial closure making tag and release, or release, the most common option for fishers angling large bluefin. An angling category quota for trophy sized fish has resulted in some giants being brought to the dock, providing an opportunity to collect samples. The development of this fishery has resulted in a recent peak in tag and release activity by rod and reel anglers (approximately 4,410 fish were NMFS tagged at this location from 1994–97). It is not uncommon for fishers on a single boat to tag and release over 20 medium and giants in a day, and in some cases, as many as 50–60 fish have been tagged and released in one day of fishing. In February and March of 1996 and 1997, we conducted archival tagging operations off Cape Hatteras and have successfully released 170 medium and giant bluefin tuna with implantable archival tags. The program was conducted simultaneously with a combined experimental design that also utilized pop-up satellite and acoustic technology for assessing survivorship of tag and released bluefin tuna (Block et al., 1997; Block et al., unpublished data).

The availability of bluefin tunas of year classes 4–9 near Cape Hatteras during the winter months (January-April), coupled with a tag-and-release recreational fishery, focused our initial efforts on this site for deployment of implantable archival tags in large medium and giant bluefin. Success with archival tagging requires that high numbers of tags be deployed. The capacity to catch large numbers of bluefin tuna close to shore, in relatively shallow water (70–110 m depth), in 5 to 15 minutes on heavy tackle using circle hooks, provided an unparalleled situation to launch an archival tagging effort. Despite the potential for rough water in the winter this was a unique opportunity to develop and test the efficacy of surgical implantation of archival tags in large fish. In other western Atlantic locations (e.g. New England waters or the Gulf of Mexico) it would likely not be possible to access the same quantity of large tunas that are quickly and easily caught with rod and reel. Techniques are being developed for archival tagging of purse seine caught bluefin tuna. Thus, in the future, it may be possible to deploy large numbers of archival tags (100–200), in short durations in northern waters.

ARCHIVAL TAGS

Archival tags are microprocessor-controlled, data-logging tags that record parameters such as depth, ambient and internal temperature, and light levels. Estimates of latitude and longitude can be determined from light intensity and an onboard clock, and is augmented by recording data on sea surface temperature (Delong et al., 1992; Gunn et al., 1994; Hill, 1994). In addition to recording light, archival tags provide a record of environmental variables and of the behavior of the animal carrying the tag. Depth and temperature measurements reveal the movements of the fish in relationship to the water column. Rapid dives by the tunas provide sub-surface sampling of temperature with depth, robust enough to provide information on the thermocline and frontal boundaries. For use on bluefin tuna, the tags are surgically implanted in the peritoneal cavity. The 12–25 cm stalk protruding from the tag, extends through the 3–7 cm ventral muscle layer of the body wall and carries the external irradiance and ambient temperature sensors. Pressure sensors and an internal temperature sensor are inside or at the surface of the tag. Currently, four companies, Northwest Marine Technology (NMT),[1] Wildlife Computers of the U.S.A.,[1] Zelcon, Inc.[1] of Hobart, Australia and Lotek of Canada[1], produce archival tags for use in fish, which cost between $1,200 to $1,500 US. These tags have different ranges of capabilities but all record light, depth and ambient temperature and provide from 256 kb up to 2 mbytes of memory. Only implantable archival tags with external stalks provide body temperature (NMT, Wildlife Computers and Zelcon).

There has been considerable concern about the accuracy of geolocating fish using changes in ambient light levels at dawn and dusk. Archival tags are specialized for recording light in the low ambient (diffuse illumination) light conditions of the open sea. The capacity to detect light at depth, as well as the ability to accurately measure internal temperature during rapid changes of depth varies significantly among the different companies' tags. This has been shown by comparing tags deployed on a conductivity, depth and temperature array or a drifter buoy in the open ocean (Block and Dewar, unpublished data). For example, whether a tag is cast in urethane or metal and the absolute amount of the casting material used, effects the thermal inertial of the tag. Latitude and longitude are calculated by recording illumination in relation to a real-time clock. Raw light measurements, collected over as many as seven decades of light, are corrected for light extinction with depth prior to being used to calculate longitude and latitude. Established nautical algorithms are used to calculate position from the light-depth corrected light data. Longitude is determined from the time of midnight or local noon, the average of sunrise and sunset. Latitude is computed from estimates of day length, which is determined from measurements of sunrise and sunset. There are a number of algorithms that can be applied to calculate latitude and longitude, which equations are used will influence the actual values for geolocation.

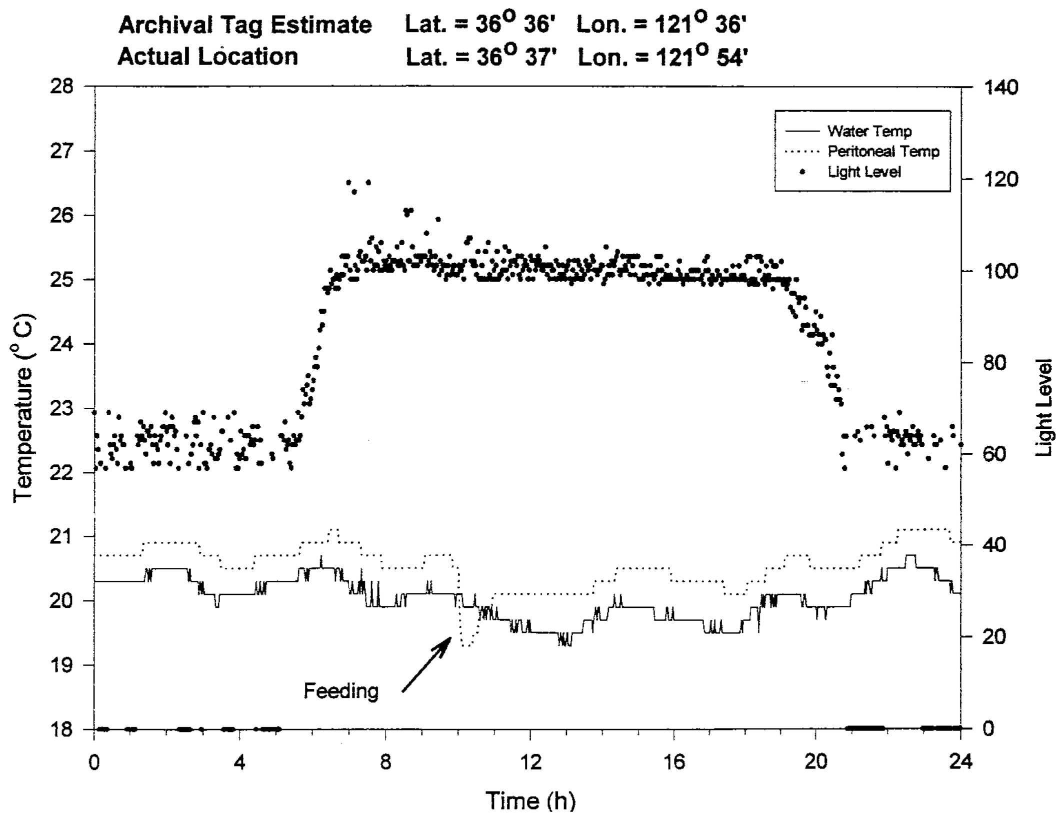
Using light based geolocation data sets, many researchers have determined that the longitude measurements tend to be more accurate than latitude (Hill, 1994; Klimley et al., 1994). Longitude is based on the accuracy of determining midday, and an error in discerning either dawn or dusk is divided by two, which reduces the total error. In contrast, the latitude is based on the day length, a difference of sunrise and sunset times, to which both times contribute their errors (if incorrect) undiminished. The accuracy in latitude estimates is also related to regional changes in day length, which are influenced by the latitude and season. Estimates of latitude can be augmented by the tags capacity to measure sea surface temperature (SST). Sea surface satellite imagery coupled with the longitude estimation and SST values provided by the archival tag, can help place the latitude of a particular fish. In the case of Atlantic bluefin tuna, preliminary results from two archival tags that have over 8 months of data, at two minute intervals, indicate the Atlantic bluefin are on the surface a high percentage of the time, on a daily basis, making the overlay of longitude, SST, and AVHRR imagery feasible.

Archival tags can be programmed to sample at various intervals but are most often set at two to four minute sampling rates. The tags may collect data daily or can be duty cycled to sample for a few days and then turn off for a few days, during which time the tag conserves power and memory allocation. Duty cycling can be problematic, the archival tags running on universal time may inadvertently be cycling the tag off during local sunrise and sunset. Researchers partition the memory of the tags depending upon the duration of a mission and the type of data required for the study. Tags are downloaded either by infra-red transmission linkage or via a direct serial connection to a personnel computer. While relatively new to studies of fish biology, archival tags have been used previously to study the movements of marine mammals (Stewart and Delong, 1991). Tags deployed on marine mammals were designed to measure light only at the surface when the animal respired, thus gathering data at intervals that were related to the animals respiration rate. Delong et al. (1992) monitored the migration patterns of five elephant seals over an average of 115 days. Elephant seals respire at intervals around twenty minutes resulting in a relatively course light sampling regime. A calibration indicated that estimated position was always less than 110 km from actual position and, for greater than half the estimates, the error was less than 60 km (Delong et al., 1992).

Archival tags have been used successfully only in teleosts with high exploitation rates. Measures of light intensity using archival tags have been used to examine the migratory movement patterns for southern and Pacific bluefin tuna (Gunn et al., 1994, 1996; Itoh et al., 1997). Experiments with school size southern bluefin tuna, *Thunnus maccoyii* (Gunn et al., 1994) and small (age 0 and 1) Pacific northern bluefin tunas, *Thunnus thynnus orientalis* (Itoh et al., 1997) have yielded over a 12 percent recovery rate of implantable archival tags. Both studies are providing an extensive understanding of movement and migration patterns. Archival tags that log depth, temperature and orientation have also been used by British fisheries scientists to study the movements of plaice (*Pleuronectes platessa*) in the North Sea (Metcalfe and Arnold, 1997).

Gunn et al. (1994) tested the accuracy of the geolocation algorithms used with the Zelcon SBT200 tag by towing a cage with archival tagged southern bluefin tuna, and comparing the archival data to the ship's GPS position. The longitude and latitude estimated were within 1–2° of the actual position. Block and Dewar (unpublished results) placed a NMT archival tag on a drifter buoy at 50 m depth with a GPS transmitter for seven days and found longitude estimates were within ± 0.1° of the GPS reported position half of the time, or at worst 1° off of the actual position. Latitude varied significantly on 3 days but was either at the correct latitude or within 2° of the correct position on 4 days. The test was done near the autumnal equinox, at 32°N. Additional tests with NMT tags implanted in captive tunas held within a 3.2 m diameter tank at the Tuna Research and Conservation Center (TRCC) in California, indicate that longitude accuracy was extremely high, within 1–15 minutes, and latitude accuracy was within 0.2–3° (Figure 1). Both the captive tank tests and the wild towed cage experiments do

Figure 1. The output of light, ambient water temperature and body temperature data from one day of a Northwest Marine Technology archival tag implanted in a yellowfin tuna at the Tuna Research and Conservation Center. The tanks are inside a building with numerous windows exposing the fish to a natural day-night cycle. Archival location is calculated from the light curve displayed and the actual location is based on GPS.



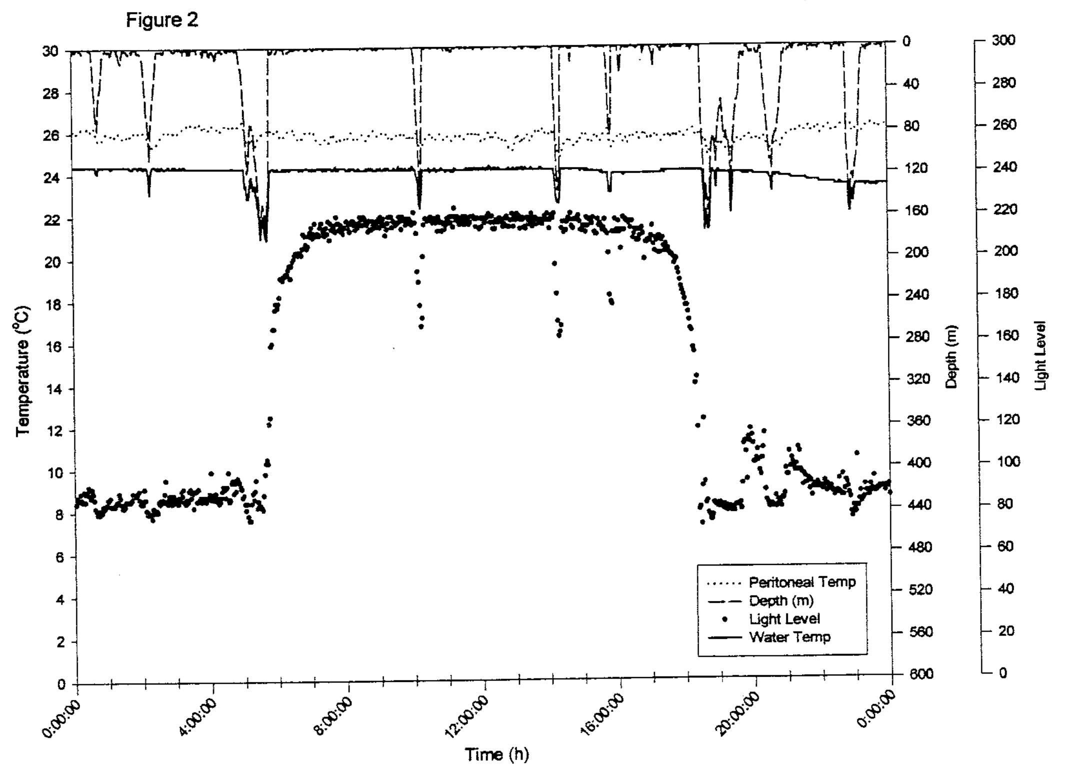
not permit deep dives which is a limitation of such experimental verifications of the geolocation accuracy. However, the drifter experiments do permit deployments to 300 m or more, with slow rates of daily drift (0.4–0.5 nautical miles per day). Simultaneous deployment of archival and ARGOS based satellite tags on marine mammals provides an additional means for accurately comparing the geolocation accuracy as well as the extinction of light with depth.

In addition to obtaining data on movement patterns, the archival tags provide data indicating the thermal preferences and behavior of bluefin tuna. Depth data at two minute intervals provides extensive detail on surface time, diving patterns and dawn and dusk behaviors (Figure 2). Internal implantation has resulted in data sets with remarkable new information about tuna thermal inertia and endothermy. Experiments with captive tunas indicate that the thermogenesis associated with digestion can be measured, thus, the warming associated with feeding in free-swimming tunas can be observed (Gunn *et al.* 1994; Dewar *et al.*, 1996).

IMPLANTATION OF ARCHIVAL TAGS IN ATLANTIC BLUEFIN TUNA

The development of the procedures for handling large bluefin tunas and for the surgical implantation of archival tags was successfully carried out in 1996 and 1997 in the western north Atlantic. The major objective was to develop the techniques for bringing on board a small fishing vessel (35′), a medium or giant bluefin tuna for the short surgical procedure. The successful release of a bluefin tuna with an archival tag is an operation that requires coordination with experienced fishermen. The bluefin tuna sport fishing fleet at Cape Hatteras, North Carolina works cooperatively during the winter months. The scientific surgical team was aboard an experienced sport-fishing vessel (the surgery boat) which maximized our success at catching and releasing large fish without harm. To provide access to a larger number of fish, a technique was developed to transfer fish from neighboring vessels to the surgery boat. Volun-

Figure 2. A single day from an archival tag record of an Atlantic bluefin tuna, *Thunnus thynnus thynnus*. Four channels of data are apparent (depth, ambient temperature, peritoneal cavity temperature and light). The day of data is from March 1997, from a bluefin close to the continental shelf off of Cape Hatteras, North Carolina swimming in warm, Gulf Stream waters.



teer transfer of large numbers of fish was facilitated by the closure of the commercial fishery due to ICCAT quota restrictions. This closure results primarily in a release, or tag and release fishery off Hatteras. The VHF radio was used to coordinate the transfer of fish from the fishing vessel to the surgery vessel. The fishing line from the surgery boat, secured to a tennis ball, was thrown to the boat fighting the fish. The fishing vessel attached their leader to the line from the surgery boat, via a snap swivel, making transfer of the hooked fish to the surgery vessel possible.

To minimize injury and trauma, most fish were caught on heavy tackle (60 kg gear) with 90 kg monofilament mainline and 180 kg fluorocarbon leader. Circle hooks were used as terminal gear over 90 percent of the time. Hooks were set immediately after a strike, resulting in the circle hook imbedding in the hinge of the jaw or in the upper lip the majority of the time. The fishing method is called "chunk fishing" and consists of heavy chumming (using menhaden, *Brevoortia tyrannus*, or other baitfish) while baited hooks are presented in the chum slick. Circle hooks were relatively easy to remove from bluefin once in the boat. No hook damage to the upper palate or gullet was observed in 88 percent of the fish released. The success using circle hooks and the chunk fishing technique is very high. Circle hooks imbedded in the jaw hinge are difficult to dislodge, so slack that develops in the line while chasing the fish does not result in fish loss.

Vessels chosen for surgery require a low water line and a "tuna door" to permit easy entry from the ocean into the cockpit of the vessel. All fish were caught on rod and reel and efforts were made to minimize fight times which were routinely less than fifteen minutes. At the stern of the vessel, the bluefin tuna were guided through the tuna door onto a wet, vinyl pad either by controlling the fish with the heavy test leader or, more often, by placing a lip hook attached to a tethered rope through the tissue at the anterior point of the lower jaw. An experienced deck hand would leader the fish to the back of the boat, while a second person established proper position with the lip hook. After inserting the lip hook, three people would guide the tuna onto the boat with one person grasping the base of the pectoral fins. The slick surface of a vinyl pad was used to cushion the fish and ease its movements in and out of the vessel. More than 250 bluefin have been handled in this fashion and not a single fish has reacted with rapid tail kicks or explosive activity on deck.

Once aboard the vessel, the bluefin was most often placed on its side. The eyes were immediately covered with a dark moist cloth, and a sea water hose provided continuous irrigation across the gills. A one inch incision with a number twenty-two scalpel blade was carefully placed about 18–25 cm anterior to the vent, 5–8 cm off the midline. The thick layer of skin and scales is nearly impossible to penetrate farther towards the head in large bluefin. The tag inserted at this location did not interfere with internal organs. DNA samples for future analysis were removed from the outer layer of muscle lining the ventral body cavity. After the incision, a trocar, swabbed with betadine, was used to make a path for the tag into the body cavity. Careful persistent pressure was required to penetrate 3–7 cm muscle layer and thick membrane lining the peritoneal cavity. The trocar is a 20 cm stainless steal rod, 1.5 cm diameter with a blunt, tapered end. The cylindrically shaped NMT archival tag, measuring 11.5 cm in length and 1.5 cm in diameter, was pushed into the peritoneal cavity with care taken to place the tag parallel to the midline and not perpendicularly into the cavity . The same techniques were used to insert the Wildlife Computer archival tag which was slightly larger than the NMT tag. Two stitches were used to close the incision. The suture material was polydioxanone, 4.0 metric, absorbable monofilament made by Ethicon. A CPX reverse-cutting, suture needle was required to penetrate the tough skin and scales. Once the tag opening was closed, two green, two-tone, external Floy tags were placed on either side of the fish (in the musculature near the first and second dorsal fins) to alert fishers of the archival tag in the peritoneal cavity. Curve-body, fork length was measured and the fish was gently eased back into the water, head first. Hand holds on the vinyl mat permitted rapid means for turning the mat and fish around. Fish estimated to be over 220 kg were too large to turn around and were eased into the water tail first. The measured procedure time ranged from 2 to 5.5 minutes and averaged 3.5 minutes.

In year one (1996), 10 bluefin tuna, ranging in size from 71–159 kg, were implanted with NMT archival tags using the above methods. The focus of this first year was primarily on the establishment of the techniques required to handle the bluefin tuna on deck. In year two, 68 additional NMT tags and 92 MK7F Wildlife Computer tags were inserted in bluefin tuna ranging in size from 76–234 kg. Of the 170 bluefin tuna tagged, only a few showed significant signs of bleeding at the hook wound (in these cases, the hook penetrated the maxillary bone of the upper jaw). On several occasions, old hooks from previous captures (up to 3) were removed during the procedure. The bluefin swam away from the boat vigorously, and all were deemed in good to excellent condition upon release. The only problem encountered with the procedure was the rare case when the swimbladder was punctured, either by the archival tag or the trocar. The gas escaping from air bladder was easily heard. We encountered this problem in less than 2 percent of the surgeries.

Additional studies to examine the survivorship and healing rate of archival tagged fish were conducted with a captive tuna population at the TRCC. To date, over a dozen archival or similarly constructed dummy tags (NMT and Wildlife Computer combined) have been implanted in yellowfin tuna ranging in size from 6–15 kg. No adverse effects of archival tag implantation were observed and, in general, archival tagged fish fed at the first available opportunity following surgery. This is in contrast to placement of external attachments of acoustic or satellite tags which often disrupt the behavior of the individual for 1–2 days in captivity (Block, personal observation). Four fish with archival tags have survived for 1.5–2 years and remain healthy members of the captive tuna population with no indication of adverse affects. Minor biofouling is apparent on the stalks of both types of archival tags. To recover data from archivally tagged individuals, we have reversed the surgical procedures to remove the archival tags, with no ill effects. Only one mortality associated with archival tagging procedures has occurred at the TRCC and it is difficult to assess whether the single archival death can be attributed to the archival tagging event or the long-term stress of captivity (the fish died eleven months after having a surgical implant of an archival tag). Five fish have been sacrificed to examine the tag placement and healing process. Postmortem examination reveals that the archival tags lie parallel to the body axis. Archival tags that have been in place for a long time are completely encased in an epithelial mesentery that is enriched in blood vessels. Minor irritation around the stalk as it exits the body is the only inflammation that we have noticed with either tag.

The captive tunas have provided an excellent opportunity to conduct controlled experiments. To test the rate of healing with different suture materials, incisions were made without inserting an archival tag. Polydioxanone sutures (n = 45) were completely gone in 80 percent of yellowfin in two to three weeks with no sign of injury. However, in three fish, the suture material remained in the tunas for many months after surgery. The wounds closed with polydioxanone appeared well healed 3–8 weeks after implantation. Experiments with coated vicryl braided sutures (n = 20), indicated a more rapid loss of the suture material but no appreciable difference in the wound appearance or healing rate. In four cases, braided vicryl did not remain long enough to promote the closure of the wound.

RECAPTURE PROGRAM

At the 1996 ICCAT meeting of the SCRS, the Commission formalized a Tagging Working Group to be run through the Bluefin Year Program (ICCAT biennial report, 1996). The main task of this working group is the development of an aggressive, Atlantic-wide, tag recovery program (archival and conventional tags) under the auspices of ICCAT. Tagging correspondents from ICCAT and non-ICCAT countries have already been surveyed for their opinion on how this program should be organized. In addition, a small amount of financial resources have tentatively been set aside in a special ICCAT account for hiring samplers to examine the catch of mature bluefin landings for archival and conventional tags, particularly in the Mediterranean Sea where so many different countries are involved. Reward posters have been translated into the main ICCAT languages (English, Spanish, and French) as well as Japanese, Chinese, Korean, Portuguese, Arabic, and Italian.

EXPECTED ARCHIVAL TAG RETURN RATE

Inferences can be made about the expected rate of return for archival tagged Atlantic bluefin tuna by examining recapture rates with conventional tags deployed by commercial and recreational fishers. The historical tag recapture rate for Atlantic bluefin tuna (all size categories and years combined) for the NMFS Cooperative Tagging Center (CTC) is 12.2 percent. (Jones et. al, 1997). However, recent quotas (which are intended to reduce exploitation) have resulted in a significant reduction of recovered fish over the historical recapture rate. In the past four years (1994–1997) 4,410 conventional tags have been deployed in bluefin tuna off of Cape Hatteras. Recapture rates during this period average 2.9 percent but range from a low of 1.4 percent (1995) to a high of 8.3 percent (1994). Using a 3 percent recapture rate and assuming a 5 percent mortality associated with the tagging procedure, one can expect 4–5 archival tags per year out of the 170 tags deployed thus far. Conventional tagging data from western Atlantic bluefin tuna indicate after three years the tag returns drop off sharply (Prince, personal observation). Thus the archival tag projected return rate emphasizes the need for implanting a high number of archival tags as well as the need for development of a pop-off satellite archival tag. It is assumed that some of the archival tagged fish from Hatteras will move to the north as well as to the eastern Atlantic. Conventional tagging in the past decade indicates that Hatteras released fish have the highest probability (76 percent) of being recaptured at Hatteras. Tag recoveries from New England waters are second to the Hatteras returns in frequency. Two of the 1997 archival tagged Hatteras bluefin were recovered in late summer and early fall of 1997 in New England waters (Figure 2). Interestingly, to date, 3.3 percent of the fish conventionally tagged at Hatteras and recaptured, have made trans-Atlantic crossings, indicating the importance of the Mediterranean in an archival tag recovery program. Pop-up satellite tag results indicate western bluefin tuna can move into the eastern management zone in only a few months (Block et al., 1997; Block et al., unpublished results). Archival tag recoveries are dependent upon an active fishery and adverse weather can cause a reduction of effort. Environmental oscillations such as the large 1997–1998 ENSO event may have negative impacts on recovery of Atlantic bluefin tuna due to increase severity of storms in the southeast region, the region of highest recovery probability, during the peak fishing season.

In the past, it has been apparent that recapture rates are not equal on both sides of the Atlantic for western tagged bluefin tuna. This situation has been addressed by Prince and Cort (in press), by first identifying major landing ports on both sides of the Atlantic, and developing an aggressive recapture program under the auspices of ICCAT, using financial rewards, local contacts to administer the program, and literature in the local language. The special recapture programs for bluefin tuna may increase the archival tag recovery rate, as has been demonstrated through the ICCAT Enhanced Research Program for Billfish (ERPB) in the eastern Caribbean Sea (Bayley and Prince, 1994). The billfish program realized an average increase in recapture rates of at least 10 percent after the ERPB program had been established. In addition, it is well known that recapture rates are closely tied to the amount of the reward (Fable, 1990). Publicity and international cooperation are key to recovering the archival tags. NMFS has established new regulations involving small quota allowances for archival tagged fish in the western Atlantic, distinguished by the fluorescent green and white external tags. The aggressive Atlantic-wide recapture and publicity program initiated with the pilot project has established the framework required to maximize archival tag recovery. An important aspect of this new western Atlantic study will be the encouragement of an equal archival tagging effort in the east Atlantic and Mediterranean sea under the auspices of ICCAT.

EXAMINING SURVIVORSHIP OF ARCHIVAL TAGGED FISH

Acoustic telemetry involves securing a sonic tag to a fish which encodes the data of interest as an acoustic pulse. Using a hydrophone and receiver, the acoustic signal can be detected enabling scientists to track the fish from a research vessel (Block et al., 1997). Although the time scale per track is short (1–7 days) and samples sizes are small, acoustic telemetry provides detailed information on the patterns of pelagic fish movements in relation to environmental parameters. This has provided insight into larger scale movements (e.g. Carey and Robison, 1981; Carey, 1982; Holland, et al., 1990; Holts and Bedford, 1990; Block et al., 1992a, 1992b, 1995; Skomal and chase, 1996; Block et al., 1997; Brill et al., 1996). When the tracking vessel is an oceanographic vessel, environmental profiles and biological features of the water column can be monitored during the track. In comparison to acoustic tags, archival tagging does not provide the resolution of movement in relation to the environmental conditions, due to the lack of an oceanographic platform (a ship) and data sampling rates. During the 1997 archival tag efforts, acoustic tracking of five fish that were handled in the same fashion as the archival-tagged fish, indicated that survivorship was high. Survivorship was also examined by deploying pop-up satellite tags on archival-tagged fish (Block et al., 1997).

Coincident with the 1997 release of archival-tagged fish, five acoustic-tagged fish were released. The first experiments were aimed at establishing whether the bluefin tuna survive the handling procedures. For these fish, four acoustic tags were secured externally. Preliminary results indicate 100 percent short-term survivorship (up to 32 h) for bluefin that are handled in the manner described above. One acoustic tagged fish was detected seven days after release, swimming with a school of fish that was targeted for archival tagging. This acoustic fish provided the opportunity to follow and mark the school for the entire day, allowing us to archival tag thirty-nine medium and giant bluefin, the most tagged in any one day. To more closely examine survivorship following surgery, one acoustic tag was implanted in the peritoneal cavity of one fish in a similar fashion to an archival tag. This fish was followed for less than a day due to weather, but indicated short-term survivorship from surgery. In addition to providing a measure of survivorship from the capture and handling of large bluefin tuna, the acoustic tracking provides the capacity to examine the short-term pattern of movements around the wrecks off the Cape Hatteras coast-line, providing new information on what attracts the tunas to this location.

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