The Use of GPS and GIS in Marine Animal Tagging Studies

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The use of Geographic Information Systems (GIS) in fishery management largely began in 1988 through studies that combined GIS and remote sensing to identify suitable areas for aquaculture. Other early studies also used GIS to address fisheries and coastal zone management issues (Riolo, 2006). However, as fishing pressure increased, the need to better manage marine fisheries and to protect endangered and threatened species also increased. To meet this conservation and management need, the advancement of marine animal tagging technology emerged as a viable tool to understand species movements and distributions. Marine animal tagging involves capturing an animal and placing a tag with various data archiving and transmitting capabilities in a specific location on the animal's body and then releasing the animal back into its natural environment. Today, animals large and small, from scallops to whale sharks, are tagged using a wide variety of techniques and devices. While tag types vary to best suit the animal being tagged, pop-up archival tags using Argos satellites remains a popular option for large marine animals (Weng et al., 2007; Gilly et al., 2006; Kitagawa et al., 2007).

Global Positioning System (GPS) and GIS are often employed in tandem in various marine animal tagging programs. This coordination of technology has contributed to better management and conservation of these animals by painting a detailed picture of their movement patterns, behaviors, and seasonal geographic locations. Marine animal tagging in general has enhanced our understanding of the movements and behavior of large, pelagic (open ocean) fish such as sharks and tuna, species which are often threatened from overfishing (Weng et al., 2007; Stokesbury et al., 2007).

The most common types of tags used on larger marine animals are either electronic tags such as satellite telemetry or pop-up satellite tags. These tags provide position information through ARGOS system satellites or by geolocation using light levels and/or sea surface temperatures (Teo et al., 2004). Another widely used tagging technique uses archival data tags, small devices often surgically attached to an animal which stores information such as water temperature and depth. The location of species tagged with archival data tags are most often determined using GPS units both upon release of the tagged fish and upon recapture, most often by fishing vessels that happen to capture a tagged animal. For example, GPS units were employed in a whale shark tagging effort off the coast of Belize in Latin America in 2001. Fourteen whale sharks were tagged from small vessels while feeding on the surface and their locations were recorded using a Garmin 12 hand-held GPS unit (Heyman et al., 2001).

While the data collected by the tags themselves is important, it is useless without an effective method of data analysis. GIS has emerged to fill this role and is continually gathering steam in science applications such as tagging studies. To aide in interpreting tagging data, GIS software is often used to analyze and compare location information. For example, in the whale shark study mentioned above, once tags were deployed, Arc-Info and Arc View GIS were used to plot where the whale sharks were tagged as well as the location of reef fish spawning sites, which are important shark feeding areas. These two components were then compared through time to determine where the sharks were concentrated at different times of the year (Heyman et al., 2001). GPS and GIS technology worked together in this study and played a considerable role in understanding where whale sharks in Belize were located and thus where management measures should be directed to protect the species.

In another study aimed at inferring feeding locations of marine predators, ARGOS tag tracking data from northern elephant seals was used. The study compiled the tagging data...
and measured the location and extent of animal feeding locations using GIS raster-based approaches. This approach showed that the animals feed in areas of high prey abundance, reasonable conclusions made visually clear with the help of GIS (Robinson et al., 2007).

An excellent example of how tagging technology has merged with GIS applications is through the Tagging of Pacific Predators (TOPP) research program, a joint effort by scientists from the U.S., Australia, Canada, Mexico, Japan, France and the UK. Using electronic tags, TOPP scientists track migrations of a variety of marine fish, mammals, and sea birds while the tags simultaneously record different oceanographic information during their journeys. The tagging data is uploaded to a website and is accessible to scientists, conservationists, and the general public alike. The large datasets of tracking information requires new software for the assimilation, storage, analysis and visualization of the data, most of which requires GIS. As evident on their website, TOPP has also been using GIS to create interactive GIS maps of animal locations, which not only assists in data analysis but also in public education and outreach efforts (TOPP website, http://topp.org/).

![GIS map of bluefin tuna movements using pop-up satellite tags (TOPP website)](image)

Tagging of marine animals is important to better understand their geographic distribution which has very practical implications for management and conservation. For instance, Weng et al. (2007) used pop-up archival tags on Great White sharks to collect depth, temperature, and light measurements. The data further added to the base of knowledge we have about Great Whites, a globally threatened species, and may contribute to its long-term protection. On the opposite spectrum of the size scale, Gilly et al. (2006) used satellite tags on jumbo squid, revealing new information about their depth distributions and behaviors. Such information is also useful to policy-makers and conservationists. For species that are known to be highly migratory, such as bluefin tuna, management is often transboundary in nature, involving multiple nations, as the fish spend different stages of their lives in waters managed by different nations. Stokesbury et al. (2007) found that bluefin tagged off Ireland can migrate as far as Portugal and the Mediterranean Sea. Therefore, bluefin management measures enacted by one nation (i.e. Ireland) mean little if there is not compliance and cooperation in other nations where bluefin are found (i.e. Portugal). Clearly,
tagging studies play a significant role in understanding marine resources and contributing to the policy decisions-making process.

The use of GIS in marine animal tagging studies will undoubtedly continue into the future. GIS is powerful in linking spatial data with relational databases, allows data to be easily shared, and results of studies are easily reproducible. These are essential components to all tagging studies. Not only is GIS useful from a data analysis perspective, but the software has proven to be a useful vehicle to relay information to the public (i.e. to fishermen who return tags from fish they capture). Interactive GIS maps on tagging program websites can enhance the success of tagging programs by allowing fishermen to understand the impact their tag returns can have on their fishing resources. For example, regional tagging programs for cod, haddock, and yellowtail offer web-based tag return options and display fish movements via GIS maps (see www.gmamapping.org/codmapping for an example). Due to the contentious nature of fisheries management, especially in places like New England, where fishermen often do not agree with policy or science decisions, tagging programs that employ tools like GIS to display and disseminate data results to key stakeholders can have an positive impact on resource protection (Tallack et al., 2005).

Figure 2. Interactive GIS map of cod release and recapture locations, Northeast Regional Cod Tagging Program (www.gmamapping.org/codmapping)

It is my opinion that as GIS technology develops even further, tagging programs will customize GIS applications to display a wider array of data, perform more detailed and specialized tagging analyses, and make tagging location data more widely accessible to interested parties. In addition, as tagging technology develops, tags will become smaller with longer battery or operating lives, which will in turn improve the quantity and quality of the data. Satellite-based tracking using ARGOS will improve and GPS-based location data will be further tailored to suit a wider range of marine animal tagging studies. It is likely that as fish resources become further depleted due to higher global demand and more pressure on
the resources, the need to understand fish behaviors and locations will become a critical management consideration, driving more tagging efforts and refining the technology. As GIS becomes an even more prevalent tool for analysis in science, knowing the software will likely become a prerequisite for most jobs and be used on a daily basis in almost all applications. As illustrated in the study by Riolo (2006), GIS applications can already be customized to suit a wide range of fisheries analyses, which certainly can include tagging studies. The refinement and customization of GIS will only expand in the future, offering an advanced suite of tools for scientific analysis and data sharing. It is my opinion that marine animal tagging efforts and thus marine conservation efforts have everything to gain from the growing use of GPS technology and the expanding role of GIS in science and society.

References


Tagging of Pacific Predators (TOPP) website, www.topp.org


Annotated Bibliography


Although this paper was published in 1994, I considered its content in my paper as a historical reference and comparison of how far GIS technology has come and how much its uses have expanded within marine fields. The authors, Evan et al. investigate the use of GIS technology to assist in efforts to protect endangered salmon in the Snake River in Washington, Oregon, and Idaho. While the fish themselves were not tagged in this study, GIS was used as a tool for understanding the dynamics of river habitats, hydrology, and the biological environment. One important outcome of the study was to show how changes in the river on which juvenile salmon depend, clearly effects the survival of the species. This study also serves as an excellent example of how GIS can link fields of study. In this case, fisheries biologist provided the biological information, the Pacific Northwest Laboratory provided bathymetry data, while the U.S. Army Corps contributed water surface elevations to the mapping project. The data was then combined to create maps of the river which in turn provided guidance and recommendations as to the proper actions government agencies should take regarding dams, reservoirs, etc. to help protect salmon. Specifically, the use of GIS in this study was used to predict spawning habitat at the tailraces of the dams on the Snake River based on the river’s physical characteristics. The major conclusions of the paper were that GIS technology is a viable tool for aquatic studies and is powerful in linking spatial data with relational databases, allows data to be easily shared, and results of studies are easily reproducible when GIS is employed in the analysis.


This article outlines a study of tagging technology by comparing the accuracy of satellite telemetry tags, pop-up satellite tags, and archival data tags for three pelagic species of fish: bluefin tuna, salmon sharks, and blue sharks. The telemetry tags provide location estimates from the Argos satellite system when the sharks are at the surface. The pop-up satellite tags detach from the animal at a preprogrammed date and record ambient temperature, pressure and light level every 60 seconds. The tags can be located on the surface after detachment and downloaded by researchers. In contrast, archival tags store light levels, pressure, body and ambient temperatures at preprogrammed intervals. Archival tags were recovered and reported by fishermen. The study also double-tagged sharks using the telemetry and pop-up tags to compare which tags were more accurate. Results from the study demonstrate that sea surface temperatures collected from tags should be used in conjunction with external light level data to improve geolocation estimates from the tags. Major objectives in the study were to validate the accuracy of geolocation estimates from electronic tags. Validation is important and critical to better understand the behavior and ecology of these animals, and also has implications for fisheries management decisions.

In this study, the authors incorporate GPS and GIS in tagging and tracking whale sharks off the coast of Belize. The results of the study showed that whale shark aggregations correspond to fish spawning periods at specific times of the year. A key outcome of the study was acquisition of first-time video footage of the sharks feeding on freshly released spawn of two snapper species. The footage brought about local consensus that measures must be taken to protect the snapper from overfishing and threats from tourism development, possibly leading to designation of a new marine protected area site. With respect to GPS, whale sharks were tagged while feeding at the surface in the evenings and their locations recorded using hand-held Garmin 12 GPS units. Once tags were deployed, Arc-Info and Arc View GIS was used to plot the tagging locations as well as the reef fish spawning sites. These two components were then compared throughout time. A significant contribution that GIS brought to this study was its utility in determining where sharks might be found, based on past tagging locations and spawning aggregations. GPS and GIS technology played a considerable role in understanding where whale sharks in Belize were located and thus where management measures should be instituted to protect the species.


The study used satellite telemetry to track Great White Sharks in the eastern North Pacific. The tagging revealed the sharks have long-distance seasonal migrations and even cycle back to the same location. The paper highlights that tagging information is essential to the management of white sharks populations which are globally threatened. Tags were deployed while the sharks were at the surface during predatory events using pop-up archival transmitting tags. The tags recorded depth, temperature, and light measurements at certain intervals. Tagging locations were recorded using GPS and mapping of shark locations was accomplished through GIS. The implications of this tagging study were that shark populations can be better understood and managed through tagging data analysis. The study also gathered insights into shark diving behaviors and predatory techniques, further adding to the base of knowledge we have about these creatures.


In this study, pop-up satellite tags and archival data tags were deployed on an oceanic squid species, representing the first long-term monitoring of the animals behaviors in its natural environment. The tags recorded depth (pressure) and temperature for 842 hours and horizontal movements were recorded, revealing predictable, diel vertical migration patterns. Squid were captured and tagged aboard commercial fishing vessels and location was recorded using hand-held GPS units (Garmin GPSMAP 76). An observation I had in the study was the small sample size (10 individuals tagged), however in one instance, the pop-up tag did not report to Argos upon release. This demonstrates one problem that can be encountered using pop-up tags. Also notable, was the use of ArcGIS 9 to plot depth contours with release and recapture locations. GIS was used to help interpret vertical migrations, with the principle finding that squid sped much of their time at depths greater than 200m. The article was clear and concise, with the technical details kept to a graspable level.
The authors also produced a good map to highlight the analysis and many figures to exemplify the squid’s behavior.


While this study did not deal specifically with marine animal tagging efforts, it presented an excellent context for how GIS can be molded and customized in the future for a wide array of uses in fisheries. The author developed a specialized GIS application tailored towards interpreting spatial and temporal patterns in American Samoa’s longline fishery. The customized software used ArcGIS 8.3 and Visual Basic for Applications and ArcObjects. The system purports a user-friendly interface that can be adapted for multiple scales, incorporating even satellite data of sea surface temperature with fishing effort and area information. Enhancing the applications flexibility, it can also be adapted to any fishery database. The screen shots of the software within the article present an easily interpretable analysis that looks very similar to ArcGIS queries and screens we have seen in our class lab. The attribute tables look identical to those we have used in lab for Block Island and USA data, only using vessel name, length, gear length, and position data instead of land classifications. One outstanding aspect of the study was the catch per unit of effort displayed in raster form, making for an intuitive and visually appealing representation for what is occurring on the water. The author did an excellent job describing the applications, presenting illustrative screen shots of the software in action, and offering suggestions for future use of such applications.

**Stokesbury, M.J.W., R. Cosgrove, A. Boustany, D. Browne, S.L.H. Teo, R.K. O’Dor, and B.A. Block. 2007. Results of satellite tagging of Atlantic Bluefin tuna, Thunnus thynnus, off the coast of Ireland. Hydrobiologia 582:91-97.**

I found this article interesting in that it highlighted the transboundary implications of tagging highly migratory species such as tuna. I also chose to annotate this article due to its recent publication date, making the results very timely and the fact that it used the most recent technology available. Using satellite pop-up archival tags on bluefin tuna off Ireland, the authors discovered three particularly distinct movements: after eight months at large, one fish traveled to the western Atlantic, another traveled to waters off Portugal, and the third to the Mediterranean Sea. These movements have significance in terms of management decisions and stock assessments, as fish managed in one country (i.e. Ireland) would require the compliance of other nations (i.e. Portugal) in order to be effective conservation policies. Also of direct significance to this paper and course, is that the tags provided an end point location based on the Doppler shift of the tags transmitted position to Argos satellites. The authors were also able to infer Geolocation positions of the fish on different days during the course of their migrations. The authors displayed tagging and Geolocation data using ArcGIS, portraying a clear and complete picture of the fish movements while at large. While not directly employing ArcGIS, the temperature data recorded by the tags was also summarized and graphically displayed, highlighting the interesting use of marine animals as “oceanographic data collectors”, a fascinating way to maximize the output generated in research experiments like tagging.

I chose to annotate this article as a demonstration of the diversity of species and geographic areas that tagging technology can be applied to. In this study, pop-up archival tags were used to study demersal fish, specifically the Pacific halibut. An important conclusion made by the authors in this study, was that the use of pop-up tags for halibut will allow researchers to collect depth, temperature, and location data during the winter season, which is closed to fishing (traditional demersal tagging methods relied on fishermen catching and reporting the location of tagged fish). The authors included in their study the effects of this technology on fishing communities by pointing out that locally depleted fish may have limited movement patterns which have implications for management. While the PAT tags have traditionally been used on large pelagic fish (i.e. tuna), the large size of halibut may mean this as a suitable option and alternative to conventional demersal fish tagging that relies on fishermen reports of tagged fish location. Again, ArcGIS maps were used to display the tagging data at the conclusion of the study. While the authors did not find any results that could be largely generalized such as clear trends in migrations or behaviors, they admirably performed a holding experiment in aquaria for the tagged halibut to assess tagging mortality and behavioral changes. Holding experiments are an important aspect of fish tagging studies that is often not possible with large pelagics like tuna.