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Tagging Techniques Can Elucidate the Biology and Exploitation of Aggregated Pelagic Species

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Abstract.—Recent advances in the analyses of tag-and-recapture data and an increase in the type and sophistication of commercially available electronic tags are combining to provide insight into horizontal and vertical movements of pelagic fishes. This information can be used to evaluate the importance of specific geographic areas to the overall movement patterns of a species and to explain exploitation patterns and vulnerability to different fishing gear types. Different types of tag are briefly reviewed and an example given of combining traditional tag-and-recapture with electronic tag data to focus on a specific fishery that targets an aggregated tuna resource. The possibility is discussed of applying similar techniques to address questions surrounding the Charleston Bump.

Tag-and-recapture techniques have played an important role in fisheries biology, especially in revealing growth and mortality rates and the movement patterns of highly mobile species. A thorough review of the history and application of tagging techniques is available (Parker et al. 1990). In recent years, improvements in computer hardware and computer program compiling software have combined to allow the testing and validation of increasingly sophisticated interpretations of the pattern of tag recoveries. These mathematical simulations seek to model the observed geographical and temporal patterns of recaptured tagged fish. When a model closely matches the empirically obtained data, the relative importance of the components (assumptions) of the model can be evaluated for their role in the goodness of fit (e.g., Sibert et al. 1999, in press; Hampton, in press).

At the same time, a variety of increasingly sophisticated electronic tags have been developed and become commercially available. Whereas the power of traditional identification tags lies in the large numbers of tags that can be released at reasonable cost, more expensive electronic tags use a comparatively few individual fish to obtain important insights into fine-scale movement patterns, vertical distribution, behavior and physiology. These fine-scale behavioral data can assist in the interpretation of other types of fishery data. For instance, blue marlin depth distribution data acquired by sonic telemetry have been used to interpret catch statistics and adjust stock assessments according to the depth of deployment of the gear types from which the fisheries data were obtained (Hinton and Nakano 1996).

Similarly, this paper will describe how combining statistically robust tag-and-recapture data with insights obtained from electronic tagging of a few individuals can result in an improved understanding of fish distribution, gear vulnerability and exploitation. These insights can lead to improved harvesting and management strategies. This paper will also briefly describe the various types of electronic tags that are currently available and review examples of how these devices have been used to study aggregations of pelagic species. The applicability of these types of tagging techniques to the situation of the Charleston Bump is discussed.

Types of Electronic Tags

Sonic transmitters

Radio waves transmit very poorly through salt water. Therefore, transmitters used on marine fish use high frequency sound as the communication medium. Sonic transmitters can be used in two basic ways. First, using techniques pioneered by Carey and his colleagues (Carey and Olson 1982; Carey 1983) and subsequently adapted for use with smaller vessels (Holland et al. 1985, 1990b), sonic transmitters are used for active tracking of the tagged individuals. In active tracking, the transmitter is attached to the fish which is then released and followed by the tracking vessel which must stay in uninterrupted sonic contact with the fish. Usually, this means staying within a few hundred meters of the tagged fish. Tracks of this type usually last between one and three days.

Sonic transmitters can be pressure sensitive which allows simultaneous monitoring of both fish depth and horizontal movement. Temperature sensitive transmitters have been used to acquire both ambient and body temperature data during active tracking (Carey and Lawson 1973; Holland et al. 1992a) and elucidating the thermal preferences of pelagic fishes has been one of the most significant products of sonic tracking (e.g., Carey and Olson 1982; Holland et al. 1990a, b)

More recently, longer-lived sonic transmitters have been used to document the return of the tagged individuals to a specific, fixed point. In this passive monitoring technique, underwater data loggers ("listening stations") are programmed to continuously listen for the presence of fish carrying sonic transmitters (Klimley et al. 1998; Klimley and Holloway 1999). When a tagged fish comes within range (a few hundred meters) of the data logger, the logger records the tag identification information and time of day data. These data can be periodically downloaded when the data logger is retrieved and interrogated. Because these transmitters can work for up to two years (depending on the size of the fish which, in turn, dictates the size of the transmitter and battery), they are typically internally implanted in the gut cavity of the fish. This eliminates the hydrodynamic drag and possible shedding of transmitters that are attached externally.

This data logger technique is well suited to the study of fish aggregations associated with fixed structures and has been used to document the periodic return of yellowfin tuna *Thunnus albacares* to fish aggregating devices (FADs) in Hawaii (Klimley and Holloway 1999) and hammerhead sharks to a seamount in the Sea of Cortez (Klimley et al. 1988). The yellowfin data show that the fish returned to the same FAD for several weeks after release and the synchronous return of multiple tagged individuals has been interpreted to indicate a high degree of school fidelity of this species under these circumstances. Holland (unpublished data) has used internally implanted transmitters and anchored data loggers to document the repeated return of tiger sharks to the same area of Hawaiian coastline for periods of up to two years.

Archival tags

Archival tags have an on-board memory that can store data which are subsequently downloaded when the tag is interrogated. The tags can be preprogrammed to sample and archive data at rates which suit the task at hand. For instance, when the animal is expected to be at liberty for long periods or cover large distances, environmental sampling can occur at widely spaced intervals or the data condensed into data "bins" of quite coarse scale. Some tags can be programmed to initially sample at a fine scale and then reduce sampling frequency as time at liberty increases. Parameters which are typically measured and recorded are depth, water temperature and internal body temperature.

Estimating geolocation (horizontal position) has so far proved to be difficult for geographical scales smaller than squares several tens of mile on a side (Welch and Eveson 1999). Because radio waves do not penetrate salt water, LORAN or GPS technologies cannot be used to estimate the position of the fish. Therefore, current geolocating archival tags attempt to use day length and the absolute time of sunrise and sunset to obtain estimates of latitude and longitude. These estimates can be difficult when the animal is swimming at great depth or when water turbidity changes frequently (Welch and Eveson 1999; West and Stevens, in press). Coarse-scale estimates are adequate for trans-oceanic movements but inadequate for questions dealing with finer-scale movements such as orientation to an estuary or a seamount.

Archived data can be recovered in a variety of ways, each of which has its own advantages and disadvantages. One method is to recapture the animal carrying the tag. This has the advantage of the investigator retrieving the tag (which can be placed internally if desired) and ensuring complete and accurate downloading of all the stored data. This strategy has the significant drawback that it relies on the recapture of the fish by fishermen and subsequent reporting of the recapture and delivery of the tag to the appropriate agency. However, the large rewards often associated with the recovery of these tags have yielded return rates that are equal or greater than the recapture rate of conventional tags in the same fishery. This is particularly true in fisheries where the population is heavily exploited and in which high percentages of the population are caught. In the Australian school shark fishery, 30% of externally mounted archival tags were recovered (West and Stevens, in press) as were over 12% of archival tags attached to plaice released in the North Sea (Metcalf and Arnold 1997).

Alternatively, the archived data can be downloaded to satellite. In these cases, the tag must be mounted externally so that, through the use of a corrosible link, the tag can release from the animal on a preset date, float to the surface ("pop-up") and communicate with the satellite. This precludes the need to recapture the fish and therefore the data are fishery independent. This technique has the disadvantages that the tag must be externally attached and the transmitter and download costs are quite high. Simpler versions of this type of tag do not store data but simply provide the location of the tag when it releases from the fish. Again, the major attribute of these types of movement data are that they are independent of fishing effort.

Pop-up satellite transmitter technologies are in active development and are currently being applied to questions concerning the movements of Atlantic bluefin tuna *T. thynnus* (Block et al. 1998; Lutcavage et al. 1999) and Pacific bigeye tuna *T. obesus* (Boggs, personal communication). In the case of Atlantic bluefin, the pop-up locations alone have already provided convincing evidence of the wide ranging, open ocean movements of specimens initially caught close to the east coast of the United States.

As with any research program, the choice of which method to use depends on a combination of the suitability of the technology and the cost of the components. In the case of satellite tags, the costs are still evolving. In addition to prices varying with the quantity ordered, the price also depends on whether the tags simply provide a single location point when they release from the fish or whether they store and then transmit archived data. Also, the advantages of possible quite low returns of recaptured archival tags (fisheries dependent) carrying high definition data must be compared with potentially high returns of fisheries independent “pop-up” satellite tags which do not provide as much raw data. An empirical approach is to conduct pilot studies with inexpensive dummy archival tags to obtain an estimate of recapture rates. In an experiment using internally and externally implanted dummy tags, West and Stevens (in press) obtained a return rate of 19% with all three types of attachment techniques having about the same recapture success. Based on these results, they proceeded with an experiment using externally mounted archival (nonsatellite) tags (West and Stevens, in press).

A recently developed tag is a hybrid of archival and sonic tag technologies. These tags use a ‘sonic modem’ to download stored data (depth, temperature) from the tag to data loggers moored on buoys or attached to the ocean floor. The tags can be attached externally or can be implanted in the gut cavity. If the fish carrying the transmitter comes within a few hundred meters of the data logger, the logger detects a regularly emitted interrogation tone from the tag, the two devices exchange sonic recognition signals and the data stored in the tag are sonically transmitted through the water column to the data logger and the fish continues on its way. This method is particularly useful where a species makes regular visits to a specific location. As with pop-up tags, recapturing the fish is not necessary. The primary disadvantage is that the sonic modem technology takes quite a long time to download the stored data. This technology has been successfully used to acquire depth and temperature data from tiger sharks that repeatedly, but irregularly, visit the same section of coastline for periods spanning at least 18 months (Holland, unpublished data).

A variety of approaches have been used to acquire fish for tagging. Because experiments using electronic tags require many fewer fish than traditional tag-and-release programs, it is not always necessary to use industrial-scale fishing vessels. Several studies have used small-scale fishing boats, small research vessels and sport-fishing boats to catch fishes for sonic tracking or other types of electronic tags (e.g., Holland et al. 1990a; Block et al. 1998; Lutcavage et al. 1999). For standard tag-and-release programs that typically depend on high numbers of releases, commercial vessels (e.g., jig boats, pole-and-line bait boats) are preferred because of the large numbers of animals they can capture (e.g., Hampton 1991, in press; Holland et al. 1999). However, in a development pertinent to the Charleston Bump, electronic and conventional identification tags have been successfully deployed on tunas and marlins captured by longline gear (Boggs 1992). This opens up the possibility of using longline vessels to tag and release species such as the tunas, marlins and swordfish that are found in association with the Charleston Bump.

Combining Electronic Tag Data and Tag-and-Release Data

Recent studies of tuna aggregations found in association with a Pacific Ocean seamount have benefited from combining tag-and-recapture data with behavioral information obtained by sonic tracking. This example can serve to illustrate the general advantage of combining different types of tagging data and has specific pertinence to possible future studies of the Charleston Bump.

The Cross Seamount is approximately 160 nm south of the island of O'ahu, Hawaii. At its shallowest point, the seamount is approximately 335 m below the sea surface. The Cross Seamount is the focal point of an active handline and jig fishery which targets mixed schools of sub-adult (35–75 cm FL) bigeye and yellowfin tuna which associate with the seamount. The ratio of bigeye tuna to yellowfin tuna in the catch is about 2:1. Longline vessels also occasionally work at the seamount and surrounding deep-water areas.

These seamount-associated schools have been the subject of an ongoing tag-and-release program and the initial analyses are showing interesting and somewhat unexpected results concerning the residence times and exploitation patterns of these aggregated resources (Holland et al. 1999; Sibert et al., in press). Of particular interest is the amount of time that individual fish spend "in residence" at the seamount. Residence time can be an indicator of how vulnerable the aggregated seamount schools are to fishing pressure and whether or not significant portions of the schools are being removed.

Modeling and analysis of the tag recapture attrition curves (the decline in the rate of recaptured tagged fish over time; Kleiber et al. 1987) of tuna recaptured at the point of release (Cross Seamount) indicate that, even though yellowfin and bigeye tuna occur in mixed schools over the seamount, their residence times are significantly different (BE mean = 32 d, $N = 61$; YF mean = 15 d, $N = 86$). That is, the role of the seamount in the larger movement patterns of these fish seems to be different for the two species. Also, for both species, the residence durations are much shorter than were expected. These quite short residence times indicate that the seamount may not be a vulnerability bottleneck for these species (Holland et al. 1999).

The recapture data also indicate that different gear types exploit different size classes of the seamount assemblages. Comparison of the length of combined bigeye and yellowfin tuna recaptured at the Cross Seamount by longline vessels and handline/jig boats shows that the longline fleet captures fish that are significantly larger (*t*-test; $P < 0.05$) than those taken by the jig fishery (Figure 1). Thus, even though the two gear types are fishing in the same location they appear to be exploiting different sectors of the seamount populations.

Further analysis of these same tag returns (Sibert et al., in press) supports the conclusion that emigration of yellowfin tuna from the seamount is much higher than for bigeye and also shows that catchability of yellowfin is much higher even though the harvest ratio at the seamount is the same and quite small (5%) for both species. Although the harvest ratio is similar, the fact that the commercial catch is predominantly bigeye indicates that the 'instantaneous' seamount popula-

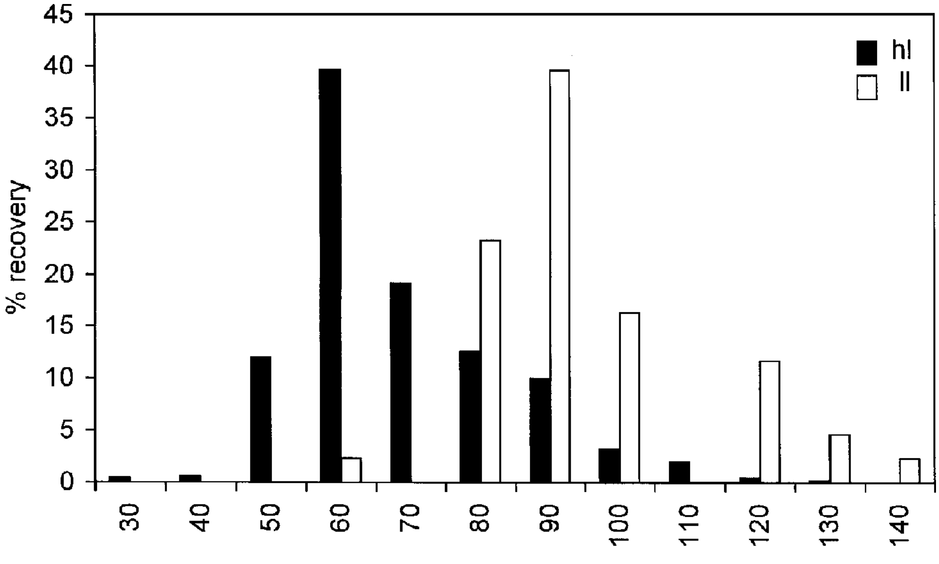

FIGURE 1. Size distribution of recaptured tagged yellowfin, and bigeye tuna at Cross Seamount by different gear types. Solid bars = handline/jig, open bars = longline.

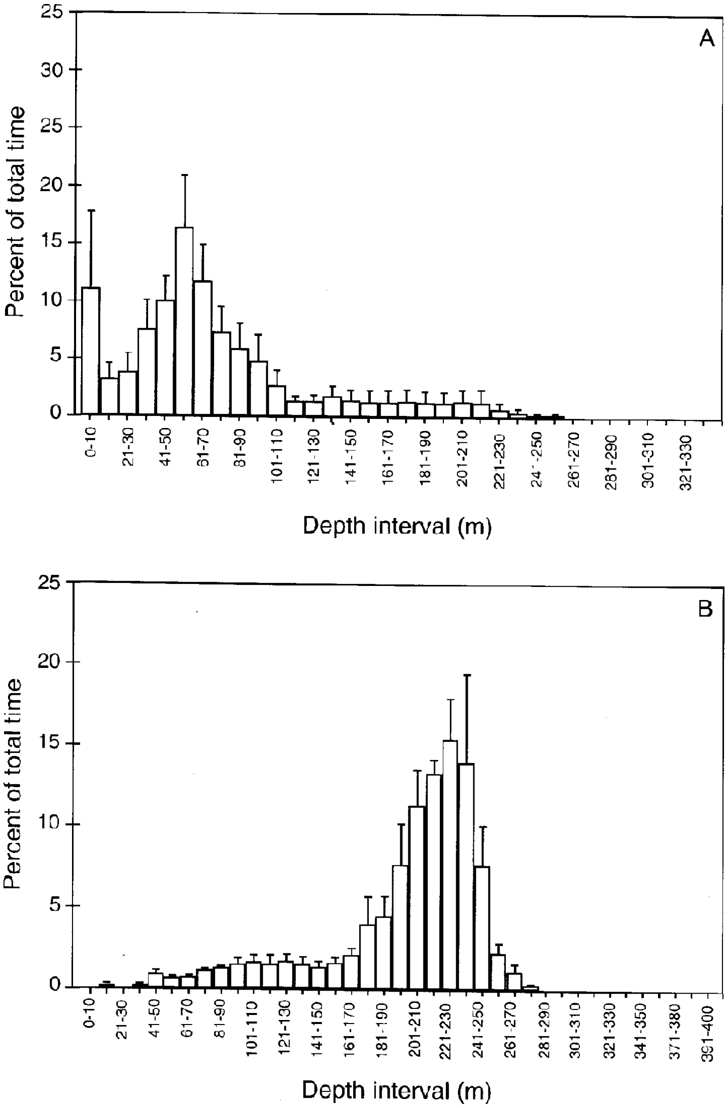

FIGURE 2. Daytime depth distribution of yellowfin (A) and bigeye tuna (B) in Hawaiian waters (from Holland et al. 1990).

tion of bigeye is larger than that of yellowfin. Stated differently, even though yellowfin are more catchable, more bigeye are taken because of their higher numbers at the seamount.

What could account for the higher catchability of yellowfin tuna? For an answer to this we turn to the sonic tracking data. Sonic tracks of both species indicate that, during daytime, yellowfin are typically in the upper, mixed layer of the ocean whereas bigeye have a much deeper distribution (Figure 2; Holland et al. 1990b). This deeper distribution is periodically interspersed with brief upward excursions into the mixed layer for purposes of thermoregulation (Holland et al. 1992a; Holland and Sibert 1994). Combining these depth distribution data with the gear vulnerability analysis from the tag recapture data and the catch statistics from the fishery it is possible to construct a schematic diagram of the tuna population at the Cross Seamount, its dispersal away from the seamount and its vulnerability to fishing gear (Figure 3).

Tagging and the Charleston Bump

Conventional tag-and-release experiments of the type described for the Cross seamount would be directly applicable to questions concerning the assemblages of pelagic species that apparently orient to the Charleston Bump region of the continental shelf of the eastern United States. Tag recapture attrition analyses could indicate residence times for different species or for different sizes or ages of a single species. It would be very useful to know if these species are spending prolonged periods of time in this area or passing through quite quickly as appears to be the case for tunas associated with the Cross Seamount. This type of information could have immediate bearing on the types of regulations that are applied to the Charleston Bump area.

Recaptures would also indicate which fleets or types of gear are taking which species or which size of fish. Longer-term dispersal could be measured by recapture of tagged fish in remote locations and by deployment of pop-up satellite tags, which would yield fishery-independent movement data and give an indication of the overall importance of the Charleston Bump to the larger migratory repertoires of these species.

In both locations (Cross Seamount, Charleston Bump) the size of the different components of the fishing fleet is quite small and their home ports well known. This greatly assists researchers in advertising the tagging program and involving the participants both in the release and recapture of the tagged fish. This allows for good levels of tag returns and realistic estimates of fishing effort. The value of incorporating user groups in studying the dynamics of the resource cannot be overstated.

Other electronic tagging methods could also be applied in this situation. Sonic tracking of individuals would give an indication of their vertical distribution and gear vulnerability and of the range of diel movements of individuals associated with this ocean floor feature. Fixed data loggers, of the type used by Klimley on FADs and seamounts, could indicate the duration of residence and the frequency of visits of individual fish to the area. Also, because the pelagic fish resource associated with the Charleston Bump appears to be under intensive fishing pressure and high exploitation rates, there would seem to be a high probability of recovering medium-duration vertical movement and thermal preferenda data from standard, internally implanted archival tags. If geolocation algorithms can be improved, these tags would also give a greatly improved understanding of the horizontal movements of indi-

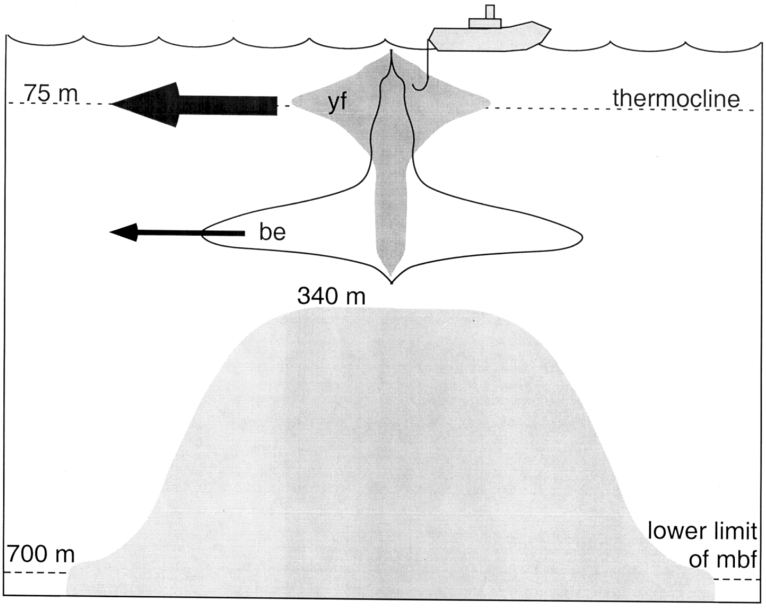

FIGURE 3. Schematic representation of possible distribution and dynamics of bigeye and yellowfin tuna schools associated with Cross Seamount. The shape of the schools is derived from the time-at-depth data acquired by sonic tracking (See Figure 2). Relative emigration rates (size of horizontal arrows) and the relative school size for the two species are derived from analysis of tag recapture data. Horizontal dimension is not to scale.

vidual fish which, for at least part of their lives, orient to the Charleston Bump.

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