From plastic darts to pop-up satellite tags

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Abstract

The development of electronic tagging technology over the last decade has provided today's fisheries researchers with many new options for studying the movement and migration of marine fishes. Conventional tags (dart, disc, internal, etc.) have provided us with only points of release and recapture, and often these reflect the distribution of fishing effort rather than the true movements of fish.

Acoustic tags provide a means of examining movement patterns in very fine detail. When they include environmental (water temperature) or physiological (EMG) sensors they also allow us to study the interaction of the animal with its environment However, the duration of most tracks is limited by the technology (in particular battery power), cost (tracking vessel charter, etc.) and human endurance (tracking is a very labour intensive activity). There is also a question of whether a tagged animal behaves "normally" in the first 24-48 hrs tagging when it is being followed by a vessel.

Since their development in the early 1990s, archival tags have been used extensively in tunas (Australia and the US) and groundfish (UK/Europe). These tags are miniature data loggers incorporating environmental sensors (light, temperature, depth). They can record data every few minutes for years, allowing researchers to study the daily/weekly/seasonal/inter-annual variation in movement, migration, behaviour and physiology of their study animals. They are relatively expensive ($2 000) and can only be used where the expected recapture rate warrants the cost of tags. The data from these tags have provided researchers with a quantum leap in the understanding of their animals, and in many cases have shown that models of movement and migration developed from conventional tagging have been seriously flawed. Although the studies conducted to date have focussed on large animals (tags currently available are 50-70 mm in length and weigh 25 g in air) archival tag manufacturers are currently designing and testing tags that will be suitable for use in fish as small as 500 g.

Pop-Up satellite transmitting archival tags currently being developed and tested in the US, Europe and Australia promise to provide all the data-logging functionality of archival tags without the need to recapture the fish. These tags are a hybrid of an archival tag and a satellite transmitter, allowing researchers to program data collection over a specified period and a predetermined release date. On that date, a corrosive link within the tag is activated, allowing the tag to release from the fish, float to the surface and start transmitting a summary of the data collected to a NOAA satellite carrying an ARGOS receiver. Only a small fraction of the data collected can be transmitted to the satellite due to low transfer rates. This presents significant problems in transmission of position estimates as these often involve considerable data manipulation. At present manufacturers are testing on-board geolocation estimation software.

Introduction

As Everhart *et al.* (1975) note in their text "Principles of Fisheries Science", "Fisheries scientists have been searching for the ideal mark since 1873 when Atlantic salmon, tagged in the Penobscot River, Maine, were recovered in fair numbers".

Over the last 120 years, hundreds of tag designs have been developed in attempts to optimise tag retention, visibility, reporting, etc. The "conventional" tags used since 1873 allow fisheries scientists to mark and release a fish (group of fish) at a one location, and then recapture the fish(es) at another location(s) after a period at liberty. With large-enough sample sizes at release and recapture, a picture of the movement and migration can be developed, for a species, populations, individual age classes, etc. For almost 100 years conventional tag technology represented the only direct method of studying movement of individuals.

When acoustic tags were developed in the 1960s, fisheries biologists had a tool that allowed them to follow fish for periods of days to weeks. These tags provided very detailed data on short-term movement and behaviour that conventional tags could not provide. They also allowed the simultaneous collection of environmental data from which links between movement and habitat parameters could be determined.

Over the last decade the development of microchip technology, particularly miniaturised, low-power memory chips and micro-controllers, has resulted in a revolution in tagging technology. Fisheries scientists now have at their disposal an exciting range of specialised electronics with which to keep tabs on fish and study their behaviour. Five years ago archival tags (also known as data storage tags) were first deployed on plaice and tunas. Archival tags are basically miniature computers complete with a range of environmental sensors that collect data on the behaviour, migration, and physiology of a fish over periods of months to years (Gunn *et al.* 1994; Metcalfe and Arnold 1997). At much the same time as archival tags were being pioneered, the first acoustic listening stations – data-logging hydrophone arrays tuned to receive signals from fish fitted with ultrasonic pingers – were developed to map the movement of fish around Fish Aggregating Devices (Klimley and Holloway 1999). In the last 18 months archival tags have been hybridised with satellite transmitters to produce the first pop-up satellite transmitting archival tags (Block *et al.* 1998; Lutcavage *et al.* 1998). These tags are able to collect data for a specified period (up to a few years), summarise these data on the tag's micro-controller and then, at a user-defined time, release from a fish, pop up to the surface and transmit data summaries to an ARGOS satellite.

The quantum leaps in technology over the last decade provide new and exciting options for studying movement and migration. There is certainly a great attraction in using the "gee whiz" technologies, particularly where conventional tagging has been unsuccessful. However, before investing large amounts of money in microchip tags, there is a very clear need to define the questions one seeks to answer, and to assess whether these questions can be addressed in a meaningful way by the various new technologies. In this brief review I've addressed what I see as some of the strengths and weaknesses of three levels of tagging technology: conventional, archival, and pop-up tags.

Conventional tags

Data from experiments using conventional tags have provided most of what we know about the movement and migration of fishes and a number of invertebrate species, and a huge literature has developed over this century from which the strengths and weaknesses of this simplest form of tagging technology can be determined.

Strengths of conventional tags

1. They provide accurate data on the point of release and recapture.
2. Data on growth, fishing mortality and natural mortality.

3. If used in conjunction with injection of chemicals such as strontium chloride or tetracycline, results can be used to validate annual formation of growth bands on hard parts.
4. A wide range of conventional tag designs is available to suit a range of species and attachment methods.
5. Tags are relatively cheap, although costs of deployment and recovery are often significant.
6. Low unit costs mean sample sizes can be large, and studies can be conducted on scales allowing results to be representative of population.

Weaknesses of conventional tags

1. Data are heavily fishery dependent. Non-reporting, inaccurate data on recapture location and size-at-recapture significantly compromise conventional tagging experiments. As it is often difficult to estimate non-reporting rates, caution must be taken when interpreting patterns of movement in cases where non-reporting is suspected.
2. For the data to be useful, it must be assumed that tagged fish behave in the same way as untagged fish. However, objective assessment of whether this assumption is met is very difficult.
3. The pattern of releases and recaptures is most often determined by the operations of commercial fisheries. Thus, tagging data often show the movement between one fishery and another, but provide no data on movement into/from unfished areas.
4. No information is collected on the movement of fish while at liberty. Thus, if an animal is recaptured close to its release location, one can either assume little movement, or some kind of cyclical movement. It is very difficult to distinguish between these two assumptions using conventional tagging data alone.
5. There are significant problems in interpreting low recapture rates. Do they mean low reporting rates, high tag shedding rates, poor tagging method, or simply a very large population?

Archival tags

The development of archival tags was driven by the requirement in many studies to bridge the information gap between the basic, but often biased, data on movement and migration collected by conventional tags and the highly detailed, but short-term information provided by ultrasonic or acoustic tracking. The tags are designed to collect data every few minutes, from which the daily position and behaviour of an animal can be determined. Archival tags have been used over the last five years to study movement and migration of demersal fish such as plaice and cod (Metcalfe and Arnold 1997), and tunas (Gunn *et al.* 1994). In the five years since the deployment of the first generations of archival tags the technology has improved significantly. However, there remain significant challenges to tag manufacturers in four areas:

- Improvements need to be made in tag reliability under the full range of environmental stresses imposed by the large oceanic pelagic species – dives to 1000+ metres, temperature ranges from 2-35°C.
- The performance of sensors must be better specified under a range of conditions, and improvements made in the consistency of performance of sensors, in particular the light sensors.
- The size of tags must be reduced significantly to allow application to a wider range of species.
- The price of tags must be reduced if they are ever to become a routine tool for studying fish movement and behaviour.

As the technology is in the early stages of application it is perhaps premature to conclude too much about its strengths and weaknesses. However, the following are offered as a personal assessment after using them for five years:

Strengths of archival tags

1. Highly detailed data are collected over periods of months to years, allowing researchers to examine variation in position, behaviour and physiology over seasonal, lunar, and inter-annual time scales.
2. Data produced are largely fishery independent. Although one still relies on fishermen to report/return the tags, the data from tags returned provide an unbiased picture of where a fish has travelled while at liberty. In the case of tuna, this often involves migrations to areas where no fisheries operate.
3. In fish recaptured close to the location of release, it is possible to distinguish between the no-movement and cyclical movement hypotheses.
4. As the tags collect data on the physical environment of the fish, it is possible with regular position estimates to examine the links between movement, behaviour and oceanographic conditions.

Weaknesses of archival tags

1. Cost: the two major manufacturers of archival tags currently charge around US $1 200-1 400 per tag. To promote returns, substantial rewards are also required. At such a cost it is very expensive to mount large tagging studies unless the expected recapture rates are high.
2. Require cooperation of fishermen to return tags.
3. There are significant overheads in the time and expertise required to analyse archival tag data. Calculating geoposition from archival tag light, depth and water temperature data is not straightforward, and there is often a requirement for a) customising analytical software, and b) access to satellite sea surface temperature archives.
4. The relatively large size of current generations of archival tags restricts their application in smaller fishes.
5. Tag attachment is a significant issue for many species.
6. Estimates of geolocation based on daily variation in light levels are prone to significant and varied sources of error. Currently, even for species that live principally in the upper 50-100 m, errors in longitude estimate are in the order of 1°, while latitude errors can be much greater, and are dependent on the time of the year and factors such as weather and depth at which a fish is swimming.

Pop-up satellite transmitting archival tags

The successful application of archival tags in the early 1990s encouraged fisheries scientists and electronics engineers to design and develop a tag that could be used in species where return rates were significantly lower than the 15-20% experienced in the bluefin tunas studied with archival tags. These tags, now known as Pop-Ups, were first conceived by Hunter *et al.* (1986), as a way of being truly independent of fisheries in the collection of movement data. The pop-up concept was a tag that could trail behind a fish, collecting and storing data for a user-defined period and then, after detaching from the fish, float to the surface to transmit these data to a satellite.

Data loggers linked to satellite transmitters had been used successfully for some time on large marine mammals and penguins. However, as these animals either spend significant periods on the surface or on land, the tags designed for them did not need to pop-up/off to allow for transmission. Also, the large size of most of these animals meant that the tags could be large, and include enough batteries for high-powered and numerous transmission.

As very few species of fish spend enough time out of the water to allow data transmission, engineers designing the pop-up tags were faced with the following challenges:

- packing all of the electronics to control tag function, store and transmit data, plus batteries to power transmission over a long-enough period to allow a significant amount of data to be transferred, into a housing small enough that a fish could tow it around for months to years;

- making the package hydrodynamically efficient, positively buoyant and stable in the floating position;
- developing smart software to summarise data collected by the tag, and undertake a series of simple calculations on board; and
- developing a release mechanism that could be controlled by the tag to allow for user-defined release times.

The first prototype tags were tested in 1997 and two pilot studies conducted later that year (Block *et al.* 1998; Lutcavage *et al.* 1998). These tests used simple pop-up tags that provided only a series of temperature records and a location at which the tag popped-up.

The second generations of tags, featuring more sensors, greatly enlarged memory, smart software and on-board processing, are currently being tested. Given successful performance it is likely that the first large-scale experiments with fully functional pop-up satellite transmitting archival tags will be conducted early in 2000.

On the basis of limited use the following appear to be the primary strengths and weaknesses of pop-up tags:

Strengths of pop-up tags

1. With no requirement for tag recapture, pop-ups are completely fishery independent.
2. Promise to be very useful in species where low recapture rates and solitary behaviour make conventional tagging impractical.
3. User-friendly and flexible data acquisition schedules.

Weaknesses of pop-up tags

1. Cost: pop-up tags currently sell for US $3 500-$4 000 per tag.
2. Size: current generations can only be used on fish >75 kg.
3. Slow transmission rates to the ARGOS satellite mean that only limited amounts of data can be transmitted. This required significant data reduction and loss of information on behaviour and movement. It also places limitations on the number of days for which a position estimate can be transmitted.
4. Attachment of a large external tag remains a problem in some species.
5. On-board geolocation estimation remains unproven and a significant challenge.
6. Pop-up may be unsuccessful if fish is at great depths when the tag releases.

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