**Advances in Fish Tagging and Marking Technologies: Enhancing Conservation and Fisheries Management**

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**ABSTARCT**

The state of global fisheries and the health of aquatic ecosystems are of paramount concern in the face of increasing anthropogenic pressures. Fish tagging and marking technologies have evolved rapidly, offering unprecedented opportunities to gather detailed information on fish behaviour, movement patterns, and environmental interactions. The conservation and effective management of fisheries are critical components of maintaining aquatic ecosystems and ensuring sustainable seafood resources. This chapter provides a comprehensive overview of recent advances in fish tagging and marking technologies that play a pivotal role in enhancing conservation efforts and fisheries management strategies. The adoption of innovative tagging methods has greatly improved our ability to track individual fish, monitor their movements, and gather crucial data on behaviour, migration patterns, and habitat utilization.

**Keywords:** fish tagging, marking technologies, conservation, fisheries management.

1. **INTRODUCTION**

The world's aquatic ecosystems, from vast oceans to freshwater lakes and rivers, host a staggering diversity of fish species that are essential to both natural ecosystems and human societies. Fish provide a critical source of food, income, and recreation for millions of people worldwide. However, the sustainability of fish populations and the ecosystems they inhabit face significant challenges due to overfishing, habitat degradation, and climate change. Understanding the behaviour, movements, and population dynamics of fish species is crucial for effective conservation and fisheries management. Fish tagging and marking have emerged as indispensable tools in the pursuit of this understanding. These techniques allow researchers, fisheries managers, and conservationists to monitor fish populations, track their migrations, and gather vital data for informed decision-making. Over the years, advancements in technology and methodology have led to innovative tagging and marking approaches that offer unprecedented insights into the lives of fish.

The key steps in conducting an effective tagging study are:

(1) to make sure that the study's objectives are met, thorough planning is required,

(2) choosing a suitable tag or label,

(3) ensuring that there are enough marked and recaptured animals to produce parameter estimations with enough accuracy to suit management needs,

(4) fulfilling the sometimes-strict assumptions needed to generate reliable parameter estimates,

(5) using the right analytical techniques, and

(6) correctly interpreting the findings

Most tagging and marking studies are similar in that they create a subset of animals from the population that are “known” and identified by their tags or marks. This subset of animals is then followed through space or time (or both) by subsequent recaptures and used to provide information on the entire population. A strength of a well-planned tagging program is that multiple characteristics of interest to researchers and managers, such as movements, growth, and mortality rates, can often be addressed in the same study.

1. **FACTORS AFFECTING TAGGING AND MARKING**

* Size of fish
* Size and colour of tag
* Number of fishes to be marked
* Area of the study
* Tag effects to the fish
* Cost of tag
* Ability of tag to detect by e.g. transmitter, X-ray etc.
* time of retention of tag/mark
* Ability to differentiate between individuals

1. **HISTORY**

Fish tagging records go all the way back to the first decade of the 20th century. They mostly concentrated on the movements of cod, haddock, and pollock, however occasionally other species like monkfish and sharks make an appearance as well. Since then, scientists have improved their techniques, and a whole industry of labelling related goods has emerged. The needs of fishery biologists were changed for many of the items that are now available to researchers; these products originally came from other industries.

1. **NECESSARY INFORMATION OBTAINED FROM TAGGING FISH**

* Stock identification
* Migrations
* Behaviour
* Age
* Mortality rates
* Abundance
* Stocking success

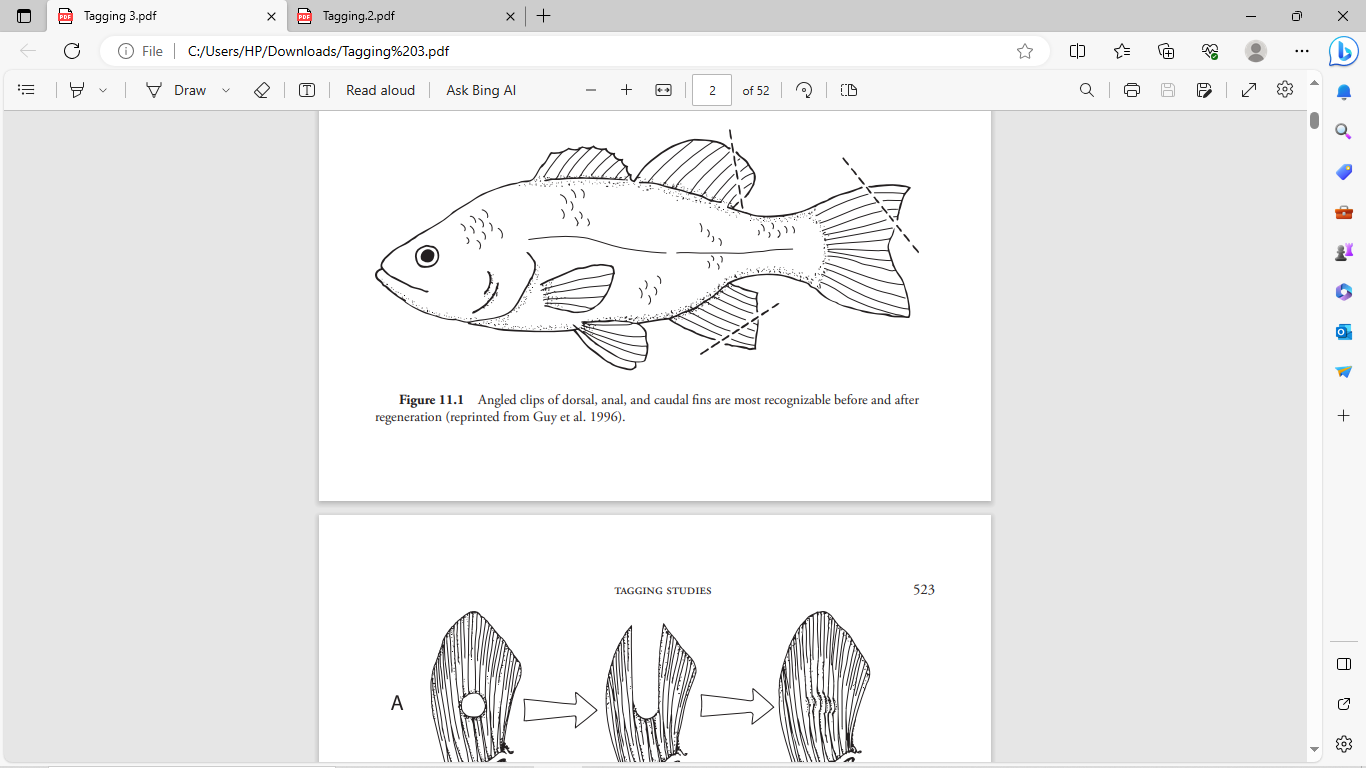
1. **METHODS AND CHOICE OF MARKING TECHNIQUES**

A known subset of a fish population can be made using a wide range of tagging or marking techniques. A tag is typically described as something affixed externally or internally to the fish and containing specific identification information, whilst marks are generally defined as anything recognisable that is external, internal, or embedded into the integument of the fish (Jones, 1979; Guy et al. 1996). Fin clips can serve as simple tags and identifiers, while more complex tags can store a variety of spatial and biological data on a particular animal and then transfer that data to the researcher via satellite. The amount of time spent designing the study design, choosing the appropriate tag, and considering the fundamental assumptions of the analysis will be reflected in the calibre of the information that is gathered (Nielsen, 1992). The time spent selecting the proper tag, developing the study design, and taking into account the analysis's underlying assumptions will improve the quality of the data collected. Different types of marking techniques are as follows: -

**A. Body Marks**

One of the earliest and most basic methods of fish marking is a fin clip. Using wire cutters, scissors, or a hole punch, a part of the fin that will be marked is cut away all at once (Fig.1). Using scissors, it is usual practise to cut a section of the pelvic or pectoral fin that is perpendicular or at an angle to the major fin ray, around halfway between the fin's end and base (Eipper and Forney, 1965). Fins that have been clipped usually grow back, but frequently they are still visible.

Fin clips are quick and affordable, however the research they may be used in are restricted due to the few combinations that are possible and the uncertainty associated with regeneration. In actuality, fin clips are frequently utilised as quick visual cues to distinguish one group of fish from another, such as in a hatchery.



**Fig.1** Angled clips of dorsal, anal, and caudal fins (Guy et al. 1996)

Fish bodies bear visible marks from both hot and cold branding. Large numbers of animals can be quickly marked by branding. Similar to fin clipping, it is best used for temporary branding since brands can fade over time or get harder to recognise as fish get bigger. Branding is generally used to provide a batch mark (Bryant et al. 1990) but can also create individual marks (Morrison and Secor, 2004).

**B. Natural Marks**

Morphological and meristic markers are physical characteristics such as scales along the lateral line or body shape, markings, size, or colour that are counted naturally. Animals from particular geographic areas frequently have distinctive markings that distinguish them from conspecifics from other areas. To identify stocks of Mediterranean horse mackerel, for instance, and demonstrate that their migration patterns were constrained to the Black, Marmara, Aegean, and eastern Mediterranean seas, morphometric and meristic features were applied (Turan, 2004). A common way to identify marine mammals is by the patterns of scars left on their bodies or fins by interactions with predators like sharks, barnacle growth, or boat propeller strikes. During visual surveys to gauge marine mammal abundances, marine mammals that are at the surface of the water to breathe are photographed. Following the analysis of these images, the distinctive features are identified and catalogued (Wilson et al. 1999). The locations and dates of animal relocation are recorded in "capture" histories created by looking back over these catalogues over time. Given the keen interest in monitoring the status of rare and endangered marine mammals, much research has been devoted to these types of assessments as scar marks can vary over time from new injuries or healing, which can make unique identification of some animals challenging (Yoshizaki et al. 2009, 2011).

1. **Otolith Microchemistry**

To identify natal origins and evaluate larval, juvenile, and adult fish migratory patterns over wide areas, researchers use naturally existing isotopic and elemental markers (Elsdon et al. 2008). Such data is necessary for creating spatial management programmes, such as marine protected areas or natal rivers identification. Fish heads have a pair of paired calcified structures called otoliths that aid with hearing and balance. To determine the ages of fish, they are frequently employed in fisheries management and they are also reliable natural tags (Thorrold et al. 2001). Since otoliths are mostly composed of calcium carbonate and a variety of trace elements, which are frequently derived from the ambient water that fish swim in, their isotopic and elemental makeup will reflect the environmental properties of the water the fish dwell.

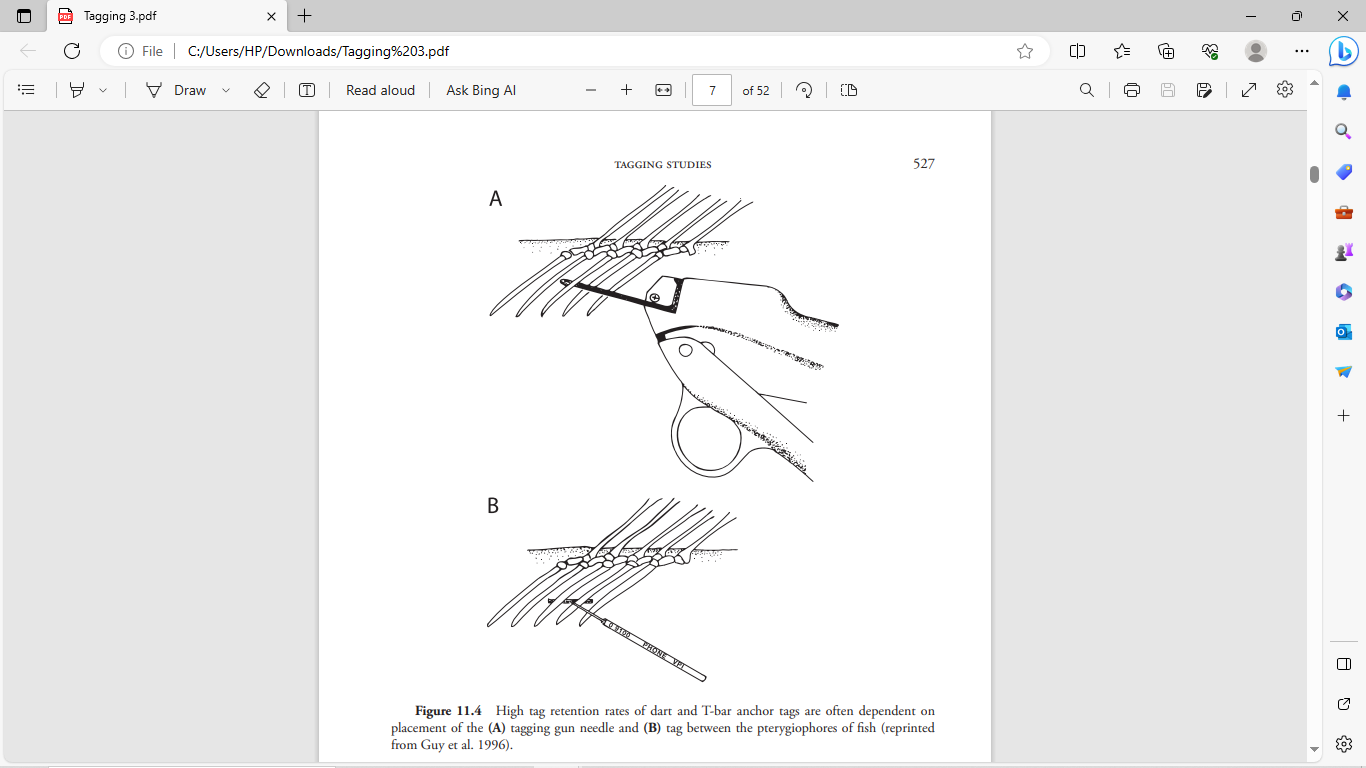


Fig.2 (A) tagging gun needle and (B) tag between the pterygiophores of fish (Guy et al. 1996)

If a fish moves between different places as it matures, its otolith development layers will reflect the spatial diversity of these water parameters. To find out where a fish lived at different times throughout its life, samples of the otolith material that were deposited at various ages can be taken out and chemically analysed.

**D. Coded Wire Tags**

In order to distinguish hatchery fish from their wild counterparts, coded wire tags are frequently employed to tag a large number of animals (Bordner et al. 1990; Johnson, 1990). Small magnetised steel wire pieces (1.1 mm×0.25 mm) with a code that can be used to identify certain fish are called coded wire tags. They must be read under a microscope because of their small size. Many different types of bony and cartilaginous fish and invertebrates have been successfully tagged using them in the hundreds of millions. Because of their size and good retention, coded wire tags can be used on little fish. It is believed that the growth or mortality risk of tagged animals is not significantly affected by coded wire tags.

Injections of coded wire tags are made into particular body parts, like the head or snout, where retention rates are high (Buckley and Blankenship, 1990). To quickly tag a large number of animals, they are implanted using portable or semiautomated injectors (Guy et al. 1996). They are typically found using automated or handheld detectors. An animal may be detected to be tagged, but in most cases the tag cannot be decoded to identify the specific animal without killing the animal and removing the tag. The placement of the tag between fin rays, for example, is an exception because it allows for surgical recovery of the tag without causing the fish undue harm (Haw et al. 1990). A more feasible strategy might be to utilise coded wire tags for group level identification or to accept the necessity to sacrifice recaptured fish at shallow tagging locations where loss rates may be higher. By injecting tags into various body components, such as the cheek one year and the snout the next, it is possible to identify distinct batches of fish. This enables the marking of multiple groups of animals for use in Brownie-type survival analyses.

1. **Visible Implant Elastomer Tags**

Visible implant elastomer (VIE) tags are implanted into translucent or transparent fish tissues, such the cheek. A coloured elastomer and a clear catalyst are combined to make a liquid that is then injected with a hypodermic needle to form them. The substance hardens into a flexible solid that appears as a coloured dot or thin stripe after a few hours. Unique identifications can be made by using various tag placements and colours. Visible implant tags are frequently employed because, with the exception of small individuals (Reeves and Buckmeier, 2009), they have little impact on fish development, survival, and behaviour. They can also be applied to invertebrates and amphibians (Replinger and Wood, 2007, Phillips and Fries, 2009). As the tag material deteriorates or is covered up by new tissue growth, retention times vary depending on the tag's position, species, and colour (Summers et al. 2006; Bolland et al. 2009).

1. **Anchor Tags**

Anchor tags are made up of an internal attachment end that is inserted into the body of the tagged animal and an exterior coloured plastic tube or streamer with information unique to the study imprinted on it. Dart-style tags have an attachment end that is either T-shaped (T-bar tag) or shaped like a single-barbed arrowhead (dart tag). A flattened rectangular or oval plate that rests flush against the body wall is where internal-anchor tags are connected (Nielsen, 1992). These tags are frequently used on a variety of fish and invertebrates because they are reasonably simple to apply, are clearly visible, and can convey a straightforward informational message (such as the agency that tagged the fish, the return and reward information, and a unique identification number). To create management plans for this species, anchor tags have been employed to collect crucial data on striped bass migration (Boreman and Lewis, 1987) and mortality (Dorazio et al. 1994; Diodati and Richards, 1996) along the Atlantic coast (Richards and Rago, 1999). Transbody Carlin tags, which may have an impact on growth, are favoured over other external tags (Nielsen, 1992). Dart-style tags are frequently attached to fish using a hollow-needle applicator that is inserted behind the fish's dorsal fin and through the pterygiophore bones.

T-bar tag applicators can be loaded with strips of numerous tags, but dart tag applicators must be reloaded with a tag for each fish. Proper anchor placement behind pterygiophores or other stiff body structures to give a secure attachment site is the key to high tag retention (Waldman et al. 1990; Sprankle et al. 1996). Tag shedding results from failure to affix to a hard structure; implantation into the muscles is insufficient. According to Nielsen (1992), the base of internal-anchor tags is typically inserted through a tiny incision in the body wall. There are two ways that anchor tags can be shed (Ebener and Copes, 1982). Long-term or "chronic" shedding is likely due to tag wear; it happens right away (hours to days) after tagging and is likely due to faulty attachment.

Tag longevity is also influenced by environmental conditions and the rate of animal development. When an animal is growing quickly, a tag anchor in the shape of a dart may be inserted into soft tissue where it is more likely to be removed by structural growth. Animals living in clear, productive waters may have tags covered by algae development, making it difficult to read the information and increasing tag shedding rates owing to increased drag. Algal-covered tags are also more likely to be missed in studies utilising fishing tag returns, which leads to underreporting.

1. **Passive Integrated Transponder Tags**

Radio-frequency identification (RFID) tags known as passive integrated transponder (PIT) tags are injected into an animal's bodily cavity or musculature and can be read and detected without the animal being dissected. The PIT tag is made up of an antenna for receiving and transmitting signals as well as an integrated circuit for information storage, processing, and signal modulation. The PIT-tag reader uses an external energy source to turn on the tag, which then sends a radio signal with a special alphanumeric code to the reader, which decodes the signal and displays the data. Compared to other tag kinds, the PIT tag has a number of significant benefits. PIT tags are embedded into the muscle or body cavity of fish; as a result, they cannot be entangled and lost, or have their shedding reduced by the growth of algae. Without removing the fish's tag, they can be read. They are also tiny, which helps tagged fish swim, survive, and grow more normally. Finally, they are virtually permanent because the reader's power powers the tag rather than an internal battery.

The maximum size of the animal that can be tagged and the tag reader's detection range are both influenced by the PIT tag's size. The most popular PIT tags are small (approximately 12 mm length and 2 mm in diameter) full-duplex PIT tags that must be close to a reader (often a few centimetres) in order to be detected. These tags can be implanted in a variety of fish. Wherever autonomous receivers and stream-spanning antennae can identify tagged fish, half-duplex technology with larger 23 mm 3 mm tags is deployed (Jepsen et al. 2000; Adams et al. 2006; Zydlewski et al. 2006).

1. **Genetic Tags**

An animal's distinct DNA can act as a tag (Waits 2004). In wildlife management, molecular genetic techniques are used somewhat frequently and more frequently in fisheries applications (Buckworth, 2004) to identify species, estimate abundances, and track population trends. In a gene-tagging programme, a tissue sample is collected from each animal and kept in alcohol before the animals are released. This tissue biopsy is typically a muscle punch or fin clip. The polymerase chain reaction (PCR) is utilised to treat the tissue sample in order to amplify 4–12 nuclear DNA microsatellite markers (depending on population variance), the combination of which is used to identify the specific animal. In the future, as animals are trapped, biopsied, and released, their DNA is checked for matches against the library that was previously compiled. By obtaining tissue samples from fish that have been caught (for example, through a creel survey or port sampling programme) and comparing them to the previously known (genetically defined) population of animals, it is possible to directly assess the mortality due to fishing.

Some of the drawbacks of conventional tagging research, such as tag shedding and low reporting rates, are reduced using genetic tags. Technical and analytical issues must be resolved since gene tagging calls for assumptions about genetic analysis that typical tagging programmes do not (Yoshizaki et al. 2009, 2011). In comparison to most other tag types, the cost of "tagging" (analysing the tissue sample) is considerable, however it is decreasing as sequencing technology develops. Another issue is amplification failure, in which the intended portion of the animal's genome is not sufficiently duplicated by PCR, maybe as a result of insufficient DNA in the sample.

**Conclusion**

The advances in fish tagging and marking technologies represent a powerful toolset for promoting sustainable fisheries management and conservation. The combination of precision, data-driven decision-making, and international collaboration positions these technologies as essential components in the ongoing effort to safeguard aquatic ecosystems and the livelihoods that depend on them. As technology continues to evolve, the future holds even greater promise for innovative solutions to the complex challenges facing our oceans and freshwater environments.

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